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A sensor based indoor localization through fingerprinting

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ABSTRACT

Fingerprint based localization mostly considers to exploit existing infrastructure (APs or FM broadcast) to avoid hardware requirement and deployment cost. On the other hand these solutions confine them with such fixed infrastructures without having any control to reorganize or include further hardware if required. Controlling the infrastructure may help localization, especially indoors where the presence of multipath is high. A dense population of infrastructure nodes placing in all required indoors may capture a precise view of the surveyed area while generating a radio map of the fingerprinting or profiling based localization. The larger the number of infrastructure nodes the higher the cost. Indeed dense node population may introduce high interference. Can we then use low-cost low-power infrastructure nodes to achieve the (1) high density, (2) low cost, (3) minimal interference in addition to have the deployment flexibility? We were curious to know the answer and designed LEMON, an indoor localization system. Extensive experiments show that in addition to have the above characteristics, LEMON also ensures good accuracy. Thus it can be a solution to locate a person (e.g., a security guard in a warehouse) or an object (e.g., equipments) indoors.

1. Introduction

Location-based service is an interesting but challenging task under the roof, where traditional GPS is not a suitable candidate because of (1) cost, (2) form factor, (3) accuracy, and (4) unavailability. However the location-based service has the potentiality to leverage the ease of indoor navigation such as shopping mall and airports. Indeed we spot another application where an accurate location measurement is crucial for on time response; we indicate a home alone elder resident, who may need immediate assistance due to unexpected health condition. Though accuracy is our first concern, we consider cost as the next issue while building an indoor localization system. We thus choose the generic RF-based technology because of its simplicity, ubiquity, low cost, and unobtrusiveness.

We have choice of measuring RSS (received signal strength) (Bahl and Padmanabhan, 2000; Youssef and Agrawala, 2005), TOA (time of arrival) (Humphrey and Hedley, 2008), or AOA (angle of arrival) (Niculescu and Nath, 2004; Amundson et al., 2011) of the signal between a transmitter and a receiver under RF-based technology. The first of these categories of techniques is most attractive from the practical point of view, as it poses minimalistic requirements on the RF technology of the requisite modules, which translates into low cost and off-the-shelf availability. We further consider RSS profiling (Bahl and Padmanabhan, 2000; Youssef and Agrawala, 2005) as the method of localization because of its potentiality of offering high accuracy (Bahl and Padmanabhan, 2000; Youssef and Agrawala, 2005).

In profiling based scheme, RSS is considered as a quantity that depends on the distance between a transmitter and a receiver as well as the indoor environment. Thus we may expect that the RSS readings from similar environment may behave similarly. This hope lies behind the construction of a *radio map* of the monitored area by gathering the RSS readings from known locations. The RSS is captured through a set of infrastructure nodes (*peg*). To estimate the location of a query (*tag*), q, based on a given set of RSS readings Φ, this map is explored to search for a set of nearest neighbors of Φ. In the radio map the locations of those chosen neighbors are also stored that are used to predict the location of q.

We may distinguish the profiling based schemes according to the technologies used to gather the signal strength. In this list WiFi APs come first because of their indoors availability. Almost all wireless devices are equipped with a RSS receiver thus localization with APs does not require any hardware and infrastructure setup. A plethora of indoor localization is done using this technology, and some of the front line solutions are Bahl and Padmanabhan (2000), Youssef and Agrawala (2005), Liu et al. (2012), Wang et al. (2012), Sen et al. (2012), Shen et al. (2013), Yang et al. (2012) and Swangmuang and Krishnamurthy (2008). RFID tags and readers can also be used for indoor localization (Wang et al., 2013; Ni et al., 2004). FM broadcasting is another choice of gathering signal strength signatures (Yoon et al., 2013; Chen et al., 2012). This option does not require any extra hardware or infrastructure as FM

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broadcast is everywhere. Other options include magnetism (Chung et al., 2011), GSM (Otsason, 2005), or electric power-line (Patel et al., 2006).

Specific hardware based approaches (Bahl and Padmanabhan, 2000; Ni et al., 2004) may suffer from large error because of the constraints on the number of costly infrastructure nodes. This problem can be tackled using APs as they are already crowded indoors. Unfortunately localization performance can be affected by the constrains on the number and the locations of these APs (no control over rearranging existing ones or adding more APs). Indeed recent investigation (Yoon et al., 2013; Chen et al., 2012) reveals that the WiFi AP based signals are highly susceptible to indoor environmental changes (like the presence of moving humans, obstacles, etc.). Furthermore WiFi signals have high special and temporal impact that may lead to reconstruct the radio map often, makes WiFi based approaches nonfeasible indoors solution. In Yoon et al. (2013) and Chen et al. (2012) FM signal is used to overcome the shortcomings of WiFi signals. FM signals are less susceptible to the environmental changes and can cover longer distances compared to the WiFi signal. Recent smart phones and other mobile devices are all equipped with FM radio receivers with the existence of plenty of FM broadcasting, makes this technology viable. We still have no control over the number and location of the FM broadcasting, and this limitation may be seen in the localization performance (similar to WiFi, Chen et al., 2012).

We thus introduce a flexible infrastructure based localization without having any constraints on the number and the locations of the infrastructure nodes. In particular we use low-cost low-power small sensor devices (from Texas Instruments) as pegs and tags to design an indoor localization system dubbed *LEMON* (*Location Estimation by Mining Oversampled Neighborhoods*) (presented in Haque et al., 2009). LEMON can effort a large number of pegs (because of their low cost) that can be placed in any locations of indoors (behind and under the furniture) to precisely capture the signal propagation in the constructed radio map. This immediately helps to achieve a good accuracy without applying any further trick to the localization procedure.

A series of experiments in various indoors of the University of Alberta campus show that LEMON can offer an accuracy of 1 m. Note that the surveyed area is divided into a grid with a cell size of 1 m × 1 m. We have analyzed the RSS discrepancy measuring approach, the averaging technique of the coordinates of the nearest neighbors, the number of nearest neighbors and fingerprint samples, the impact of the temporal and special variation on the RSS, and the impact of the types of obstacles to evaluate LEMON. Surprisingly LEMON was not affected by the temporal variations, which makes the radio map construction phase simple. As long as indoors setup remains unchanged we need no more site surveying. However, our deeper analysis reveals that the captured RSS is contaminated by the multipaths and introduced error in the estimation. Thus we further investigated the robustness of LEMON in the presence of noisy RSS and faulty devices and proposed solutions to handle noisy RSS.

In the remaining paper LEMON is presented in Section 3 and next comes the description of the hardware and the logistics. Experimental results are presented in Section 5 and the robustness study comes in the following section. We wrap up the paper with concluding remarks.

2. Related work

In this section we briefly outline the fingerprint based localization schemes related to our work.

RADAR (Bahl and Padmanabhan, 2000) can be considered the pioneer of the fingerprint based localization indoors. During the radio map construction, RSS samples are gathered from four different directions for the same location to overcome the orientation effect. For localization, a collected sample is compared to the stored set and the coordinates of the closest fingerprint from the signal space is reported as the estimated location. Choosing more nearest neighbors and averaging their locations tends to improve the estimation. However, RADAR still suffers from large errors due to the limited number of infrastructure nodes: three long range APs covering the entire monitored area. One attempt to fix the problem involved a signal propagation model taking into account the presence of walls between transmitters and receivers. That attempt was not effective as the observed performance was even worse, which should be taken as a strong hint that, generally, propagation models cannot compensate for inadequate coverage with infrastructure nodes.

Several popular localization approaches rely on RFID technology. Such a system usually consists of a set of RFID readers, comprising the infrastructure, and trackable RFID tags. An RFID reader is able to detect the signal from a tag, if it gets sufficiently close. For a passive RFID tag, this will happen when the distance to the reader is so small that the scheme becomes range-free: detection by a reader is a sufficient estimation of the tag's location. A localization system like this may not provide a full coverage of the monitored area and be only concerned about detecting the presence of tags in certain “critical” places or regions. With active tags, on the other hand, which act like cheap low-range transmitters, the readers may be able to meaningfully assess the received signal strength and use it as a representation of the tag's distance, e.g., quantized into a few coarse discrete levels.

One RFID-based representative of the fingerprint based schemes is LANDMARC (Ni et al., 2004). The network consists of a set of RFID readers as the infrastructure nodes and RFID tags as the sending (tracked) devices. LANDMARC suffers from the technological limitation of RFID readers (the lack of a direct measurement of RSS by the reader). Also, the large diversity of hardware versions of tags impacts the performance.

In Patel et al. (2006) the existing residential powerline network is used for localization purposes, with the infrastructure nodes being attached to the powerline around the perimeter of the household. The system, called PLP (Power Line Positioning) targets residential applications. The signal transmitted by the infrastructure nodes is received by the tracked tag. Thus, with this approach, tags collect signal samples from the infrastructure nodes, not the other way around, as in RADAR, LANDMARC, and also LEMON. During fingerprinting, signatures of signals from known locations are stored in a database. The estimation stage proceeds in two phases: first the room where the tag appears to be present is identified, and using a respectively trimmed down population of samples, the more exact assessment of the tag's location within that room is carried out. However our experimental results show that the two-phased approach to location estimation in PLP may not be an effective approach. The task of accurately inferring whether a tag is in a particular room is often difficult (especially when the tag is positioned close to the wall), and once that decision is made incorrectly, its subsequent refinement is not useful.

With respect to WiFi-based solutions, Swangmuang and Krishnamurthy (2008) investigate the performance impact of a localization scheme for various AP density. The fingerprints are gathered at every grid point, where the grid consists of 1 m × 1 m cells. The closest neighbor from the signal space, like in RADAR, is then reported. The authors propose a model for ranking the collected RSS samples with respect to their contamination level and selecting less contaminated samples for location estimation.