COOPERATIVE LOCATION ESTIMATION IN HIGH-DENSITY MOBILE AD HOC NETWORKS

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Abstract—Location-aware ad hoc routing protocols use the position of nodes to forward packets from sources to destinations. A simple and accurate way to provide location information is using a GPS receiver in each mobile node. However, embedding GPS receivers in all the mobile nodes is not applicable in many low-cost applications. Thus, other mechanisms have been proposed to estimate the location of a mobile node. In this paper we propose a novel location estimation approach called Cooperative Location Estimation. The main idea in this approach is the cooperation of mobile nodes in order to estimate their locations. The performance of the proposed approach is evaluated by performing a series of simulations.

1. INTRODUCTION

Location-aware ad hoc routing protocols use the position of nodes to forward either route discovery or data packets from sources to destinations. During forwarding, a node selects the next hop based on its own position, the positions of its neighbors, and the position of the destination. The packets are forwarded to a neighbor in the receiver direction. For this reason, these routing protocols are also referred to as position-based or geographic approaches. Generally, a location service is used to solve the queries about the current positions of the network’s nodes [1]-[5].

A simple and accurate way to provide location information is using a GPS receiver [6] in each mobile node. However, embedding GPS receivers in all the mobile nodes is not applicable in many low-cost applications. Thus, other mechanisms have been proposed to estimate the location of a mobile node. The system proposed in [7] determines the proximity of a node based on a set of pre-deployed location-aware reference nodes that transmit spatially overlapping beacon signals. Nodes localize themselves at the centroids of the reference nodes, from which they can receive beacon signals. The accuracy of localization depends on the density of the reference nodes and their transmission range. The system described in [8] and developed as part of the Terminode project [9] uses radio time of flight (ToF) measurements to provide locations in mobile ad hoc networks. Despite the existence of measurement errors, this system is reported to support mobile nodes with speeds up to 20 m/s and can provide adequate location accuracies for supporting basic network services such as location-aided routing. Reference [10] describes a localization system that uses Bayesian methods. The convex position estimation algorithm described in [11] computes the locations of nodes in an ad hoc network by performing computation at a central point in the network. Location estimation is formulated as a linear program (LP) or a semi-definite program (SDP), and the solutions are computed using a special optimization software package.

In this paper we propose a novel approach for location estimation in mobile ad hoc networks. It estimates the location of a node with an acceptable approximation. We call this approach Cooperative Location Estimation since the main idea in it is the cooperation of mobile nodes in order to estimate their locations. This is in contrast to the previously proposed location estimation approaches which only use some external entities to help the network’s nodes estimate their locations.

This paper is organized as follows. Section 2 describes the proposed approach. The simulation results are presented in Section 3. Finally, Section 4 concludes the paper.

2. COOPERATIVE LOCATION ESTIMATION

In many places like a conference workshop or a book fair, where installation of infrastructure is not logical and mobile devices can only connect to each other through an ad hoc network, installation of some low-power base stations, which broadcast their location information periodically, is not so difficult. Broadcasting so-called location update messages, these base stations help mobile nodes estimate their positions.

As well as base stations, mobile nodes broadcast location update messages periodically with a predetermined time period. The period of broadcasting messages by base stations and mobile nodes are identical. Each location update message contains the estimation of the sender’s location (either precise in base stations or approximate in mobile nodes), and a quantity called the weight of the message. This quantity is mainly calculated based on the sender node’s desire to affect its neighboring nodes (i.e. the mobile nodes within its transmission range). In addition, a node can enter another parameter to its weight calculations – its confidence to its own location information. We describe this parameter later.

Each mobile node uses the location update messages from its neighbors. It calculates its approximate location as a weighted average of the location of neighboring nodes. The main calculation performed by each node to estimate its location is described as
Figure 1. An example of a non-uniform network density. Node N receives more location update messages from the direction of the region where nodes 1-4 are located compared to other directions.

\[ P_{\text{new}} = \frac{\sum_{i \in \text{neighbors}} w_i P_i + S w P_{\text{old}}}{\sum_{i \in \text{neighbors}} w_i + S w}, \tag{1} \]

where \( P_{\text{old}} \) and \( P_{\text{new}} \) are, respectively, the previous and the current estimations of the location; \( w_i \)’s and \( P_i \)’s are, respectively, the message weights and estimated locations received from neighboring nodes during the last location update period; \( S \) is a constant value called the self-confidence of the node and \( w \) is the last calculated weight of the node’s own. This calculation is performed once in a location update period.

All the mobile nodes should broadcast location update messages containing their estimations of their own locations as well as the weights of their messages. The most important part of this approach is calculating the weights so that it leads to the best approximation of location in all the mobile nodes. The first parameter determining the weight of a message is the sender node’s desire to affect its neighboring nodes. There may be situations that a sender has less desire to affect its neighbors despite the high confidence to its own estimation. An instance of such a situation is when the density of mobile nodes in a small area is high. This high density of nodes can cause erroneous estimations in the neighbors of the area. Fig. 1 illustrates such a situation. Each of the mobile nodes inside the congested area (here nodes 1-4) can detect the congestion of nodes and decrease the weight of their messages to balance the total weight of messages from each direction to a neighboring node (i.e., node N).

Another parameter to calculate the weight of a message is the sender node’s confidence to its own estimation. Such quantity can be calculated by considering different factors. For example base stations which broadcast their real, possibly preset, locations can easily set the weight of their messages to a global large constant. Another example is a newly booting node that has not met any base stations yet and has only received low-weight location update messages from some mobile nodes. This node has less confidence to its estimation and will broadcast a low-weight message. In this paper we ignore such a case.

One possible way to calculate the weight of a message is

\[ w = \min(w_{\text{ms}} \cdot \frac{w_{\text{ms}}}{\max(N,1)}), \tag{2} \]

and \( w_{\text{ms}} \) can be set to

\[ w_{\text{ms}} = \min \{w_{\text{bs}}\}, \tag{3} \]

where \( \{w_{\text{bs}}\} \) is the set of constant weight of the base station messages, \( w_{\text{bs}} \) is a predetermined constant and \( N \) is the number of location update messages received during the last location update period (i.e. the number of neighboring nodes). Other similar expressions can be used to calculate the weights of messages, but the term division to \( N \) seems to be necessary in order to make adaptability to non-uniform densities of nodes in the network. This term also allows using a constant \( w_{\text{ms}} \) in a large range of network sizes for a constant set of \( \{w_{\text{bs}}\} \).

The proposed approach has advantages over currently existing ones:

- One of the main advantages of this approach is its very good performance in high-density networks. Generally, high density of mobile nodes is a typical problem in routing protocols. Here, such a high density can help statistical calculations work better.
- The algorithm is simple and easy to implement. There’s no geometric calculation commonly used in many proposed approaches.
- It is possible to use low-power, low-cost, easy-to-deploy base stations with low coverage ratios.
- Location update messages are small and do not waste much bandwidth.
- No cross-layering is needed. All the calculations are performed in the network layer.
- The calculations are statistical and the fault tolerance is acceptable. For example, sensitivity to the transmission power of the base stations is, to some extent, trivial.

### 3. Performance Evaluation

#### 3.1 General Behavior

The performance of the proposed approach is evaluated by a series of simulations. The first step is illustrating the general behavior of the nodes’ calculations (i.e. how the estimations converge to the real values of the locations). The network in this step is composed of 500 nodes within a 1000x1000 m² area. The transmission range of mobile nodes is 150 meters. The mobility model used is random waypoint with the maximum and minimum speed of 10 m/s and 5 m/s respectively. The locations of the base stations are chosen around the area (i.e. the worst case from the coverage ratio point of view). Forty low-power base stations are deployed uniformly around the area. The transmission range of the base stations is chosen identical to that of mobile nodes. The simulation run-time is 150 seconds and the time interval for broadcasting location
update messages is one second. Other simulation parameters are listed in Table I.

Fig. 2 shows the average result of running the described simulation scenario for five times. It shows that this approach can reach the estimation error of $0.2R$ in average and $0.7R$ maximum, where $R$ is the radius of the transmission range of the mobile nodes and the base stations. This approximation is acceptable compared to some previous significant works ($0.7R$ in CPE and $R/3$ in APS and RPAD; See [12]). It is worth mentioning that this approach applies no hard limitations on the locations of the base stations and their overall coverage ratio unlike almost all the currently existing approaches. Better results can be obtained by installing the base stations in certain places, for example in the middle of the network area. However, the results show the good performance of the proposed cooperative approach when the environment imposes constraints on the places which can be chosen to install the base stations.

In the above simulations the initial values of the estimated locations are simply set to zero. This causes large estimation errors in the first few seconds. However the estimations converge to proper values after an acceptable time relative to low location update rate. It is obvious that decreasing the location update period will speed up the convergence of the estimations and it also reduces the undesired effect of mobility of the nodes. To investigate how the initial values can affect the illustrated behavior, the previous scenario can be run again with initial values set to the actual locations of nodes. This scenario is run for five times and the results are shown in Fig. 3. It shows that the initial values only affect the process of convergence and do not make significant improvement in the estimated values in steady state.

### 3.2 The Effect of Network Density

As described in Section 2, the proposed approach works well in high density networks. To illustrate the effect of the density of the network’s nodes, the previous scenario was run for different number of nodes (and hence different network densities). Fig. 4 shows the effect of the density of the nodes. As can be seen, increasing the density of the nodes improves the performance in both the estimation error and the time of convergence. However, this improvement is limited in very high network densities due to the increasing number of

![Figure 2](image2.png)

Figure 2. Convergence of the estimations to the actual values of the locations. The large errors in the first few seconds are due to arbitrarily chosen initial values.

![Figure 3](image3.png)

Figure 3. Convergence of the estimations with proper initial values. Improvement in the estimations in steady state is trivial. Hence, choosing the initial values is not a main concern.

![Figure 4](image4.png)

Figure 4. The effect of network density. Higher densities reduce the estimation errors as well as the time of convergence.

![Figure 5](image5.png)

Figure 5. The effect of mobility. More mobility cause larger estimation errors and slower convergence. Note that the minimum speed is set to half the maximum speed.

![Figure 6](image6.png)

Figure 6. The effect of transmission range. Both a small and a large transmission range increase estimation errors.
location update messages over the network’s limited bandwidth.

3.3 The Effect of Mobility

Mobility of the nodes is expected to have undesired effects on the estimation error. Simulation confirms this expectation. Fig. 5 illustrates the result of a simulation scenario similar to that of Part A for different values of network’s nodes’ mobility.

3.4 The Effect of Transmission Range

Small transmission ranges, either in base stations or in mobile nodes, lead to small number of neighbors for each node. This consequently leads to large estimation errors due to lack of enough information obtained by location update messages. In contrast, extensive transmission ranges can cause the nodes make errors in distant nodes’ calculations. Thus, choosing the power of transmission (and hence the transmission range) of the nodes is important. Fig. 6 shows how the transmission range can affect the performance of the proposed approach.

4. CONCLUSION

In this paper, a novel approach for location estimation, called Cooperative Location Estimation, was proposed. In this approach, unlike previous works, the mobile nodes inside the network cooperate to estimate their locations. Simulations show the acceptable approximation of estimation in the proposed approach. Good performance in high network densities, simplicity, and the use of low-power base stations are the main advantages of this approach.

5. REFERENCES