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Using smart vehicles for localizing isolated Things

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ABSTRACT

Elementary to the success of the Internet of Things (IoT) is the capability to accurately and efficiently localize its network components, information, and processes. In this paper, we focus on enabling localization of Things that have limited capabilities deployed in isolated areas. Specifically, we explore the scenario where the deployment or the utilization of dedicated anchor nodes becomes costly or practically unfeasible, and where the dependence on multi-hop localization techniques becomes inevitable. We further advocate the use of emerging IoT components such as smart vehicles, capable of self-localization and short-range communication. The proposed scheme thus illustrates the feasibility of a multi-hop wireless localization scheme dependent on mobile anchors (reference points). A key advantage of the proposed scheme is overcoming collinear trajectory (flip-ambiguity) problem, which arises whenever the smart vehicle moves in a straight trajectory. A Kalman Filter (KF) is used to decrease the location error introduced from the multi-hopping during the localization process. Through simulation, we show that the use of our localization scheme with KF reduces errors by 31% compared to localization using anchors from a single direction and 16% compared to a weighted means approach. Moreover, our scheme with KF consistently outperforms the typical range-based DV-Distance scheme with fixed anchors.

1. Introduction

Rapid evolutions in wireless communication and electronic technologies have substantially decreased the cost and size of embedded devices with sensing, processing and communication capabilities. Such devices have made ubiquitous monitoring and tracking applications cost-effective by enabling the collection of data from hundreds of different locations in large-scale scenarios [1]. These advancements have facilitated a new vision where information from millions or even billions of devices can be collected, processed and exploited collaboratively within a global Internet of Things (IoT) [2].

In IoT, "Things" communicate and collaborate with each other. Energy consumption, storage management, heterogeneity of devices and communication bandwidth are major challenges facing this emerging paradigm. As well, Things have to be locatable and addressable in order to be trackable and accessible in application domains such as geographic routing, marketing, data aggregation algorithms and environmental monitoring applications [3]. However, many Things cannot autonomously identify their position, and may require multiple anchors to estimate their location. Given the important role assumed by Sensor Nodes (SNs) in IoT, our focus in this paper is on location of SNs with limited capabilities.

Many Wireless Sensor Networks (WSNs) applications involve a random deployment of SNs in isolated areas with challenging terrains and no central access roads, e.g., dense rain forest or rocky mountainous areas. Due to the limited transmission range of WSNs, SNs collect information about the environment and send the collected information to the sink node at the edge of the topology using multi-hop communication. Fig. 1 shows an example of isolated SNs. To localize SNs isolated from the network edge, a multi-hop localization scheme is needed. As the processing of the position information propagates to the isolated nodes, error accumulates, decreasing the estimation accuracy as the number of hops increases [4].

Localizing SNs using multi-hop schemes involves deploying anchor nodes that broadcast their location information with operation instructions to the SNs. In turn, SNs would utilize this information to estimate their own positions. Such schemes

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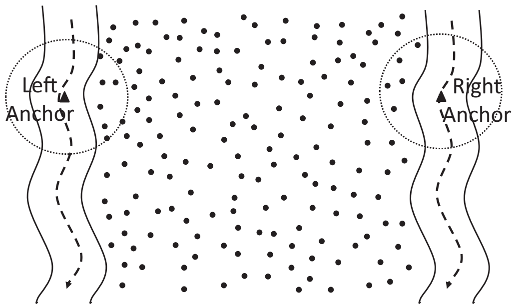

Fig. 1. WSN with anchor nodes from multiple directions.

commonly relied on high-density deployment of costly anchor nodes to ensure the availability of sufficient reference points for all SNs. Such assumptions become problematic in the context of IoT, where densities of SNs or Things are expected to be higher, more ad hoc, and spread over wider areas, and where the use of dedicated "anchoring" becomes, eventually, both costly and ineffective.

While IoT emerges with its unique challenges, it also brings forth unique opportunities. A relevant example can be readily seen in the ubiquity of today's smartphones that possess a collective capability of communication, processing, storage, recording (audio, image and video), and localization (GPS and assisted GPS). However, a more pronounced manifestation of an IoT opportunistic resource are smart vehicles that interact not only with navigation and broadcast satellites, but also with passenger smartphones, roadside components, and other vehicles on the road.

In this work we abstract on the emergence of these smart vehicles, specifically by using them as mobile anchors. When smart vehicles move in straight trajectories, the flip ambiguity problem results [5]. Traditionally, the term "flip ambiguity" labels the confusion resulting from collinear anchor nodes. As illustrated in Fig. 2, anchor nodes a, b, and c are collinear. Node n estimates its position through measurements d_a, d_b, and d_c. Each measurement defines a ranging circle centered at the anchor node. Due to measurement errors, the three measured circles do not intersect at a common point, which causes ambiguities in determining whether the position of the SN is n or n' [6].

We propose a new and robust localization scheme that uses smart vehicles to localize isolated SNs. In the proposed scheme, the SNs estimate their positions from multiple directions, which decrease the effect of the error propagation. After this process, a Kalman Filter (KF) is used to decreases the localization error coming from the longer hop direction, based on the information

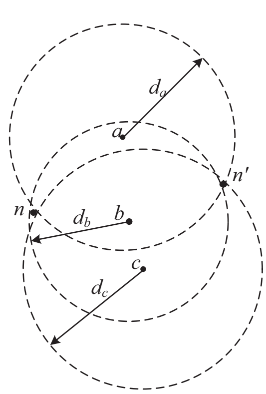

Fig. 2. Collinear anchor nodes a, b and c causing a flip ambiguity for SN n.

coming from the shorter hop direction. Simulation results show that using information from two different directions significantly increases localization accuracy.

The **contributions** presented in this work are listed as follows:

1. Illustrating the use of smart vehicles as mobile anchors (reference points) for localization.
2. Facilitating wireless multi-hop localization based on location information received from multiple directions.
3. Overcoming collinearity to account for smart vehicles moving in straight trajectories.
4. Employing Kalman filtering to reduce localization error in multi-hop wireless localization scheme which utilize mobile anchors (reference points).

The remainder of this paper is organized as follows. In Section 2, we present the motivation behind our work through reviewing related effort in the literature and establishing the addressed void. Section 3 offers a concise definition of the problem addressed, and details the proposed solution. Section 4 details the simulation environment used for validation and analysis, along with results and discussions. Finally, conclusions are made in Section 5, along with an elaboration on possible future directions.

2. Related work and motivation

The specific tool with which a thing can be localized depends on its capabilities, in addition to the type of nodes or localization services available in its direct context. Readers interested in surveys on various localization schemes should refer to references [7,8]. Our interest in this work is in localizing Things that are isolated from direct access to location information, i.e., have no direct access or interaction with a self-localizing entity, or a location broadcasting network element. To this end, the use of mobile anchors and multi-hop localization becomes inevitable if the Thing is to label its communication with accurate location information. The independent application of these localization techniques have been extensively discussed within the context of localizing sensors in WSNs. In motivating our work, we review the state of the art in three relevant aspects: (1) multi-hop localization techniques, (2) addressing the problem of flip ambiguity, and (3) localization using mobile anchors.

2.1. Multi-hop localization

Multi-hop localization schemes are based on either distance-based or connectivity-based strategies. In connectivity-based strategies the SNs obtain the absolute measurements of node distances using Receive Signal Strength Indicator (RSSI), Time of Arrival (ToA), or Time Difference of Arrival (TDoA) [4,9,10], while in distance-based strategies the SNs use the connectivity information to estimate the location of SNs based on the position of the anchor nodes [4,11–13].

Niculescu and Nath propose two localization schemes, one based on distance measurement, the other is based on connectivity information [4]. The authors' distance-based scheme is called Distance Vector (DV)-distance, and has the anchor node sending beacon messages to all its immediate neighbors. Immediate (first-hop) neighbors to the anchor node estimate the distance to the anchor by using signal strength measurement. These neighboring nodes then forward the beacon message to the second-hop neighbors to infer the distance to the anchor, and so on until the network is completely covered in a controlled flooding manner. Once an unknown node has three or more distances estimated to