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Mobility prediction in mobile wireless networks

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A B S T R A C T

In realistic mobile ad-hoc network scenarios, the hosts usually travel to the pre-specified destinations, and often exhibit non-random motion behaviors. In such mobility patterns, the future motion behavior of the mobile is correlated with its past and current mobility characteristics. Therefore, the memoryless mobility models are not capable of realistically emulating such a mobility behavior. In this paper, an adaptive learning automata-based mobility prediction method is proposed in which the prediction is made based on the Gauss–Markov random process, and exploiting the correlation of the mobility parameters over time. In this prediction method, using a continuous-valued reinforcement scheme, the proposed algorithm learns how to predict the future mobility behaviors relying only on the mobility history. Therefore, it requires no a prior knowledge of the distribution parameters of the mobility characteristics. Furthermore, since in realistic mobile ad hoc networks the mobiles move with a wide variety of the mobility models, the proposed algorithm can be tuned for duplicating a wide spectrum of the mobility patterns with various randomness degrees. Since the proposed method predicts the basic mobility characteristics of the host (i.e., speed, direction and randomness degree), it can be also used to estimate the various ad-hoc network parameters like link availability time, path reliability, route duration and so on. In this paper, the convergence properties of the proposed algorithm are also studied and a strong convergence theorem is presented to show the convergence of the algorithm to the actual characteristics of the mobility model. The simulation results conform to the theoretically expected convergence results and show that the proposed algorithm precisely estimates the motion behaviors.
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1. Introduction

A mobile ad-hoc network (MANET) is a self-organizing and self-configuring multi-hop wireless network, which can be instantly developed in situations where either a fixed infrastructure is unavailable (e.g., disaster recovery), or a fixed infrastructure is difficult to install (e.g., battlefields). In addition to the multi-hop nature of the wireless ad-hoc networks and the lack of a fixed infrastructure, these networks inherit the traditional problems of the wireless and mobile communications. Host mobility brings about a wide range of new challenges in the design of the mobile ad-hoc network protocols. Since to predict the mobility of a given host in the mobile wireless ad-hoc networks, the mobility parameters of the other relative hosts also need to be taken into account, the mobility of such networks is generally hard to predict. Frequent and hard to predict topology changes due to the host mobility are the most important issues and must be taken into consideration in mobile ad-hoc networking. The best-known solutions proposed to alleviate the negative effects of the host mobility on the network performance focus on the estimation of the future state of the network by predicting the mobility characteristics of the hosts. To realistically predict the mobility behaviors of the hosts, the predictive schemes should emulate the changes in the mobility speed and movement direction as the real mobiles do.

Unlike the cellular networks, where each host easily communicates to a fixed base station and so the mobility prediction is easily achieved over a static structure, in wireless ad-hoc networks, the prediction must be done in a fully dynamic environment, where there is neither a fixed infrastructure nor a centralized administration. In such networks, two hosts directly communicate when they are within the transmission range of each other, and indirectly through the intermediate hosts. Therefore, the host mobility results in considerable changes in the network topology, and it may even cause link breakage and route expiration (Camp et al., 2002).

In mobile wireless ad-hoc networks, the hosts move freely anywhere, and so the protocols are considerably different from those in traditional networks. In these networks, the mobility prediction is an imperative issue and needs to be considered so as to design the more effective protocols. A lot of mobility patterns have been proposed to emulate the motion behavior of the mobile users. Some mobility patterns model the erratic behavior of the mobiles, and some other mobility models present a mobility tracking system that takes advantage of the predictable behaviors of the mobiles. In realistic applications, the mobile hosts usually move according to the pre-specified plans and rarely exhibit random motions. In such cases, the future mobility speed and

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movement direction of the host can be estimated on the basis of the host mobility history (the previous speed and direction). Indeed, in these cases, the mobility characteristics are correlated in time, and so the memoryless mobility models (e.g., random walk or Brownian motion mobility models) cannot realistically duplicate such mobility behaviors (Liang and Haas, 2003).

In this paper, an adaptive learning automata-based mobility prediction method is proposed. In this method, it is assumed that the mobility speed and movement direction of a mobile are correlated in time and modeled by a Gauss–Markov random process. The continuous action-set learning automaton is used to estimate the expected speed and direction of a mobile. In this class of the learning automata, a Gaussian distribution function is defined over the action-set of the learning automaton, by which the automaton chooses its actions. The automaton updates the parameters (mean and variance) of the Gaussian distribution based upon a continuous-valued reinforcement signal received from the environment. Through the interaction with the environment the learning automaton gradually is known, asymptotically with a high probability, the optimal action with the minimum penalty probability. That is, the learning automaton estimates the expected values of the mobility parameters with a probability close to unity. These estimations enable the proposed algorithm to predict the future mobility parameters relying only on the host mobility history, and therefore the proposed algorithm requires no prior knowledge of the host mobility parameters.

In wireless mobile ad-hoc networks, the mobiles move with a wide variety of the mobility models, and this causes the mobility prediction to be a challenging issue. The proposed mobility prediction algorithm is capable of duplicating a wide spectrum of the mobility patterns when the mobility model is unknown or the hosts move with various mobility models. For this purpose, in the proposed method, a continuous action-set learning automaton is also dedicated to estimate the randomness degree of the host mobility pattern. Thus, the proposed algorithm is able to simultaneously predict the future mobility characteristics (i.e., speed and direction) and to fine tune the randomness degree of the mobility pattern. Since the proposed algorithm estimates the basic mobility characteristics of a given host (i.e., speed and direction and randomness degree), it can be effectively used for prediction of the various parameters which are used in mobile ad-hoc networking, such as link availability duration, path reliability estimation, network partitioning prediction, and some other useful parameters.

In this paper, the convergence properties of the proposed mobility prediction algorithm are theoretically studied. To show the convergence of the proposed algorithm to the actual mobility parameters, a strong convergence theorem is presented. This theorem proves the convergence of the random process by which the Gaussian distribution parameters are updated. The simulation results conform to the theoretical results and show the correctness of the proposed algorithm for estimating the motion behaviors. The performance of the proposed algorithm is compared with a neural network-based mobility prediction technique presented in Ref. Kaaniche and Kamoun (2010). Experimental results show the superiority of the proposed algorithm over the other in terms of the prediction precision.

The rest of the paper is organized as follows. The next section describes related work on the mobility prediction in mobile ad-hoc networks. Section 3 summarizes some preliminaries on the continuous action-set learning automata and ad-hoc network mobility models. The proposed learning automata-based mobility prediction method is described in Section 4, and Section 5 presents a convergence proof for the proposed algorithm. Section 6 shows the efficiency of the proposed algorithm through the simulation experiments, and Section 7 concludes the paper.

2. Related work

Frequent network topology changes, due to the mobility of the hosts, is the most challenging problem in the design of the mobile ad-hoc network protocols, since the protocols should be adapted to these topological changes. The mobility prediction schemes which attempt to estimate the mobility characteristics of the mobile hosts are the most common solutions to relieve the adaptation problem. During the past couple of decades, mobility prediction has received unprecedented attention from the research community and many works (Refs. An and Papavassilou, 2001, 2003; Son et al., 2004; Yu et al., 2007; Venkateswaran et al., 2009; Zhou et al., 2011; Ni et al., 2011) have been conducted to improve the precision of the mobility prediction schemes or to enhance the performance of the mobility-based networking protocols. This section aims to survey the literature on the mobility prediction techniques and applications. Mobility prediction has been extensively studied in cellular networks, however, it is in the early stage for the multi-hop networks. Estimation of the future location, mobility speed, and movement direction of the mobile users, the network region (cluster or cell) a user may join or leave in future, and the next nodes to which a given user might be connected are several well-known forms of prediction of mobility behavior in wireless networks (Su and Gerla, 1999; Chellapa-Doss et al., 2003; Su et al., 2001a,b; Kaaniche and Kamoun, 2010; Li et al., 2011). The most frequently reported applications of the mobility prediction in MANET can be summarized as estimation of the link availability time, path reliability, route duration, network partitioning prediction, and routing enhancement (Chellapa-Doss et al., 2003; Dekar and Kheddouci, 2008).

The Markov model has shown to be useful in predictive systems (Begleiter et al., 2004). Several attempts (Lassabe et al., 2006; Bellahsene and Kloul, 2010; Si et al., 2010; Abu-Ghazaleh and Alfa, 2010) have been recently done to apply the Markov model in mobility prediction. For instance, a mobility prediction mechanism based on the *k*th Markov model was proposed by Lasabe et al. Lassabe et al., (2006). Another mobility prediction and modeling technique based on the Markov renewal processes was proposed by Abu-Ghazaleh and Alfa (2010). In these methods, to form the Markov chain the area in which the mobiles move is geographically partitioned into regions (or cells). Each geographical region corresponds to a logical state of the Markov chain. Then, the Markov model is applied to determine the probability of joining to, being in, or leaving a given region. The major problem with the Markov-based models is that the mobility can be predicted at a high level (region level) and for the long time-intervals. To enhance the accuracy rate (i.e., to determine the mobility behavior in a shorter time), the number of states must be increased. That is, the geographical area must be subdivided into a larger number of regions of a smaller size. This increases the prediction accuracy, however significantly overloads the network. Furthermore, since there is no a fixed infrastructure in a multi-hop network, a fixed physical partitioning is not possible. Therefore, the Markov-based mobility prediction technique is more suitable for infra-structured environments like cellular networks (Bellahsene and Kloul, 2010; Abu-Ghazaleh and Alfa, 2010).

Mobility prediction is widely used to estimate the link lifespan in a wireless mobile network. A link is available between every two hosts as long as they are within the transmission range of one another. In these methods, using the information on the geographical position provided by the global positioning system (GPS), mobility speed, movement direction, and transmission range of the mobile hosts, the future position of each host can be predicted. Depending on these predictions, the methods are also capable of estimating the links lifespan. Su and Gerla (1999) and

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