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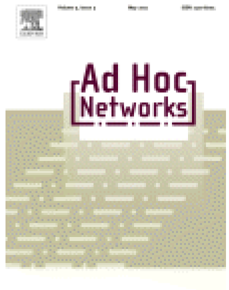

Evaluation and design of beaconing in mobile wireless networks

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Abstract

One of the intrinsic problems of mobility in wireless networks is the discovery of mobile nodes. A widely used solution for this problem is to use different variations of beacons, such as hello packets. Although a poorly designed beaconing scheme may lead to unnecessary energy usage or poor throughput, a systematic approach to analyze and select beaconing parameters is not provided in the literature. Here, we propose a model to study the beaconing efficiency using some measures such as the link lifetime, the probability of link establishment, and the delay to discover a new

neighbor. The model is general and does not adhere to any particular mobility model; the only input from the mobility is the distribution of physical link durations, which not only abstracts away the mobility details but also all effects that contribute to the link stability such as non-perfectly omni-directional antennas and the path loss exponents. Among our results, we prove that the periodic beaconing (which is widely used owing to its simplicity) is the best in terms of beacon hits; we compare one-way and two-way beaconing schemes and study beaconing energy optimization. Finally, the model is applied to three cases of ad hoc, delay-tolerant, and sensor networks, and a simple rule of thumb is proposed to efficiently adjust the beacon interval.

Introduction

Mobility is an essential property of many wireless networks and poses several problems into the design space of network protocols. Mobile wireless networks are dynamic environments in which the mobile nodes can be discovered or lost at any moment. Thus, the network topology is constantly changing. Wireless network protocols rely on different levels of knowledge of the network topology. The wider the range of the topology information each node keeps, the better routing decision it can potentially make. However, in a mobile environment with rapid topology changes, keeping updated topology information in each node incurs a vast amount of overhead. Generally, a common problem in several protocols is to maintain link-state information of immediate neighbors. A widely-used approach to collect the link-state information is to issue beacons in forms of hello packets, queries, special radio signals, etc. Numerous protocols that use beacons for neighbor discovery are reported in the literature. DSDV [1], Ad hoc Multicast Routing (AMRoute) [2], and On-Demand Multicast Routing Protocol (ODMRP) [3] are examples of ad hoc network protocols that use beacons for neighbor discovery and topology updating.

Although beacon transmission is widely used, only few performance evaluation studies in the literature take the effect of the beaconing scheme into account. Even these few studies do not provide a systematic and analytic approach for the selection of beaconing parameters and evaluation of beaconing efficiency. In this paper, an analytic model is presented to study the efficiency and overhead of beaconing in the presence of mobility. Our model is solely based on the statistical information of the physical link durations. The physical link duration is thoroughly investigated in the literature both analytically and experimentally [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15]. Since physical link duration statistics may abstract the details of the mobility pattern and radio propagation, the mathematical derivations provided in this paper are not restricted to some particular scenarios and the proposed model is applicable for a wide range of settings.

Although the results obtained through the paper may be used in designing traditional ad hoc and cellular networks, in these networks the volume of data transmission is typically higher than that of beacons. Thus, beaconing is taken for granted most of the times. The importance of the study rises when considering the emerging strictly low-power networks, such as delay-tolerant and mobile wireless sensor networks, for which transmission of unnecessary beacons can deplete a considerable portion of the nodes' energy. Three case studies, at the final sections of the paper, clearly show how important the beaconing is in such networks and how essential our model is to adjust the beaconing.

The contributions of the paper can be summarized as follows:

- Proposing an analytic model that researchers can apply to their systems under study to obtain beaconing performance measures, e.g. probability of beacon hit (the probability that an incoming node to the transmission area of a particular node is detected by the beacon process before leaving the area) and discovery delay with different distributions of inter-beacon time and different types of mobility models.

- Obtaining simplified beaconing performance measures for particular case of periodic beaconing and proving that one-way periodic beaconing is the optimal one.

- Modeling different beaconing schemes such as one-way, two-way, and selective beaconing for a general mobility model and an arbitrary inter-beacon distribution.
- Evaluation of the effect of beacon loss on the performance measures of beaconing.
- Using an energy model to obtain the optimal beaconing interval that optimizes beaconing energy per a successful contact.
- Modeling the capacity of a DTN and optimizing the beaconing energy dissipation per bit.
- Analyzing the propagation delay of a data chunk in a low-density wireless sensor network versus beaconing interval.

As the final note, since Palm's theorem is used as a primary background for the current study, we provide a short description of the theorem here [16]. Palm calculus is concerned with stationary processes obtained as functions of a stationary marked point process. As a simple informal example, consider the point process of arrival of buses to a bus station. In general, the average time that a person, who arrives at a random point of time, waits for the next bus is not equal to the half of the average inter-arrival time of busses. Informally, palm calculus provides a tool to relate the view of the random observer and the view of the observer at the arrival times.

The rest of the paper is organized as follows. The next section, Section 2, provides the related work. Section 3 provides the preliminaries on physical link duration distribution and introduces some definitions. The model and its variations are presented in Section 4. Section 5 provides some derivations of the model and instantiates the model for periodic and exponential beaconing cases. Moreover, it discusses an energy optimization problem and investigates the optimal beaconing scheme. Three case studies are presented and discussed in Section 6. And finally, Section 7 concludes the paper.

Section snippets

Related work

What we will refer to as a *beacon* is widely used in the literature with different names. Although it is recognized that a beacon transmission scheme impacts the performance of several mobile wireless networks, only few studies take the effects of the beaconing scheme into account. Authors in [17] describe a topology construction scheme that uses periodic beaconing. The effect of the beacon interval on the end-to-end delay and delivery ratio is studied by simulations that confirm the importance

Preliminaries

Some of the important quantities used throughout the paper are defined in Table 1 (Fig. 1 illustrates some of these definitions). We denote the probability density function and cumulative distribution function (abbreviated as *pdf* and *cdf*, respectively) by $f_X(\cdot)$ and $F_X(\cdot)$, respectively, for a random variable X. Although the model is not restricted to a particular scenario, in order to exemplify and discuss some results in the paper, the following scenario is introduced. (A street section

The analytic model

In this section a model is provided to exploit the distribution of ELDB, discovery delay, dead time, number of beacon hits, and number of redundant link detections for an arbitrary mobility model. A node may send or receive a sequence of beacons, which is modeled as a stochastic point process [29]. We assume that the process is stationary, i.e. the behavior of the system does not change by time. Obviously, in practical situations, the system behavior can be changing in long term, e.g. when a

Derivations and sample results

In this section, the model is applied to the cases of periodic and exponential beaconing. Then, the model is extended for the two-way beaconing case. The idea of beacon retransmission where there is a high beacon loss probability is analyzed by the model provided for the beacon loss. As energy consumption is a key factor when designing wireless networks, the results are used to define an auxiliary measure for optimizing energy consumption. Since network designers use beacons in a vast number of

Case studies

Table 2 lists some typical applications of the beaconing measures defined in this paper. In this section, the proposed model is used to investigate three cases (that are interesting in their own right) that serve as examples of the usefulness of the model.

Conclusion

In this paper, beaconing was investigated as an important tool that is widely used in mobile wireless networks to discover moving neighboring nodes. A general model was introduced to study the effect of different beaconing schemes and beacon intervals on discovery delay, effective link duration, dead time, number of beacon hits, and probability of beacon hit. The model was not based on any particular mobility model. Instead, the input from the mobility was only the *pdf* of physical link

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