Ad Hoc Networks 11 (2013) 2264–2272

Contents lists available at SciVerse ScienceDirect

Ad Hoc Networks

journal homepage: www.elsevier.com/locate/adhoc

RFID-based localization with Non-Blocking tag scanning

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ARTICLE INFO

Article history:
Received 16 November 2011
Received in revised form 13 November 2012
Accepted 17 May 2013
Available online 28 May 2013

Keywords:
RFID
Passive tags
Indoors
Localization
Automatic

ABSTRACT

The simple and cheap passive RFID tag systems have recently been used for efficient localization of indoor mobile robots, where each RFID tag stores its own absolute position and the mobile robot carrying an RFID reader scans the RFID tags to localize itself. The available localization schemes using passive RFID systems do not consider the scanning delay which may cause location estimation error, especially when the robot moves at a high speed. In this paper, a new Non-Blocking scanning (reading) scheme is proposed to avoid collisions so that the scanning delay, and consequently the localization error, can be reduced. This scheme avoids collisions among tag replies by assigning tag IDs based on the FCA coloring scheme. Theoretical and simulation studies indicate that the new Non-Blocking scheme combined with the new tag arrangement pattern can achieve a good RFID localization performance in terms of both estimation error and scanning delay with reduction of tag/reader required complexities.

1. Introduction

Radio frequency identification (RFID) is an automatic identification system consisting of readers and tags, where each tag has a unique identification number (ID) so the reader can recognize the information embedded in each tag through consecutive communications with them. The passive class of RFID tags receive their energy from the reader, and thus have found various applications. The typical applications of passive RFID systems include inventory management, real-time monitoring, and its new applications include popular items identification [1], traffic tracking [2], etc. The passive RFID technology has also been utilized to recognize the position of the service robot.

In the localization process, tags with their absolute location written on them are installed in the environment, and a reader is installed on the mobile object (e.g. robot). The reader probes nearby tags and receives their embedded location information (this process is called tag reading), based on this information it estimates its location. Accurate localization is necessary for locating the object, and for avoiding barriers (e.g., walls) in the environment, etc. (e.g., for detecting its movement direction). On the other hand, since the reader antenna detects several tags within its detecting range and the mobile robot is moving while the reader is gathering the data from the tags, the position-estimation error is inherent for this method.

Some localization schemes have been proposed using technologies other than passive RFID (please refer to the related work in Section 2). In general, these schemes can localize an object with high accuracy, but they usually either incur high costs or are not suitable for indoor environments. The schemes applying a grid of passive RFID tags on the other hand [3–5] are suitable for indoor applications. Nonetheless, they either do not support an accurate localization, or increase costs by using multiple readers and/or active tags. Moreover, the delay for scanning (reading) tags is not taken into consideration. However, this factor is very important because in localization systems based on passive RFID networks there are basically two critical factors which deteriorate the localization accuracy: the distance between the tags (causing a *stationary error*) and the scanning time (which causes a *motion error*). Adding more tags decreases the stationary error, but it triggers a

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http://dx.doi.org/10.1016/j.adhoc.2013.05.007

higher cost and also increases the scanning time. Our objective is to develop an RFID-based localization prototype that can accurately localize a mobile robot even when it is moving at a high speed. We try to achieve this through a smarter system deployment which triggers smaller stationary and motion errors.

In this paper, we first review in Section 2 related work on localization schemes using RFID and non-RFID technologies, then in Section 3 we analyze the hexagonal tag distribution pattern [6], and based on this pattern propose a Non-Blocking (NB) scanning scheme to be used for reading tags during the localization process for passive RFID systems. In this scheme the reader can receive tag replies without collisions among them and thus the reading delay is reduced. We demonstrate through simulation results in Section 4 that the proposed scheme can guarantee a desirable performance in terms of both localization error and delay. Finally Section 5 concludes and summarizes the main contributions of this paper and discusses the possible extensions of the Non-Blocking scheme.

2. Related works

There have been schemes proposed for localization based on non-RFID technologies. For example, one of the most well-known location-based systems is the Global Positioning System (GPS), a satellite-based navigation system made up of a network of 24 satellites placed into orbit. GPS is widely used to track moving objects located outdoors. While GPS works well outdoors, it performs poorly and may not even work in indoor environments. This is because buildings block the radio signals [7].

Inspired by existing GPS localization techniques, a new type of RFID tag, the laser-activated RFID tag, was designed and used as the artificial landmark in [8]. Stereo vision and LARFID are combined together with triangulation, which studies show to be promising for the accurate localization of a mobile robot. However, this technology is not yet feasible and also the line-of-sight requirement of LARFID tags suggests it may not be practical for indoor localization.

IEEE 802.11. RADAR applies a standard 802.11 network adapter to measure signal strengths at multiple base stations positioned to provide overlapping coverage in a given area. The major strengths of this system are that it is easy to set up, requires few base stations, and uses the same infrastructure that provides general wireless networking in the building. However, the object being tracked must be supported by a Wave LAN NIC, which may be impractical on small or power constrained devices [9,7]. In summary, some of these technologies can provide us with accurate localization, but are either not suitable for indoor applications or incur high costs.

In addition to the above approaches several RFID-based approaches have been proposed for localization applications. A localization prototype called LANDMARC (LocAtioN iDentification based on dynaMic Active Rfid Calibration) [7] deploys a set of reference RFID tags and a number of readers, where each reader has several transmission power levels. The location of the tracking tag is estimated based on the signal strength information using a k-nearest neighbor approach. This system requires active tags and a wireless network that allows wireless communication between mobile devices and the Internet. Wasif et al., investigated a novel location sensing system based on a geometric grid covering algorithm for positioning or tracking objects inside buildings [10]. This study involves the design of a RFID reader antenna network which focuses on placing the reader antennas on a grid to cover all the tags distributed at two dimensional planes. This system and the ones proposed in [3] require multiple readers and/or active tags installed in the environment. Other than being expensive, active tags use a battery which needs to be recharged or replaced, but this is very difficult when tags are distributed in the environment.

In summary, these available schemes are either not accurate or apply an expensive infrastructure. On the other hand, the scheme proposed in [4] employs simple and cheap passive tags and only a single reader per mobile robot. Therefore, it is very cost effective compared to the above schemes and is also suitable for indoor environments. However, in [4] and also other passive RFID-based localization schemes [3], no solution has been proposed to reduce the scanning (tag reading) delay which may cause location estimation error.

The problem of tag reading delay in passive RFID systems has been the focus for much research, mainly for applications like inventory systems. The problem is that tags cannot sense each other and therefore collisions occur. To read tags successfully the available schemes go through a collision-arbitration process, which is usually time consuming. To reduce the delay (which is mainly determined by number of time slots used for reading tags), the reader continuously sends some feedback information to tags during the reading process, which can significantly help the tags for collision arbitration. For example, if only a single tag replied in a slot (successful slot), the reader acknowledges the success of this tag [11–14], and this tag keeps silent in subsequent frames until the end of the reading process. In some other methods, the reader continuously sends a prefix that should match the tag ID to reply, and thus, avoid non-matching tags from replying [15–19].

Although by using such feedbacks the collisions can be alleviated and number of slots can be reduced, collisions are not totally eliminated and the reader needs to go through the collision-arbitration process. Additionally, such feedbacks trigger a high overhead (up to one feedback message per slot), and also some delay (although this delay is less than the delay if feedback messages are not used). The methods also require smarter and thus a more complex RFID reader and tags, because tags need to process the feedback information and also the reader needs to perform such a collision arbitration process continuously. For a thorough review of available tag scanning schemes please refer to [20].

The method proposed in this paper is based on the prototype in [4] while we target a solution for this problem. I.e., we configure the tag reading process for the localization application such that collisions are totally eliminated and delay can be reduced. Minor contributions of the proposed scheme include significant reduction of overhead and reader/tag complexities and hence, their cost: as tags