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Effective and efficient neighbor detection for proximity-based mobile applications

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ABSTRACT

We consider the problem of maximizing both *effectiveness* and *efficiency* of the detection of a device by another device in a mobile ad hoc network, given a maximum amount of time that they remain in the proximity of each other. Effectiveness refers to the degree to which the detection is successful, while efficiency refers to the degree to which the detection is energy saving. Our motivation lies in the emergence of a new trend of mobile applications known as proximity-based mobile applications which enable a user to communicate with other users in some defined range and for a certain amount of time. The highly dynamic nature of these applications makes neighbor detection time-constrained, i.e., even if a device remains in proximity for a limited amount of time, it should be detected with a high probability as a neighbor. In addition, the limited battery life of mobile devices requires the neighbor-detection to be performed by consuming as little energy as possible. To address this problem, we perform a realistic simulation-based study in mobile ad hoc networks and we consider three typical urban environments where proximity-based mobile applications are used, namely *indoor with hard partitions*, *indoor with soft partitions* and *outdoor urban areas*. In our study, a node periodically broadcasts a message in order to be detected as a neighbor. Thus, we study the effect of parameters that we believe could influence effectiveness and efficiency, i.e., *the transmission power* and *the time interval between two consecutive broadcasts*. Our results show that regardless of the environment, effectiveness and efficiency are in conflict with each other. Thus, we propose a metric that can be used to make good tradeoffs between effectiveness and efficiency.

1. Introduction

With the increasing use of mobile devices and particularly smartphones, we face the emergence of a new blend of distributed applications known as *Proximity-Based Mobile* (*PBM*) applications [10–12]. These applications enable a user to interact with others in a defined range and for a given time duration e.g., for social networking (WhosHere [53], LoKast [31]), gaming (Bluetooth gaming apps [8]) and driving (Waze [52]).

Discovering who is nearby is a basic requirement of various PBM applications. In a simple usage scenario of social networking applications such as WhosHere [53] or LoKast [31], a user can discover other users in a defined range, view their profiles and chat with a user or a group of users with her phone. Usually, the highly dynamic nature of these applications (which is basically due to the mobility of devices) makes neighbor detection time-constrained, i.e., even if a device remains in proximity for a limited amount of time, it should be detected with a high probability as a neighbor. In addition, the limited battery life of

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mobile devices requires the neighbor-detection to be performed by consuming as little energy as possible.

In this paper, we consider the following problem: *how can a device be detected by another device with both maximum effectiveness and maximum efficiency, given a maximum amount of time that they remain in proximity of each other? If not, how can an effectiveness-efficiency tradeoff be made?* Effectiveness refers to the degree to which the detection is successful and is measured by the detection probability, while efficiency refers to the degree to which the detection is energy saving and is measured by the inverse of energy consumption per device. To address this problem, we evaluate effectiveness and efficiency in a single-hop mobile ad hoc network (MANET). The evaluations are performed under realistic assumptions and based partly on simulations using the ns-2 [37] network simulator.[1]

There are two main reasons behind our choice of a MANET as the underlying network architecture. Firstly, MANETs seem to be the most natural existing technology to enable PBM applications. In fact, similarly to PBM applications, in a MANET two nodes can communicate if they are within a certain distance of each other (to have radio connectivity) for a certain amount of time. Secondly, mobile devices are increasingly equipped with ad hoc communications capabilities (e.g., WiFi in ad hoc mode or Bluetooth) which increases the chance of MANETs to be one of the future mainstream technologies for PBM applications.

Since the quality of radio signals (and consequently the detection probability) is affected by the environment attenuation, for our study we consider three typical urban environments where PBM applications are used, i.e., *indoor with hard partitions* (corresponding to offices with thick walls), *indoor with soft partitions* (corresponding to exhibitions with temporary partitions) and *outdoor urban areas* (corresponding to a music festival in downtown). To simulate these environments, we use a radio propagation model known for modeling the obstructed urban environments called *Log-Normal Shadowing* (LNS).

In our study, a node periodically broadcasts a *hello* message during a fixed time interval in order to be detected as a neighbor. We assume that the nodes use the *IEEE 802.11a* standard for the physical and MAC layer. Thus, we study the impact of two key parameters that influence effectiveness and efficiency, i.e., *the transmission power* and *the time interval between two consecutive broadcasts*. In performing the evaluations, we are particularly interested to answer the following questions:

- *In each environment, when does a change in the value of any of the above mentioned parameters increase effectiveness and efficiency, or on the contrary, when does it deteriorate them?*
- *In each environment, is there a unique combination of these parameters that could maximize both effectiveness and efficiency? If not, how could a tradeoff between effectiveness and efficiency be made?*

[1] The version 2.35 (the latest version), released on November 4, 2011.

1.1. Contributions and roadmap

This paper is, to the best of our knowledge, the first study on the impact of transmission power and broadcast interval on effectiveness and efficiency of neighbor detection for MANETs in urban environments. It provides a detailed simulation study and defines the metrics that can be used to interpret the results. In order for our results to be close to reality, the study is performed under realistic assumptions. For one thing, we use 802.11a technology for communication between nodes and we assume a probabilistic radio propagation model for urban environments. Furthermore, we calculate the energy consumption using the specification of typical smartphones.

The remainder of the paper is as follows. In Section 2, we describe our system model. In particular, we define the *neighbor detection algorithm*, which takes transmission power and broadcast interval (this pair constitutes a *strategy*) as input. In Section 3, we formulate the problem studied in this paper. It basically consists of finding the most effective and the most efficient strategy in each environment. If these strategies are not equal in an environment, we intend to find a strategy that makes a reasonable tradeoff between effectiveness and efficiency. We also define the set of strategies for which the effectiveness and efficiency are evaluated. In Section 4, we evaluate the effectiveness for the set of predefined strategies. We also discuss the impact of changing transmission power and broadcast interval on effectiveness. Finally, we identify the most effective strategy in each environment. In Section 5, we evaluate the efficiency for the set of predefined strategies. We show that efficiency is independent of the environment and we discuss the impact of changing transmission power and broadcast interval on efficiency. Finally, we identify the most efficient strategy. In Section 6, we compare the results of Sections 4 and 5. We observe that we cannot find a strategy that maximizes both effectiveness and efficiency in any environment. The reason is that, regardless of environment, effectiveness and efficiency are in conflict with each other. We then propose an approach to make a tradeoff between effectiveness and efficiency. Using this approach, we find the tradeoff strategy in each environment and we show that it has a relatively good effectiveness and efficiency compared to other strategies. Finally, we discuss related work in Section 7 before concluding in Section 8 with a perspective on future work.

2. System model

In this section, we present the system model, and whenever necessary, we describe the reasons behind our modeling choices.

2.1. Processes

We consider a mobile ad-hoc network (MANET) consisting of a finite set of n processes $P = \{p_1, \ldots, p_n\}$. We use the terms *process* and *node* interchangeably. Processes are in a two-dimensional plane. Each process has a unique identifier and is aware of its own geographic location at