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Accident aware localization mechanism for wireless sensor networks

Chao-Tsun Chang[a], Chih-Yung Chang[b,*], Tzu-Lin Wang[b]

[a] Hsiuping University of Science & Technology, Taichung, Taiwan
[b] Tamkang University, Taiwan

HIGHLIGHTS

- Improving the location accuracy with off-the-shelf hardware.
- Active location detection and correction with low computing complexity for each sensor.
- The proposed ALCP mechanism is energy efficient for location-error detection and correction.
- Complete analysis and extensive simulations to verify the performance of the ALCP.

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ABSTRACT

Accurate location information is important for event reporting, coverage estimation, and location-aware routing in a Wireless Sensor Network (WSN). Recently, a number of range-free localization schemes have been proposed to provide each static sensor with location information, which is represented by a rectangular region. However, most WSN applications are applied in outdoor environments where the sensors' location regions could be incorrect due to sudden accidents. This paper proposes an Active Location Correction Protocol, called ALCP, for detecting and correcting the occurrence of location error based on the bounding box technology. Performance study reveals that applying the ALCP to improve the location accuracies can enhance the performance of the well-known GPSR routing in terms of routing length, sensing coverage, and packet arrival rate.

1. Introduction

In a WSN, locations of sensor nodes are critical information in most applications of WSN, such as coverage calculation, event detection, object tracking, and location-aware routing. The sensor nodes have to be aware of their locations to specify "where" a certain event occurs. The simplest way for obtaining the location information is to equip each sensor node with a *Global Positioning System* (*GPS*). However, it leads to expensive hardware cost and considerable power consumption. To reduce hardware cost, a number of location discovery schemes have been proposed in recent years. These schemes [10,17] share the common feature wherein some static beacon nodes (or anchors), which are aware of their own location information, are deployed in the WSN. All the other sensor nodes discover their locations based on the information provided by these beacon nodes. These schemes still have the undetermined location accuracy of each sensor node since they highly depend on the number and deployed positions of the static anchors. To obtain high location accuracy, the number of anchor nodes tends to be increased, which adds to the localization cost. Another problem is that the static anchors play no role after broadcasting the beacons [8].

Studies [4,5,23,19,22,8,26,20,15,16,21,18,6] proposed a mobile anchor localization mechanism for a resource-constrained WSN. Each mobile anchor is aware of its own location information by equipping the GPS or other location support system. In previous works [8,26,20,15,13], the mobile anchor broadcasts its coordinates at certain locations which can be treated as the virtual static anchor at those locations. Upon receiving the coordinate packet, each static sensor can locally identify whether it is located within the communication range of the mobile anchor. When a static sensor receives multiple coordinate packets from the mobile anchor, the static sensor can calculate its new estimative region by the intersection of all possible location regions. To simplify the calculation of estimative region, studies [8,26,20,18] treat the communication circle of each sensor as the quadratic region, called *bounding box*.

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[*] Corresponding author.
E-mail addresses: cctas@mail.hust.edu.tw (C.-T. Chang), cychang@mail.tku.edu.tw, cychang@cs.tku.edu.tw (C.-Y. Chang), tlwang@wireless.cs.tku.edu.tw (T.-L. Wang).

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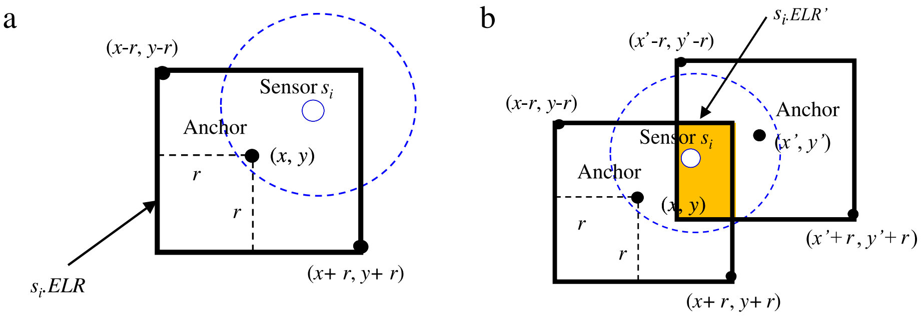
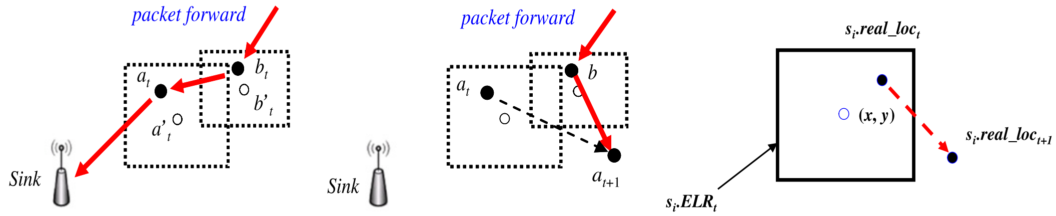


Fig. 1. (a) If sensor s_i receives the location (x, y) from the mobile anchor, and its communication range is r, the *Estimated Location Region* can be represented by $(x - r, y - r) - (x + r, y + r)$ or $s_i.ELR$. (b) The area of $s_i.ELR'$ can be determined by the $s_i.ELR$ and the anchor's broadcast message. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



(a) In location-aware routing, the packets from sensor b to the sink can be forwarded by sensor a at time t. The circle a'_t and dot a_t denote the center of the *ELR* and the actual location of the sensor a, respectively.

(b) When sensor a is moved at time $t + 1$ in the accident, the location error might lead to a situation that sensor a forwards the data packet to a location which is far away from the sink.

(c) Sensor s_i has a location error at time $t + 1$ if $s_i.real\_loc_{t+1} \notin s_i.ELR_t$.

Fig. 2. An example illustrating the location error and impact on the location-aware routing.

The mobile anchor mainly helps the static sensors to estimate their locations by periodically broadcasting its location. Let the location and communication range of a mobile anchor be (x, y) and r, respectively. The bounding box of the sensor s_i can be presented by $(x - r, y - r) - (x + r, y + r)$ and denoted by an *Estimated Location Region* (or $s_i.ELR$), as shown in Fig. 1(a). In Fig. 1(a), sensor s_i determines that it is located in $s_i.ELR$ when it receives the location message (x, y) from the mobile anchor. As shown in Fig. 1(b), upon receiving the location messages (x, y) and (x', y') which are sent by the mobile anchor, sensor s_i intersects two *ELR* regions to determine its new region $s_i.ELR'$ which is presented by $(x'-r, y-r)-(x+r, y'+r)$, marked by yellow ink. Consequently, this observation indicates that the original localization accuracy of sensor s_i, represented by the area size of $s_i.ELR$, can be improved by receiving a new broadcasting rectangle from the anchor.

Since most WSN applications are applied in an outdoor environment, the real location of each static sensor could be changed due to unexpected events, such as malicious changes, hurricanes, and mudflows. For example, detecting intruders crossing an international border is increasingly being seen as an important application for wireless sensor networks [14,25]. The barrier construction using the static sensors has been considered to reduce the patrolling cost. Take the border between America and Mexico as an example. The length of the border is about 3000 km. This border crosses two wide deserts, Sonoran and Chihuahuan, which frequently have strong breezes. In this scenario, the sensors should maintain high localization accuracy for reporting the accurate location of an intruder. However, the strength of the strong breeze in the deserts can be higher than 17 m/s, which can easily cause sensors to move, resulting in location errors for sensor nodes. The deserts of China are another example. The deserts in the Junggar Basin have strong breeze with strength of 17 m/s for an average of 80 days in a year [11]. The location errors will impact the effectiveness of the monitoring tasks, such as the coverage, target tracking, and packet routing.

The accidents could raise a location error problem where the real location of the sensor is out of its *ELR*. Fig. 2(a) and (b) show an example to illustrate the impact of location error on routing. In Fig. 2(a), the packet sent from sensor b to the sink node can be forwarded by sensor a at time t by applying the location-aware routing. When sensor a is moved at time $t + 1$ due to the accident, the location error leads to a situation where sensor a forwards the packet to a location which is far away from the sink, as shown in Fig. 2(b). Let the real location of sensor s_i at time t be $s_i.real\_loc_t$. If $s_i.real\_loc_{t+1}$ is moved due to an accident such that the condition $s_i.real\_loc_{t+1} \notin s_i.ELR$ is satisfied, sensor s_i has a *location error* at time $t + 1$, as shown in Fig. 2(c). The location error will further degrade the performance of coverage estimation, tracking, or packet routing.

This paper aims to develop an active location correction protocol based on the bounding box technique. The proposed *ALCP* mechanism actively detects the location errors and cooperates with the neighboring sensors to correct the *ELR* information. The remaining part of this paper is organized as follows. Section 2 gives the related works of localization and location error detection mechanisms while Section 3 illustrates the network environment and problem formulation of the proposed scheme. Section 4 details the proposed active location correction mechanism and presents the analysis of its impact on routing. Section 5 compares the proposed mechanisms with existing works. Section 6 presents the conclusion.

2. Related work

Localization with low cost and high accuracy is very important in wireless sensor networks [26,20,15,7,24]. To eliminate the