Journal of Network and Computer Applications 53 (2015) 156–163

Contents lists available at ScienceDirect

Journal of Network and Computer Applications

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

Analyzing and modeling mobility for infrastructure-less communication

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ARTICLE INFO

Article history:
Received 21 May 2014
Received in revised form
5 September 2014
Accepted 6 April 2015
Available online 22 April 2015

Keywords:
Mobility model
Infrastructure-less communication
Opportunistic networks

ABSTRACT

Unlike infrastructure-based counterparts, services and applications of future infrastructure-less mobile networks highly depend on the mobility patterns of wireless device carriers. Analyzing and modeling their mobility is essential in precise performance evaluation of these opportunistic networks, where inter-contacts are taken advantage of as opportunities for message forwarding. Recently, the fact that human mobility is not entirely random has been proved. To this end, some sophisticated mobility models have emerged to try to capture observed aggregate mobility characteristics. However, characteristics in aggregate level are different from those in individual node level. We provided general analysis and found that distributions of rates and durations played important roles in determining the nature of the aggregate distribution. Aggregate distribution can be regarded as being formed by distributions of different nodes or distributions of different rates. In addition, an individual node usually experiences active or inactive periods alternatively. Using only cumulative distribution characteristics cannot appropriately describe the nodal mobility. So as to precisely analyze the nature of the device carriers' mobility in both levels and capture transitions between active and inactive periods, we proposed a flexible framework, where the sequences of inter-contact times were modeled as Semi-Markov Modulated Process. This framework provides flexibility to configure each node's inter-contact time distribution independently, thus capturing the heterogenous behavior at will. At the same time, it could obtain required aggregate distribution and variable activities.

1. Introduction

Communication in infrastructure-less mobile networks is often facilitated by the mobility of the devices, because it is through their movement that initially unreachable nodes become connected (Nunes and Obraczka, 2014). In general cases, wireless devices in the cyber world are representatives of their carriers in the physical world. Therefore, the networking applications performance highly depends on the mobility characteristics of devices carriers (Passarella et al., 2012; Lee et al., 2009). Inter-contact pattern and dynamic activity are two notable mobility characteristics because they affect forwarding performance, including the end-to-end delays and the relays selection. Some significant statistical patterns of the carriers' mobility have been discovered by various measurement studies. However, it would not allow an extensive exploration of the design space, if we only rely on real traces (Nunes and Obraczka, 2014). In the past few years, the area of the mobility modeling has been quite active with numerous sophisticated mobility models proposed and used in researches (Hossmann et al., 2011; Boldrini and Passarella, 2010; Heimlicher and Salamatian, 2010). Many of these proposed models are shown to effectively capture one or more observed mobility characteristics. These solutions are often sensitive to the movement patterns and rely on a particular vision of how the mobile nodes behave. And most early models exclusively focus on demonstrating exponential decay, power-law, and truncated power-law, which is comprised of a power law head and an exponential tail. Recently, it has been found that inter-contact patterns in theme parks are best characterized by gamma distribution (Vukadinovic and Mangold, 2011). Related studies are followed in (Seshadri et al., 2008; Helgason et al., 2010). In the near future, other distributions may also be found. What is lacking, on one hand, is a flexibility framework for modeling different mobility patterns. Flexibility means different distributions can be employed within the same model. And, it should be easy and convenient to modify the model when new discoveries are found without the need to start over from the beginning (Karamshuk et al., 2012). On the other hand, most studies assume the aggregate complementary cumulative distribution function (CCDF) of inter-contact times (ICTs) can represent the CCDF of a specific devices pair. Lately, Andrea Passarella and Marco Conti carefully reviewed the

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http://dx.doi.org/10.1016/j.jnca.2015.04.003
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hypothesis by deriving an analytical model (Passarella and Conti, 2011). This is an excellent work. But, they do not consider that rates of inter-contact times (i.e., the reciprocal of the average inter-contact time) may change over time. They also did not take into account that the durations of different rates may be different.

To this end, in this paper, we propose a mobility framework whose goal is, starting from the Semi-Markov Modulated Process (SMMP) describing the carriers' (nodes') mobility, to generate traces featuring predictable probability distributions and changeable activities. Key contributions of this work are summarized as follows:

- Inter-contact times are modeled as Semi-Markov Modulated Process to describe the variable activities of carriers. Consequently, durations of different rates may not be the same. We provide more general analysis and results with that in mind.
- Propose a flexibility framework, which allows for different distributions and variable activities.
- Since simply knowing the distributions of different nodes' inter-contact times, we are not able to analyze and simulate the performance of mobile network protocols. We provide a method to generate traces featuring predictable probability distributions in both individual node level and aggregate level.

The rest of this paper is organized as follows. In Section 2, we briefly review several relevant studies on mobility modeling. In Section 3, we present the details of how to model inter-contact times as Semi-Markov Modulated Process, and provide more general analysis and results. Section 4 describes a flexibility framework for mobility modeling. A method is presented to generate traces, in the same section. Section 5 gives simulations that evaluate the proposed framework with some existing forwarding protocols. Finally, we conclude the paper in Section 6.

2. Related work

This paper is mainly related to the study of inter-contact times, which is the times elapsed between two consecutive contacts. Inter-contacts can be modeled by different distributions, and be taken advantage of as opportunities for message forwarding in opportunistic networks. Contact models have a strong impact on the distributions of inter-contact times, and the performance of protocols (Passarella et al., 2012). Under the Reference Point Group Mobility Model (RPGMM) (Camp et al., 2002), nodes are grouped and the movements of a group are following the traveling path of the logical center of the group. Mirco Musolesi proposed another mobility model based on the social network theory (Musolesi and Mascolo, 2006). Nodes are grouped together according to their social relationships. Network is divided into grids, and each node is randomly assigned to a specific grid. The new destination can be inside the same grid again or in a different one. However, if the number of nodes belonging to the same community exceeds a certain level inside a certain grid, new destinations will be chosen inside the same grid (Lin et al., 2009). SLAW mobility model is presented to try to capture the characteristic of human mobility patterns (Lee et al., 2009). Kyunghan Lee et al. reported that real human mobility traces can be modeled by gaps among fractal waypoints. Based on this, they developed a simple heuristic algorithm which could generate heavy-tail flights using the least action principle. This algorithm belongs to waypoint-based mobility regime. It is a mobility pattern characterized by having nodes probabilistically choosing the next destination, or waypoint, based on some probability density functions, moving to this destination with a given speed, pausing for some time, and starting the process again. In (Nunes and Obraczka, 2014), authors proposed a framework to mathematically model spatial node density of waypoint-based mobility. And they used the proposed framework to show the inability of some waypoint-based mobility regimes to maintain original spatial node density distributions. The most important feature of the model introduced in (Thakur and Helmy, 2013) is capturing the collective behavior based on realistic aspects of human mobility. The systematic approach achieves a very close match in all the protocol performance metrics, thus closing the significant gap in mobility and protocol evaluation. But in order to obtain the above results many parameters such as the distributions of node density, speed, and pause time need to be extracted from real traces. Dmytro Karamshuk et al. proposed a framework which added the spatial dimension and took the social graph as input (Karamshuk et al., 2012). They also assigned people of the same social community to the same location, and described the way nodes visited their associated locations with the help of a stochastic process. So as to ameliorate the scenario realism, they combined meeting places into a preset number of geographic locations. However, in the theoretical analysis section, the authors ignored the fact that the nodes met each other in the same geographic location. Marin et al. proposed a methodology and a set of guidelines to be used in analyzing the predictability of interaction between mobile users and wireless APs. By applying the methodology on three cases, they proved that mobile users had a predictable wireless behavior when the studied traced sets were convergent, complete and correct (Marin et al., 2014). To provide the metrics by which different mobility models can be compared, Agoston Petz et al. argued for standardizing simulations to a single capable simulator, and implemented three mobility models —Zebra Mobility (Juang et al., 2002), Village Mobility (Pentland et al., 2004), and Levy Walk Mobility (Rhee et al., 2011)—in OMNeT++ and made their code available online (Petz and Enderle, 2008; Petz et al., 2009). In (Passarella et al., 2012), authors presented and validated a useful model to create synthetic ego networks. But, possible social links between alters cannot be told by ego network models. It needs to model the entire network formed by egos and alters. Most previous studies simply considered the aggregate CCDF, and took it for granted that distributions of the aggregate level can represent those of the individual level. Andrea Passarella and Marco Conti took the first step to analysis how the aggregate CCDF related to the CCDF for a device pair (Passarella and Conti, 2011). This is an excellent work, and no previous work has dealt with this specific problem at their level. But, they ignore the fact that the durations of different rates may be different and different individuals may have different online time. Meanwhile, they do not consider that rates of inter-contact times may change over time. Unlike their study focusing on relationship between the aggregate ICTs distribution and the pairs' ICTs distributions, we investigate the dependence among the aggregate ICTs distribution, the nodes' ICTs distributions, the rates distribution, and the durations distribution.

3. Modeling and analyzing

3.1. A model to understand period behavior

Since we focus on the model that describes how the characteristics in aggregate level relates to those in individual node level, we define the inter-contact times, as *the interval times between two successive contacts of a certain node with any other nodes*, in this paper. Inter-contact time is a chief factor to opportunistic networks routing as ICT affects the end-to-end delays and the relays selection. In order to generate traces featuring characteristics found in real mobility traces, the following question arises naturally: Is the contact rates constant or variable?

The consecutive contacts are plotted in Fig. 1. They are obtained from monitors installed in Anhui University library. Two monitoring modules are installed in two doors of the library. They can detect the