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Fingerprinting based localization in heterogeneous wireless networks

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ABSTRACT

Due to advances in mobile technology, context-aware applications are continuously growing in importance; therefore, the ability of developing accurate and reliable localization system has become a necessity. Since methods based on received signal strength (RSS) fingerprints are today widely adopted and most of mobile devices comprise different wireless access technologies, it is feasible to use fingerprints from heterogeneous wireless networks (HWN) for localization purposes. In this paper we propose a novel approach for localization based on searching the area which best matches the test RSS fingerprint. We evaluated the proposed method in realistic environment in WLAN, GSM and UMTS networks, and compared it with other commonly used approaches. The results showed that our method compares favorably to others, and practically always achieves the lowest localization error. We also extended the proposed system using a model of cooperative positioning by combining the estimates obtained in the heterogeneous wireless network. The obtained results showed that with combined location estimate, significant improvement over any single system was achieved.

1. Introduction

For various location-based services (LBS) ability of accurate localization has become a key issue (Gustafsson & Gunnarsson, 2005; Hightower & Borriello, 2001; Sayed, Tarighat, & Khajehnouri, 2005; Wymeersch, Lien, & Win, 2009). An example of such service is the US government requirement for E-911 emergency positioning, while other location-aware applications can be found in industrial, commercial, everyday life and military settings. Although global positioning system (GPS) is the most well known localization technique for open environment, there is an unmet need for a reliable positioning system for indoor and dense urban environment, where GPS signals are greatly attenuated and there is no line-of-sight (NLOS) (Bull, 2009; Fang & Lin, 2008; Pahlavan, Li, & Makela, 2002; Sayed et al., 2005).

Various positioning systems have been proposed, employing various technologies, from ultrasonic (Hazas & Hopper, 2006; Priyantha, Chakraborty, & Balakrishnan, 2000), infrared (Aitenbichler & Muhlhauser, 2003; Want, Hopper, Falcão, & Gibbons, 1992), radio frequency (Bahl & Padmanabhan, 2000; Castro, Chiu, Kremenek, & Muntz, 2001; Kaemarungsi & Krishnamurthy, 2004; Ni, Liu, Lau, & Patil, 2004), ultra-wideband (UWB) (Gezici et al., 2005; Zhang, Liu, Fang, Wu, & localization, 2006), audible sound (Mandal et al., 2005) to vision analysis (Brumitt, Meyers, Krumm, Kern, & Shafer, 2000; Focken & Stiefelhagen, 2002), and achieving location estimation accuracy from few centimeters to few meters. However, the use of some of these systems requires a great deal of infrastructure investment in order to be highly effective and accurate, and the costs make it inaccessible to most users. To determine the location within the network, it is preferable to employ the existing wireless communications infrastructure. Most research in indoor localization systems uses the wireless communication infrastructure primarily based on the wireless local area networks (WLANs), in particular the IEEE 802.11 standard because of its widely deployed equipment and easily obtainable RSS measurements from IEEE 802.11 MAC software. Generally, there are two approaches based on RSS measurements, general exponential path loss model (Gustafsson & Gunnarsson, 2005; Lin & Juang, 2005; Mazuelas et al., 2009) and RSS fingerprinting model (Bahl & Padmanabhan, 2000; Brunato & Battiti, 2005; Fang & Lin, 2008; Hossain & soh, 2010; Nerguizian, Despins, & Affès, 2006; Stella, Russo, & Begušić, 2012; Yim, Jeong, Gwon, & Joo, 2010; Youssef & Agrawala, 2004).

The greatest technical difficulty of developing a localization system based on RSS path loss model is the fact that the relationship between the RSS values and the user location depends to a great extent on the propagation environment present, being very difficult to know which propagation models are the most suitable to describe such a relationship in real environments. Simple exponential path loss model, known as the Okumura–Hata model (Hata,

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1980; Okumura, Ohmori, Kawano, & Fukuda, 1968), has been used in many proposed localization algorithms. Although the model is very simple and easy to deploy, disadvantages of such approach are the facts that transmitted power, the position of the antenna and the path loss constant need to be known, while, in practice, it depends on the local environment and on multipath and non-line-of-sight (NLOS) conditions. In order to achieve higher localization accuracy, authors use different path loss exponents (Shirahama & Ohtsuki, 2008; Mao, Anderson, & Fidan, 2007) and different models (Bshara, Orguner, Gustafsson, & Van Biesen, 2010).

Currently, the most popular solution based on WLAN systems is the fingerprinting architecture (Bahl & Padmanabhan, 2000; Brunato & Battiti, 2005; Fang & Lin, 2008; Hossain & soh, 2010; Nerguizian et al., 2006; Stella et al., 2012; Youssef & Agrawala, 2004). Since it was first proposed in Bahl and Padmanabhan (2000), RSS is the most common signal parameter used in location fingerprints. Besides easily obtainable RSS measurements and no requirement for additional hardware, the advantage of this method is its lower sensitivity to multipath and NLOS conditions.

A location fingerprint based on characteristics such as RSS is the basis for representing a unique position or location. It is created under the assumption that each position or location inside a building has a unique signature. The process is composed of two phases: a phase of data collection called off-line phase and a phase of locating a user in real-time called on-line phase. The first phase consists of recording a set of RSS fingerprints in a database as a function of the users location covering the entire zone of interest and using this data as input and as the target of a pattern matching algorithm. During the second phase, RSS fingerprint is measured by a receiver and applied on pattern-matching algorithm to estimate location. In literature, various algorithms have been investigated from probabilistic method (Fang, Lin, & Lee, 2008; Fox, Hightower, Liao, Schulz, & Borriello, 2003; Kushki, Plataniotis, & Venetsanopoulos, 2007; Roos, Myllymäki, Tirri, Misikangas, & Sievänen, 2002), *k*-nearest-neighbor (Bahl & Padmanabhan, 2000) or a later approach of weighted *k*-nearest-neighbor (Hossain & soh, 2010), neural networks (Battiti, Le, & Villani, 2002; Fang & Lin, 2008; Laoudias, Kemppi, & Panayiotou, 2009; Nerguizian et al., 2006), and support vector machines (Kushki, Plataniotis, & Venetsanopoulos, 2010; Wu, Li, Ng, & Leung, 2007).

Besides WLAN, RSS measurement can also be easily obtained in other wireless networks. As a part of GSM standard (e.g. ETSI, 1997) which is required for successful handovers, mobile phones are required to report signal strength of 6 neighboring cells. This limitation could be easily overcome only with changing software since every GSM hardware has to have ability of screening the whole GSM band (GSM specification request). In UMTS, MS (mobile station) is required to measure received signal code power. For distinction of base stations (BSs), Scrambling Code (SC) can be used.

WiMAX modems contain RSS-based measurement called SCORE which is used to indicate connection quality. SCORE values are subject to higher variations than RSS because they depend on the signal strength and the output of the Viterbi decoder. It was shown in Bshara et al. (2010) that using the actual RSS values gives higher accuracy than using SCORE values.

LTE networks support a range of complementary positioning methods (Ericsson, 2011). The basic method Cell ID (CID) utilizes cellular system knowledge about the serving cell of a specific user. Support for this method has been mandatory since Release 8, and the following methods became available with Release 9: Enhanced Cell ID (E-CID), OTDOA (Observed Time Difference of Arrival), A-GNSS (Assisted Global Navigation Satellite System). E-CID enables UE (user equipment) to report to the network the serving cell ID, Rx−Tx time difference (only for the serving cell), RSRP (Reference Signals Received Power) – measurement of the received power level, RSRQ (Reference Signals Received Quality) – measurement of the received quality (SNR). In Wigren (2012), authors use enhanced cell identity information for fingerprinting based localization in the LTE cellular system.

Today, mobile technology comprises highly sophisticated devices like smartphones, tablets or notebooks with different wireless access technologies such as cellular networks (GSM/UMTS) and WLAN, so it can be feasible to use fingerprints from HWN for localization purposes. While there is a great number of research on wireless positioning, work on fusing multiple information from HWNs for localization purpose is still largely missing, only a few researches have already been done supporting such approach (Fang & Lin, 2010; Mahtab Hossain, Jin, Soh, & Van, 2013; Kwon, Dundar, & Varaiya, 2004; Varshavsky, de Lara, Hightower, LaMarca, & Otsason, 2007). A hybrid algorithm is presented in Kwon et al. (2004) for indoor positioning using WLAN based system that combines the fingerprinting method and propagation loss model. In Mahtab Hossain et al. (2013) authors combine WLAN and Bluetooth system. In Fang and Lin (2010) cooperative approach is used for positioning in HWN, where spatial correlation embedded in measurements is exploited.

The focus of our research in this paper is to provide cost-effective location estimation, utilizing existing infrastructure. Due to a wide availability of WLAN infrastructure and practically ubiquitous GSM/UMTS service we choose these wireless technologies for our analysis and experiments.

In this paper we propose a novel approach for localization based on determining the area which best matches the test RSS

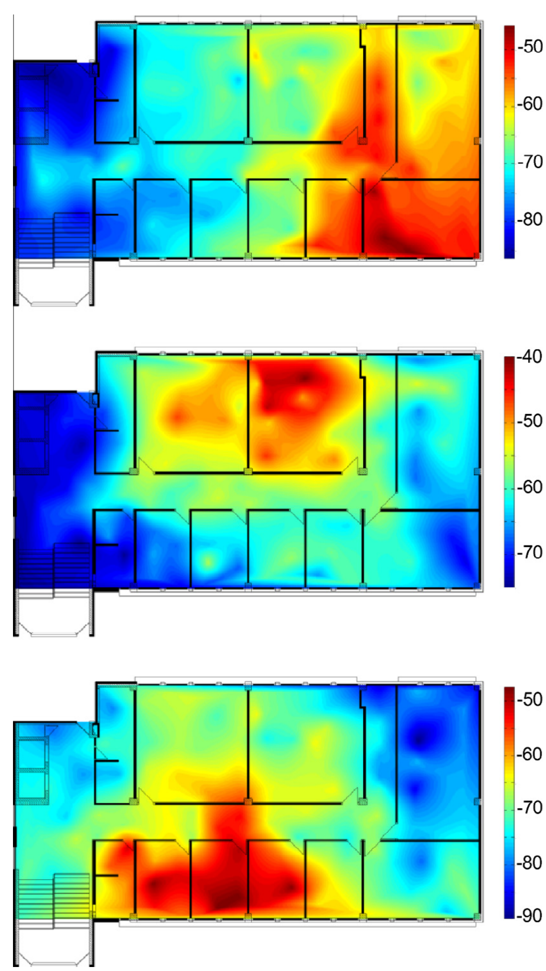

Fig. 1. RSS maps for AP1, AP2, AP3.