Ad Hoc Networks 33 (2015) 71–86

Contents lists available at ScienceDirect

Ad Hoc Networks

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

On the exact multicast delay in mobile ad hoc networks with f-cast relay

Bin Yang [a,b,*], Ying Cai [c], Yin Chen [d], Xiaohong Jiang [a,1]

[a] School of Systems Information Science, Future University Hakodate, Hokkaido 041-8655, Japan
[b] School of Computer and Information Engineering, Chuzhou University, Chuzhou 239000, PR China
[c] Beijing Key Laboratory of Internet Culture and Digital Dissemination Research, Beijing Information Science & Technology University, Beijing 100101, PR China
[d] Graduate School of Media and Governance, Keio University, Kanagawa 252-8520, Japan

ARTICLE INFO

Article history:
Received 16 December 2014
Received in revised form 16 March 2015
Accepted 18 April 2015
Available online 24 April 2015

Keywords:
Mobile ad hoc networks
Multicast delay
Two-hop relay
Packet replication

ABSTRACT

The study of multicast delay performance in mobile ad hoc networks (MANETs) is critical for supporting future multicast-intensive applications in such networks. Different from available works that mainly focus on the study of asymptotic scaling laws of the multicast delay in MANETs, this paper explores the exact multicast delay achievable in MANETs under a general multicast two-hop relay (M2HR)-(f,g) algorithm with packet replication limit f and multicast fanout g. In such an algorithm, each packet can be replicated up to f distinct relay nodes and it should be delivered to its g destination nodes through either its source node or these relay nodes. We first develop a Markov chain-based theoretical framework to model the complicated packet delivery process under the M2HR-(f,g) algorithm and then determine some basic probabilities related to packet delivery process. With the help of the theoretical framework and related basic packet delivery probabilities, the analytical models are further derived for both the mean value and variance of exact multicast delay. Finally, simulation and numerical results are provided to illustrate the accuracy of the multicast delay models as well as our theoretical findings.

1. Introduction

Mobile ad hoc networks (MANETs) represent a class of self-organized networks where mobile devices communicate with each other via point-to-point wireless channel without any infrastructure support. Multicast in MANETs is a fundamental routing service for supporting many practical applications with one-to-many communication pattern [1–10], like the information exchanges among a group of soldiers in battlefield communication, emergency communications among the rescuers in disaster relief, video conferencing, real-time monitoring, and VoIP. For an efficient support of these critical multicast-intensive applications in the future MANETs, multicast delay analysis in such networks has been a critical research issue, where multicast delay is defined as the time it takes for a packet to be delivered out to all its destination nodes. However, the multicast delay analysis is extremely complicated because of dynamic network topology and multiple destination nodes associated with each node. By now, the multicast delay performance still remains largely unexplored in MANETs.

Recently, some research has reported the asymptotic bounds on the multicast delay in MANETs. Wang et al. showed in [11,12] that by adopting packet replication technique in MANETs, a multicast delay of $\Theta(\sqrt{n\log k})$ is achievable under a two-hop relay algorithm, which is

* Corresponding author at: Beijing Key Laboratory of Internet Culture and Digital Dissemination Research, Beijing Information Science & Technology University, Beijing 100101, PR China.
E-mail addresses: yangbinchi@gmail.com (B. Yang), ycai@bistu.edu.cn (Y. Cai), yin@ht.sfc.keio.ac.jp (Y. Chen), jiang@fun.ac.jp (X. Jiang).
[1] Principal corresponding author.

http://dx.doi.org/10.1016/j.adhoc.2015.04.005
1570-8705/

better than the $\Theta(n\log k)$ delay reported without packet replication, where n represents the number of nodes in the considered networks and k is the number of destination nodes associated with each source node.[2] Wang et al. also showed in [13] packet replication technique can improve the multicast delay performance in MANETs under two different mobility models, where nodes move either in a local region or in a global region. Later, Wang et al. found in [14] that under the two-hop relay algorithm with packet replications, cooperations among destination nodes can achieve the multicast delay smaller than $\Theta(\sqrt{n})$ in MANETs. More recently, Liu et al. studied in [15] the asymptotic multicast delay in sparse MANETs and showed that the multicast delay can achieve $\Omega(\log k\cdot n^{2(\gamma+\omega)})$, $\Omega(\log k\cdot n^{2(\gamma+\omega)})$ and $O\left(\max\left\{\log\frac{n-k}{n-k-f},\frac{\log k}{f}\right\}\cdot n^{2(\gamma+\omega)}\right)$ under three packet delivery algorithms: one-hop relay, two-hop relay without packet replication and two-hop relay with packet replications, respectively, where the network area is first evenly divided into $n^{2\gamma}$ cells and each cell is then divided into $n^{2\omega}$ equal subcells $(\gamma,\omega\geqslant 0,\gamma+\omega>1/2)$. The main difference between the M2HR-(f,g) algorithm in this paper and those two-hop relay algorithms in Refs. [14,15] is that the direct source-to-destination transmission is incorporated into the M2HR-(f, g) algorithm, while it was neglected in Refs. [14,15].

We note that although asymptotic results can help us understand how the multicast delay varies with network size and the number of destination nodes associated with each source node, they cannot be used to estimate the actually achievable delay performance, which provides more meaningful insights for network designers. Recently, Li et al. in [16] studied the exact multicast delay with the help of a Makov chain model and showed how the selfish behaviors of nodes affect the delay performance in DTNs, i.e., a class of very sparse MANETs where the interference is neglected.

It is notable that the available research on MANET multicast delay investigated either the asymptotic multicast delay or the exact multicast delay in special MANETs where the interference and medium access contention are largely neglected, therefore these results cannot be used to estimate the actual multicast delay performance in general MANETs. In this paper, we study the exact multicast delay performance in a general MANET where both the interference and medium access control are taken into account. The main contributions of this paper are summarized as follows.

- We first develop a finite-state absorbing Markov chain-based theoretical framework to model the complicated packet delivery process under the M2HR-(f,g) algorithm in the considered MANET.
- We determine some basic probabilities related to packet delivery process, where the important issues of wireless interference and medium access contention in such network are carefully considered in these probabilities. Based on the theoretical framework and these basic packet delivery probabilities, the analytical models are further derived for both the mean value and variance of exact multicast delay.
- Extensive simulation and numerical results are presented to validate the accuracy of the multicast delay models and to explore how the multicast delay performance varies with system parameters.

The rest of this paper is organized as follows. In Section 2, we introduce system models. Section 3 first introduces the M2HR-(f,g) algorithm, and then develops a finite-state absorbing Markov chain-based theoretical framework and also determines some basic packet delivery probabilities. Section 4 further derives the analytical models for both the mean and variance of exact multicast delay. Simulation/numerical studies are provided in Section 5. Finally, we conclude this paper in Section 6.

2. System models

In this section, we first introduce network, communication, traffic and transmission scheduling models and then give the definition of multicast delay involved in this study.

2.1. Network model

We consider a network consisting of n nodes that move inside a unit square region with torus boundaries, i.e., a node goes across one edge and then appears on the opposite edge of the square region. Similar to previous studies [17–23], the network is divided into $m\times m$ non-overlapping cells of equal size (see Fig. 1). The time is slotted and the nodes move independently from cell to cell in the network according to the independent and identically distributed (i.i.d.) mobility model [17,22,24]. Under this mobility model, each node selects a cell from the m^2 cells with equal probability $(1/m^2)$ at the beginning of each time slot, and then moves into and stays at it during the time slot. Each node will repeat this mobility process in every subsequent time slot.

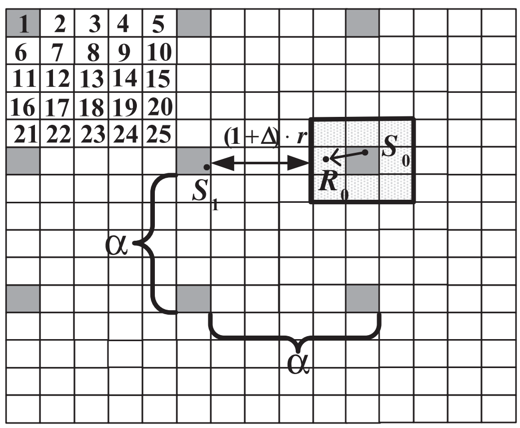

Fig. 1. Network model and an example of transmission scheduling with the case of $m=15$ and $\alpha=5$.

[2] Let $f(n)$ and $g(n)$ denote two non-negative functions. Then we say that: (1) $f(n)=O(g(n))$ if there exist a positive integer N and a positive constant c such that for all $n>N, f(n)\leqslant cg(n)$; (2) $f(n)=\Omega(g(n))$ if $g(n)=O(f(n))$; (3) $f(n)=\Theta(g(n))$ if $f(n)=O(g(n))$ and $g(n)=O(f(n))$.