Chapter 20
LOCALE:
Collaborative Localization Estimation for Sparse Mobile Sensor Networks

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ABSTRACT

Mobile devices, by their nature, are very personal devices. As the field of mobile application matures, applications are beginning to include location and other context aware services. In addition, current research is trending to more peer-to-peer capable systems. They will often be very sparse for all or part of their operation because of mobility. While some of these devices localizes with fixed location beacons or per-node GPS, these methods are not always possible due to many constraints. This chapter focuses on a robust statistical method in mobile networks to both determine the location of the device and provide an estimation of the accuracy. This method is provides seamless operation despite the local density of a mobile network, providing the application with a meaningful measure of location with accuracy. While this chapter only focuses on localization, the methods discussed here can be applied to provide other estimation based in-system measurements.

1 INTRODUCTION

Mobile devices have become ubiquitous devices used in daily life. Applications used on these devices today utilize various user contexts, including location, in order to perform greater personal services. Currently, mobile systems relies on a system of infrastructure, which both limits their coverage and bandwidth. As these devices becomes more widespread, current research in mobile systems are trending to more distributed systems with peer-to-peer capabilities. For both technical and logistical reasons, such networks will often be very sparse for all or part of their operation, sometimes functioning more as disruption-tolerant networks (DTNs).

In these mobile systems, it is common to require the knowledge of a node's physical location. This information can be recorded and extensively used as sensed data (Juang, 2002), in routing decisions

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(Yu, 2001), or for policy decisions. However, it is a non-trivial task to obtain the location both accurately and efficiently, especially in a sparse network. There have been works in dense-and-fixed networks for localization (Langendoen, 2003). Unfortunately, most of these methods require reliable connections between localizing nodes. When applied to a sparsely mobile network, these methods are inefficient, and often ineffective. In sparse systems, two methods are mainly used for localization: GPS (Zhang, 2005), and beacon triangulation (Moses, 2002). In the ZebraNet deployments, GPS localization, while producing accuracy within 100 meters, used nearly 50% of total system energy. Beacon triangulation, on the other hand, requires a high density of beacons, which is too costly for many, if not most, applications.

One way to localize sparse mobile nodes is by using a Global Positioning System (GPS) on each node. This technique is widely used in mobile phones, vehicle tracking systems, and others. Unfortunately, many prerequisites have to be met for GPS to function properly. For example, the GPS antenna needs an unobstructed view of the sky, making it difficult for use indoors or in urban canyons. Furthermore, power consumption of the GPS greatly shortens the lifetime of sensor nodes, while considerably increasing the cost of each device.

To solve these problems, several mobile networks use radio location beacons as localization references. Nodes use a variety of methods to measure their distance from multiple fixed or mobile beacons with known locations in order to estimate their own locations (Moses, 2002). However, this method requires that beacons cover all areas of the network where localization is desired. Since mobile devices are free to wonder, this can translate into unacceptably high infrastructure costs in order to provide the needed coverage (in sparse areas) and needed bandwidth (in dense areas).

To reduce infrastructure requirements in dense networks, many collaborative methods have been developed for dense networks. Typically, nodes in these networks localize by collaboratively deducing network topology and using several anchor beacons to calculate absolute locations (Langendoen, 2003). If nodes are mobile, however, these methods become inefficient or ineffective due to increasing communication overhead needed for the collaboration. Furthermore, in sparse areas of the mobile networks, these kinds of naive collaboration becomes unworkable due to the low number of nodes within each node's communication range.

This chapter presents Low-density Collaborative Ad hoc Localization Estimation (LOCALE). This method employs a distributed localization algorithm designed to enable collaborative localization in sparse mobile networks, such as future peer-to-peer mobile phone networks. It not only merges location information when neighbors are present, but also actively predicts and maintains the location estimation during periods of disconnection.

LOCALE maintains an ongoing, rough estimation of the nodes' location and certainty about this estimation during disconnects by using a dead-reckoning (DR) system. (This is simpler, cheaper, and more energy-efficient than per-node GPS.) When a node meets a neighbor, they swap position estimates and then refine information on the nodes' location by a linear combination of the two estimates, weighted by the variances. Over time, in a delay-tolerant manner, LOCALE effectively averages movements of nodes and generates for each node a distribution describing its location. Unlike most localization techniques, which maintains an implicit assumption of accuracy, the nodes maintain not only a prediction of their actual location, but also a ``confidence estimate'' of the likely accuracy of this prediction.

LOCALE has the following key characteristics:

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