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Source delay in mobile ad hoc networks

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ABSTRACT

Source delay, the time a packet experiences in its source node, serves as a fundamental quantity for delay performance analysis in networks. However, the source delay performance in highly dynamic mobile ad hoc networks (MANETs) is still largely unknown by now. This paper studies the source delay in MANETs based on a general packet dispatching scheme with dispatch limit f (PD-f for short), where a same packet will be dispatched out up to f times by its source node such that packet dispatching process can be flexibly controlled through a proper setting of f. We first apply the Quasi-Birth-and-Death (QBD) theory to develop a theoretical framework to capture the complex packet dispatching process in PD-f MANETs. With the help of the theoretical framework, we then derive the cumulative distribution function as well as mean and variance of the source delay in such networks. Finally, extensive simulation and theoretical results are provided to validate our source delay analysis and illustrate how source delay in MANETs is related to network parameters.

1. Introduction

Mobile ad hoc networks (MANETs) represent a class of self-configuring and infrastructureless networks with mobile nodes. As MANETs can be rapidly deployed, reconfigured and extended at low cost, they are highly appealing for a lot of critical applications, like disaster relief, emergency rescue, battle field communications, environment monitoring, etc. [1,2]. To facilitate the application of MANETs in providing delay guaranteed services in above applications, understanding the delay performance of these networks is of fundamental importance [3,4].

Source delay, the time a packet experiences in its source node, is an indispensable behavior in any network. Since the source delay is a delay quantity common to all MANETs, it serves as a fundamental quantity for delay performance analysis in MANETs. For MANETs where a packet is transmitted only once by its source node (through either unicast [5,6] or broadcast [7]), the source delay actually serves as a practical lower bound for and thus constitutes an essential part of overall delay in those networks. The source delay is also an indicator of packet lifetime, i.e., the maximum time a packet could stay in a network; in particular, it lower bounds the lifetime of a packet and thus serves as a crucial performance metric for MANETs with packet lifetime constraint.

Despite much research activity on delay performance analysis in MANETs (see Section 6 for related works), the source delay performance of such networks is still largely unknown by now. The source delay analysis in highly

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dynamic MANETs is challenging, since it involves not only complex network dynamics like node mobility, but also issues related to medium contention, interference, packet generating and packet dispatching. This paper is devoted to a thorough study on the source delay in MANETs under the practical scenario of limited buffer size and also a general packet dispatching scheme with dispatch limit f (PD-f for short). With the PD-f scheme, a same packet will be dispatched out up to f times by its source node such that packet dispatching process can be flexibly controlled through a proper setting of f. The main contributions of this paper are summarized as follows.

- We first apply the Quasi-Birth-and-Death (QBD) theory to develop a theoretical framework to capture the complex packet dispatching process in a PD-f MANET. The theoretical framework is powerful in the sense it enables complex network dynamics to be incorporated into source delay analysis, like node mobility, medium contention, interference, packet transmitting and packet generating processes.
- With the help of the theoretical framework, we then derive the cumulative distribution function (CDF) as well as mean and variance of the source delay in the considered MANET. By setting $f = 1$ in a PD-f MANET, the corresponding source delay actually serves as a lower bound for overall delay.
- Extensive simulation results are provided to validate our theoretical framework and the source delay models. Based on the theoretical source delay models, we further demonstrate how source delay in MANETs is related to network parameters, such as packet dispatch limit, buffer size and packet dispatch probability.

The rest of this paper is organized as follows. Section 2 introduces preliminaries involved in this source delay study. A QBD based theoretical framework is developed to model the source delay in Section 3. We derive in Section 4 the CDF as well as mean and variance of the source delay. Simulation/numerical studies and the corresponding discussions are provided in Section 5. Finally, we introduce related works regarding delay performance analysis in MANETs in Section 6 and conclude the paper in Section 7.

2. Preliminaries

In this section, we introduce the basic system models, the Medium Access Control (MAC) protocol and the packet dispatching scheme involved in this study.

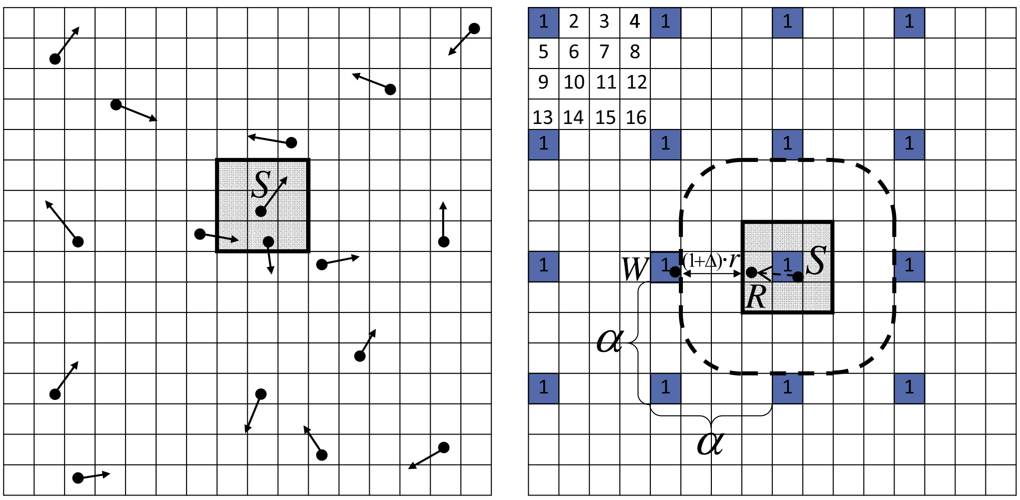
2.1. System models

2.1.1. Network model and mobility model

We consider a time slotted torus MANET of unit area. Similar to previous works, we assume that the network area is evenly partitioned into $m \times m$ cells as shown in Fig. 1a [8–11]. There are n mobile nodes in the network and they randomly move around following the Independent and Identically Distributed (IID) mobility model [6,12,13]. According to the IID mobility model, each node first moves into a randomly and uniformly selected cell at the beginning of a time slot and then stays in that cell during the whole time slot.

2.1.2. Communication model

We assume that all nodes transmit data through one common wireless channel, and each node (say S in Fig. 1a) employs the same transmission range $r = \sqrt{8}/m$ to cover 9 cells, including S's current cell and its 8 neighboring cells. To account for mutual interference and interruption among concurrent transmissions, the commonly used protocol model is adopted [10,12,14,15]. According to the protocol model, node i could successfully transmit to another node j if and only if $d_{ij} \leqslant r$ and for another simultaneously transmitting node $k \neq i,j$, $d_{kj} \geqslant (1+\Delta) \cdot r$, where



(a) A snapshot of a cell partitioned MANET. (b) Illustration of MAC-EC protocol.

Fig. 1. An example of a cell partitioned MANET with a MAC protocol.