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CrowdSensing: A crowd-sourcing based indoor navigation using RFID-based delay tolerant network

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ABSTRACT

As a supporting technology for most pervasive applications, indoor localization and navigation has attracted extensive attention in recent years. Conventional solutions mainly leverage techniques like WiFi and cellular network to effectively locate the user for indoor localization and navigation. In this paper, we investigate the problem of indoor navigation by using the RFID-based delay tolerant network. Different from the previous work, we aim to efficiently locate and navigate to a specified mobile user who is continuously moving within the indoor environment. As the low-cost RFID tags are widely deployed inside the indoor environment and acting as landmarks, the mobile users can actively interrogate the surrounding tags with devices like smart phones and leave messages or traces to the tags. These messages or traces can be carried and forwarded to more tags by other mobile users. In this way, the RFID-based infrastructure forms a delay tolerant network. By using the crowd-sourcing technology in RFID-based delay tolerant network, we respectively propose a framework, namely CrowdSensing, to schedule the tasks and manage the resources in the network. We further propose a navigation algorithm to locate and navigate to the moving target. We verify the performance of proposed framework and navigation algorithm on mobility model built on real-world human traceset. Experiment results show that our solution can efficiently reduce the average searching time for indoor navigation.

1. Introduction

As the rapid proliferation of pervasive applications in indoor environment, a lot of location-based services and context-aware services are put forward in which location is viewed as one of the most significant factors. For most applications, it is required to provide an accurate location for the specified objects. However, the current mature technology like global position system (GPS) can only be used in the outdoor environment for localization, several issues like the multi-path effect and severe path loss make the indoor localization a lot more complicated than the outdoor situation. Therefore, a lot of research works have focused on localization and navigation schemes for indoor environment (Priyantha et al., 2001; Minami et al., 2004; Fischer et al., 2004; Azizyan et al., 2009; Biswas and Veloso, 2010; Jiang et al., 2011, 2012). Most of the solutions are rather complicated and fairly expensive.

Recent technological advances have enabled the development of low-cost and low-powered devices (Xie et al., 2010, 2013). RFID, as a novel technology for automatic identification, provides us with a new opportunity for indoor localization and navigation. For example, the low-cost RFID tags can be widely deployed inside the indoor environment and act as landmarks for localization. Since current smart phones can be equipped with near field communication (NFC) or bluetooth modules, which can effectively communicate with the active/passive tags, the mobile users can actively interrogate the surrounding tags with tiny devices like smart phones and leave messages or traces to the tags. In this way, the RFID-based infrastructure forms a delay tolerant network. As the scanning range of RFID system is usually no more than 5 m, the system can effectively locate the users by limiting the positioning error to at most 5 m.

In conventional indoor applications, the users are continuously moving within the indoor environment. Then, one important problem is how to locate and navigate to a specified mobile user. For example, when a baby or a dog is lost in a shopping mall, how to quickly locate and navigate to the mobile target? Obviously, the mobile target can only passively leave some traces in the environment through the equipped NFC or bluetooth modules. It cannot actively propagate its current position directly to the searchers. Besides, time-efficiency is very critical to the searchers, since the less time to use, the more opportunities to find the target.

Therefore, it is essential to devise a time-efficient navigation scheme by using the RFID-based delay tolerant network. In this paper, we first propose a framework to schedule the tasks and manage the resources in this network. Furthermore, we propose a navigation algorithm to locate and navigate to the moving target.

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A preliminary version of this work appeared in Ji et al. (2013), the main differences of this paper are three folds. First, we conduct an in-depth study on the storage management of RFID tags, we propose four strategies of writing and replacing tag storage memory and their corresponding usage scenarios (Section 4.3). Second, we conduct detailed analysis on the relationship between tag density and network parameters, such as the number of users, the movement speed of each user and the range of each users' activity area. It provides a fundamental guidance for the deployment of RFID-based delay tolerant network (Section 4.5). Third, we conduct the experiments with real-world human traces under shopping mall mobility model, illustrate some novel observations from the experiment results, and further verify the rationality of our navigation solution in practical situations (Section 5.1.1).

The main contributions of this paper are summarized as follows:

- We propose a framework leveraging RFID-based delay tolerant network for localization and navigation. By sufficiently leveraging the "store-and-forward" properties of the delay tolerant network, our solution provides an effective mechanism for navigation using "crowdsourcing" capabilities. By effectively scheduling the tasks and managing the limited resources in the tags, the system can provide navigation services for a large number of users.
- We propose a time-efficient scheme to locate and navigate to a mobile target who is continuously moving. According to the latest obtained spots of appearance, our solution navigates the searcher to the most possible region of the target, which achieves a good performance in terms of the time-efficiency.
- We conduct two kinds of experiments: large-scale experiment through simulation and fairly small-scale experiment using realistic human traces. In the large-scale simulation experiments, we investigate the relationships among number of users, tag density and performance of navigation. In the small-scale experiments, we strive to accurately reconstruct the movement scenes of a shopping mall founded on real-world human traces to verify our navigation framework and scheme.

The rest of this paper is organized as follows. Section 2 presents the related work. Section 3 provides an overview of the system. Section 4 introduces the distributed solution for indoor navigation. Section 5 shows the performance evaluation. Section 6 concludes this paper.

2. Related work

Many research works use RFID technology for indoor localization. LANDMARC (Ni et al., 2004) is a tag localization prototype in indoor environment. By utilizing extra fixed location reference tags to help location calibration, it can increase location accuracy without deploying large numbers of RFID readers. Lee and Lee (2006) construct an absolute positioning system based on RFID and investigate how localization technique can be enhanced by RFID through experiment to measure the location of a mobile robot. Saad and Nakad (2011) present a standalone indoor positioning system using RFID technology. The concept is based on an object carrying an RFID reader module, which reads low-cost passive tags installed next to the object path. The positioning system uses Kalman filter to iteratively estimate the location of the reader. Zhu et al. (2012) propose a fault-tolerant RFID reader localization approach to solve the problem of frequently occurred RFID faults. Moreover, they also propose the index to measure the quality of a localization result. Since the localization accuracy of LANDMARC approach largely depends on the density of reference tags and the high cost of RFID readers, Zou et al. (2013) propose two localization algorithms, namely weighted path loss (WPL) and extreme learning machine (ELM), to overcome these drawbacks. Ng et al. (2011) apply Radial Basis Function Neural Network (RBFNN) to estimate location of objects based on RFID signal strengths. Tong and Wang (2014) propose a novel RFID indoor positioning system based on Doppler Effect of moving RFID antenna. The Doppler frequency of RFID signal is recorded to compute the relative velocity between the antenna and target tags. By comparing the antenna movement with the relative velocity data, the position of the target is estimated using triangulation. Escort (Constandache et al., 2010) is an office environment localization and navigation system which uses client/server architecture. The client running on the user-carried mobile phones periodically measures the value of accelerometer and compass of the user's walking trail, and reports it to escort server. Encounter between two mobile phones, and encounter between a mobile phone and an audio beacon placed in the building will both be reported to escort server. Escort server utilizes users' walking trail and encounters to compute the current position of each user and routing directions.

In the theoretical research of delay tolerant network, a lot of work have been done to reveal the relationship between latency and network parameters, such as node density, connectivity range, node and movement speed. Dousse et al. (2004) prove that under certain assumptions the message sent by a sensing node reaches the sink node with a fixed asymptotic speed that does not depend on the random location of the nodes, but only on the network parameters. Kong and Yeh (2008) use percolation theory to analyze the latency for information dissemination in large-scale mobile wireless networks. They show that under a constrained mobility model, the scaling behavior of the latency falls into two regimes. When the network is not percolated, the latency scales linearly with the initial Euclidean distance between the sender and the receiver; when the network is percolated, the latency scales sub-linearly with the distance. Zhao et al. (2011) present fundamental relationship between node density and transmission delay in large-scale wireless ad hoc networks with unreliable links from percolation perspective. Yang et al. focus on the problem of rostering in intermittently connected passive RFID networks. They propose a rostering algorithm that employs a dynamic space-efficient coding scheme to construct hypothetic packet candidates (Yang et al., 2013). Bogo and Peserico (2013) study delay and throughput achievable in delay tolerant networks with ballistic mobility. They show that, under some very mild and natural hypotheses, as the number of nodes grows, (a) per-node throughput does not become vanishingly small and (b) communication delay does not become infinitely large. Kim et al. (2014) propose an efficient DTN routing scheme by using a node's social relation where each node chooses a proper relay node based on its contact history.

Greatly different from previous works, in this paper we focus on the problem of navigating to a moving target in indoor environment. The localization and navigation service are provided based on a RFID-based delay tolerant network. There is no central server in the system which can record all users' positions in real-time. The size of each RFID tag's memory space is small. By sufficiently leveraging the "store-and-forward" properties of the delay tolerant network and the 'crowdsourcing" capabilities brought by encounters between users and tags, we propose a time-efficient scheme to locate and navigate to a mobile target.

3. System overview

Most of the previous indoor positioning and navigation systems are centralized architecture which have the advantages of timeliness