Journal of Network and Computer Applications 64 (2016) 89–97

Contents lists available at ScienceDirect

Journal of Network and Computer Applications

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

Cooperative energy-efficient localization with node lifetime extension in mobile long-thin networks

Lien-Wu Chen

Department of Information Engineering and Computer Science, Feng Chia University, Taichung 407, Taiwan

ARTICLE INFO

Article history:
Received 22 August 2015
Received in revised form
18 January 2016
Accepted 28 January 2016
Available online 5 February 2016

Keywords:
Ad hoc network
Clustering
Localization
Power saving
Mobile long-thin network

ABSTRACT

In this paper, we propose a *Cooperative Energy-Efficient Localization Framework* (*CELF*) for power saving in mobile long-thin networks (MLTNs). We use the cycling ad hoc network with fleet cyclists using mobile phones along a common cycling route as an example (our results could be applicable to other scenarios as well, such as the mountaineering party and army troops). As cyclists need to upload their position data and download global fleet information, all power-consuming GPS receivers have to be switched on for obtaining their current locations. In CELF, distributed localization among cyclists without central control is designed to minimize the energy consumption of positioning. To the best of our knowledge, CELF is the first distributed solution for localization which provides the following features: (i) CELF does not rely on costly roadside infrastructures but only employs cyclist-to-cyclist communications; (ii) CELF can supply group members with the up-to-date locations without activating GPS receivers; (iii) CELF can estimate member positions only based on single mobile anchor instead of multiple static anchors. Simulation and experimental results show that CELF outperforms existing works, which can significantly reduce the energy consumption for localization while keeping the positioning accuracy similar to GPS.

1. Introduction

Recently cycling has gained a lot of popularity due to concerns of the environment and health. Existing works include public bike rental systems (Luo and Shen, 2009), electric bikes (Liang et al., 2006), and bike-based sensing systems (Eisenman et al., 2007). On the other hand, mobile phones have been widely used for location-based services (LBSs) by mobile users. A number of applications and systems utilizing mobile phones for social networks (Hwang et al., 2009), Intelligent Transportation Systems (Koukoumidis et al., 2011), and biker group communications (Chen et al., 2011) are developed by academic and industrial organizations. For network lifetime extension, the issues of power saving and energy optimization have been studied for mobile ad hoc networks (Mohsin et al., 2012) and wireless sensor networks (Sendra et al., 2011; Garcia et al., 2013).

A distributed network with fleet cyclists using mobile phones forms a *mobile long-thin network* (*MLTN*) consisting of IEEE 802.11 interfaces along a common cycling route. In a fleet, individual cyclists may frequently upload personal information and download global status information such as common messages, member locations, and points of interests (Chen et al., 2011). Therefore, there are potential power and lifetime issues that need to be addressed by optimizing the energy consumption of positioning for cyclists. This work focuses on minimizing the power consumption in positioning through cooperative localization among cyclists in a cycling fleet without central control.

Several existing mechanisms (Cheung et al., 2004; Deligiannis et al., 2006; Martin-Escalona et al., 2010; Yamasaki et al., 2005; Boukerche et al., 2008; Lu et al., 2008; Bajaj et al., 2002) have been adopted for localization, which can be classified as *terrestrial-based* or *satellite-based* solutions. Terrestrial-based solutions include positioning methods based on Time of Arrival (TOA) (Cheung et al., 2004; Deligiannis et al., 2006), Time Difference of Arrival (TDOA) (Martin-Escalona et al., 2010; Yamasaki et al., 2005), Angle of Arrival (AOA) (Boukerche et al., 2008), and Received Signal Strength (RSS) (Lu et al., 2008). However, TOA and TDOA methods require global time synchronization in most cases and at least three anchor nodes to calculate an unique position. AOA method relies on high-accuracy directional antennas and thus make the hardware cost high. RSS method is feasible for outdoor environments with no obstacle but indoor RSS localization encounters serious multi-path problems and thus needs additional database of environmental signal strength distribution collected beforehand by pattern training and error adjusting (Haque, 2014).

Satellite-based solutions rely on Global Positioning System (GPS) (Bajaj et al., 2002; Karim et al., 2015), which is a worldwide localization technology adopted by vehicles. GPS consists of a number of satellites transmitting periodical coded signals. GPS

E-mail address: lwuchen@fcu.edu.tw

http://dx.doi.org/10.1016/j.jnca.2016.01.019
1084-8045/

receivers with multiple radio channels can observe multiple GPS satellites at once and obtain a distance measurement from each satellite signal. A GPS receiver can compute its location in three dimensions from four distance measurements. However, the receiver of GPS is an energy-consuming component for mobile phones powered by batteries. In addition, the distance measurement contains global and local errors caused by atmospheric and multi-path effects, respectively, with a typical accuracy range of tens of meters. To reduce the power consumption of GPS, existing works (Kjargaard et al., 2009; Constandache et al., 2009; Lee et al., 2010; Paek et al., 2010) have shown that the power consumption of Wi-Fi antenna/Accelerometer is much lower than that of GPS receiver in a mobile phone, and designed the rate-adaptive localization schemes to turn off the GPS receiver (i.e., switched to the sleep mode) for a specific while in single mobile phone by using Wi-Fi communications and/or Accelerometer measurements instead.

In this work, we propose a *Cooperative Energy-Efficient Localization Framework* (*CELF*) for energy saving in MLTNs. We use the cycling ad hoc network with fleet cyclists using mobile phones along a common cycling route as an example (our results could be applicable to other scenarios as well, such as the mountaineering party and army troops). To the best of our knowledge, CELF is the first distributed solution for MLTN localization, which consists of a cyclist grouping mechanism, an anchor selection scheme, and a position estimation method. The contributions of our framework are four-fold. First, it only employs cyclist-to-cyclist communications for localization instead of relying on costly roadside infrastructures. Second, we propose a way to obtain the up-to-date locations for group members without activating GPS receivers. Third, it estimates member positions by only using single mobile anchor instead of multiple static anchors. Finally, the proposed framework can turn off most of GPS receivers (i.e., into the sleep mode) to save the battery power for mobile devices and to extend the network lifetime for MLTNs while keeping the positioning accuracy similar to GPS. Extensive performance studies are conducted and the simulation results show that our framework can achieve better energy efficiency and higher handset lifetime compared with existing results. In addition, the experimental results show that our framework can keep the positioning accuracy similar to GPS in rural areas and better than GPS in urban and suburban areas.

The rest of this paper is organized as follows. Section 2 discusses related works. Section 3 defines our cooperative localization problem for fleet cyclists. Section 4 describes our framework to solve this problem, which consists of a cyclist grouping mechanism, an anchor selection scheme, and a position estimation method. Simulation and experimental results are shown in Section 5. Finally, Section 6 concludes the paper.

2. Related works

Several individual-based localization schemes for power saving have been proposed on mobile phones (Kjargaard et al., 2009; Constandache et al., 2009; Lee et al., 2010; Paek et al., 2010; Kjaergaard, 2012; Ergen et al., 2014; Lee et al., 2014; Khan et al., 2014). Table 1 compares the features provided by existing schemes and ours according to if these solutions supply users with the up-to-date positions by GPS, Wi-Fi/GSM, accelerometer, received signal strength, single mobile anchor, or fleet-based localization. Our framework offers the most complete solution for cooperative localization.

Kjargaard et al. (2009) propose a system called EnTracked that schedules position updates to both minimize energy consumption and optimize robustness based on the estimation and prediction of system conditions and mobility. EnTracked tracks pedestrian targets equipped with GPS-enabled devices, which can be configured to realize different tradeoffs between energy consumption and robustness. To use EnTracked, error limits in tracked targets have to be provided by location-based applications, but the highest possible accuracy may be required by most of location-based applications.

Constandache et al. (2009) develop an energy-efficient localization framework called EnLoc, which uses dynamic programming to characterize the optimal localization accuracy for a given energy budget. In addition, Constandache et al. (2009) adopt habitual mobility patterns and population-driven probability maps to develop prediction-based heuristics for real-time use. EnLoc assumes that the location of the phone is accurately tracked as moving along a predicted path, but varying speeds or pauses in reality cause an imprecise prediction.

Lee et al. (2010) propose a method to adjust the frequency of GPS localization according to human motion state detected by tri-axis accelerometers. The positioning rate of GPS receivers can be adjusted to achieve power saving for mobile devices, but the location information cannot be obtained anymore as turning off GPS receivers. In addition to tri-axis accelerometers, Paek et al. (2010) consider the history of user mobility to adjust the frequency of GPS localization. Paek et al. (2010) present a rate-adaptive positioning system for mobile phone applications, which estimates user velocity based on the location-time history of the user. The GPS receiver of a mobile phone is switched on adaptively only if the estimated position uncertainty exceeds the accuracy threshold. However, the moving trajectories of mobile users need to be collected and analyzed beforehand.

Kjaergaard (2012) investigates energy-related issues, such as the frequencies of positioning, caching, and uploading, in minimizing the power consumption for LBSs on mobile phones. In addition, Kjaergaard (2012) also introduces existing energy-efficient systems that consider switching between GPS, Wi-Fi, and GSM positioning (depending on the required accuracy) or switching between GPS and

Table 1
Comparison of prior works (Kjargaard et al., 2009; Constandache et al., 2009; Lee et al., 2010; Paek et al., 2010; Kjaergaard, 2012; Ergen et al., 2014; Lee et al., 2014; Khan et al., 2014), and our framework.

Features	GPS enabled	Wi-Fi/GSM enabled	Accelerometer enabled	Received signal strength	Single mobile anchor	Fleet-based localization
Kjargaard et al. (2009)	√		√			
Constandache et al. (2009)	√	√		√		
Lee et al. (2010)	√	√	√	√		
Paek et al. (2010)	√	√	√	√		
Kjaergaard (2012)	√	√	√	√		
Ergen et al. (2014)	√	√		√		
Lee et al. (2014)	√		√			
Khan et al. (2014)	√	√		√		
Our framework	√	√		√	√	√