Ad Hoc Networks 15 (2014) 39–52

Contents lists available at ScienceDirect

Ad Hoc Networks

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

Hop count based distance estimation in mobile ad hoc networks – Challenges and consequences

Sabrina Merkel *, Sanaz Mostaghim, Hartmut Schmeck

Institute AIFB, Karlsruhe Institute of Technology (KIT), 76128 Karlsruhe, Germany

ARTICLE INFO

Article history:
Received 31 October 2012
Received in revised form 25 April 2013
Accepted 25 August 2013
Available online 31 August 2013

Keywords:
MANET
Mobility
Hop count
Localization
Distance estimation

ABSTRACT

Hop Count based distance estimation is an important element for localization of devices in mobile ad hoc networks. Deriving distance estimates from hop counts is prone to error, especially in networks with low density. This paper shows that mobility can affect the accuracy of hop count based distance estimation. Two types of error are defined to describe and analyze the source of underestimation and overestimation of distances in a mobile ad hoc network. Different movement patterns are examined to get an insight of their impact on the hop counts and the estimated distances accordingly. Our experiments and analysis indicate that mobility can have a positive effect on the accuracy of distance estimates which results from a combination of asynchronous computation of hop counts and mobility of the nodes. At the same time, this positive effect can turn into a negative one with increasing mobility. Therefore, we determine characteristics, such as direction, speed, and similarity in movements of neighbors which are responsible for the disparity in the influences of the investigated mobility patterns. A study of these properties is presented and their individual effect is explained in detail. The difference between mobility and density induced error is discussed and their individual adverse effect is weighted against each other. In addition, we introduce a modified algorithm to determine hop counts which is designed to mitigate the effect of mobility. Two indicators are presented to identify and characterize the mobility of devices in a decentralized way.

1. Introduction

In many applications, such as geographic monitoring or target tracking, a large number of possibly mobile devices is used to accomplish a specific goal. In general, such devices have limited resources and wireless communication range to exchange short messages with other nearby devices. To send messages to remote devices in the network all nodes act as relay nodes and forward messages from other devices. A network of such devices is called mobile ad hoc network (MANET) as the network's connectivity is dynamic and formed ad hoc. MANETs are widely studied in literature and there is a working group founded by the Internet Engineering Task Force (IETF) to investigate related issues [1]. As bulks of such devices might be necessary to perform a task, they are generally assumed to be mass-produced, therefore inexpensive, and of small sizes. In such networks, there is often a trade-off between reliability and cost. Additionally, to avoid further expenses, the devices usually are not equipped with any localization technique. This makes it hard to realize applications which depend on the location of each device such as the allocation of event reporting in a monitoring sensor network [2,3], location dependent routing [4,5], and many more. Localization can also support several MANET characteristic tasks, such as optimal area coverage in routing [6], assistance of network querying [7,8], or security [9,10]. Therefore, alternative localization techniques were proposed for ad hoc networks (cf. [11–14] for an overview). Many

* Corresponding author. Tel.: +49 721 608 4 4556.
E-mail address: sabrina.merkel@kit.edu (S. Merkel).

1570-8705/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.adhoc.2013.08.013

of these algorithms rely on the estimation of the distances between each node and a small number of so called anchor nodes. Anchor nodes are assumed to know their own coordinates either through a GPS-receiver or a priori configuration. There are several ways to estimate distances. In this paper, we consider distance estimation based on hop counts, i.e. the minimum number of relay nodes needed for communication, and analyze the effects of mobility on this estimation technique.

For our investigations, we focus on mobile devices which are not autonomous and cannot move by themselves like robots. Instead, they are passive, i.e. they can be moved by people, animals, or nature. This implies that the distance estimation algorithm has no information about whether or to which position a device has been moved. As the movement of devices in a mobile ad hoc network highly depends on the application and the environment, a large spectrum of mobility models is analyzed here. Two different error types are identified caused by either the distribution of the devices or mobility. Our goal is to quantify the error of such hop count based distance estimation in a dynamic network and to identify the main influencing factors by comparing various mobility patterns. Our observations and analysis indicate that mobility positively influences the error rate, counteracting the error induced by low density. Nevertheless, a high mobility can also increase the error, turning a natural overestimation into an underestimation of the respective distances. We identify various characteristics of the applied mobility, such as speed, direction and similarity of moves in a neighborhood, which have a different impact on the height of the mobility induced overestimation. Furthermore, we quantify, compare, and explain their individual impact on the hop counts and suggest two indicators, which can be computed in a decentralized way and are able to give information about the characteristic of the mobility exerted on a device.

This paper is structured as follows. Section 2 describes the related work. In Section 3, the network model and basic algorithmic concepts are introduced. Section 4 presents the investigated mobility models and Section 5 addresses the error model. Section 6 introduces the experiment settings, their results, and interpretation. The paper is concluded in Section 7.

2. Related work

Many localization algorithms rely on special anchor nodes, i.e. nodes which know their own location, to derive the location of all other nodes in the network. For example, a node's position can be estimated to be in the centroid of the closest surrounding anchor nodes, such as proposed in [15–23]. The main drawback of this approach is the need for numerous anchor nodes to be able to distinguish the positions of all other network nodes. To avoid this issue, there are algorithms, e.g. [24] which rely on the estimation of the distance between the node of which the location is needed and a small number of anchor nodes. Anchor nodes can be sensor nodes in the network [24] nearby cell-towers [25] or even wireless local area network routers [26,27]. The computation of distance estimates has been widely studied in literature. The most commonly described methods to assess the distance between two devices are called *range-based* approaches. In range-based distance estimation the communication signal is analyzed using special hardware. This is mostly done by evaluating its strength on receipt [12,25–36], its transmission time [37–41], or its angle of arrival [42,43]. Another way to estimate distances without relying on hardware is called *range-free* distance estimation. Range-free distance estimation only works for multi-hop networks. There are two types of range-free distance estimation algorithms. The first one uses the number of shared communication partners to approximate the surface of the common communication range between two nodes and deduces the distance from it [44–47]. The second kind of range-free distance estimation is based on hop counts [24,30,48–54]. To estimate the distances between the nodes in the network and the anchor nodes, all nodes count the communication hops between themselves and the anchor nodes. This value is called the hop count and is subsequently multiplied with an estimate for the physical length of one hop to compute the distance estimate. Various methods are proposed to estimate the length of one hop. The most basic idea is to use the communication range r as an approximation for the length of a hop because in a dense and uniformly distributed network, the nodes with the same hop count are located in rings around the anchor node and each ring has approximately the width of the communication range r [55]. Nevertheless, in a network which is not perfectly dense this assumption is rarely fulfilled. Fig. 1 shows the perfect gradient rings with black lines and it is easy to see that the gradient rings formed by the GA differ from the perfect gradient rings. Due to this density problem, a more sophisticated estimation method for the length of one hop is needed. In [55], the expected length of a hop is given for uniformly random distributed networks, depending on the local neighborhood density. A similar principle is used in [50] for networks with varying density. Here, density dependent reduction rates are chosen empirically. Another method to estimate the hop length is provided by the *DV-HOP* approach [30,48,49,51] which uses the known Euclidean distances between anchor nodes and divides them by the hop counts determined with GA

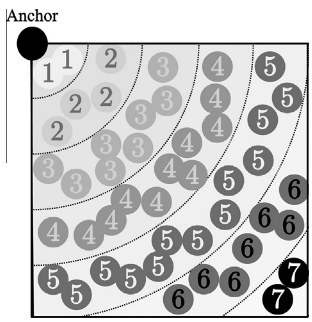

Fig. 1. Example network with devices labeled with their hop count values from the Gradient Algorithm. The rings indicate perfect gradient rings with a width of r.