Wireless Networks 8, 275–288, 2002

Analysis of TCP Performance over Mobile Ad Hoc Networks

GAVIN HOLLAND *
Department of Computer Science, Texas A&M University, College Station, TX 77843-3112, USA

NITIN VAIDYA
Department of Electrical and Computer Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801, USA

Abstract. Mobile ad hoc networks have attracted attention lately as a means of providing continuous network connectivity to mobile computing devices regardless of physical location. Recent research has focused primarily on the routing protocols needed in such an environment. In this paper, we investigate the effects that link breakage due to mobility has on TCP performance. Through simulation, we show that TCP throughput drops significantly when nodes move, due to TCP's inability to recognize the difference between link failure and congestion. We also analyze specific examples, such as a situation where throughput is zero for a particular connection. We introduce a new metric, *expected throughput*, for the comparison of throughput in multi-hop networks, and then use this metric to show how the use of explicit link failure notification (ELFN) techniques can significantly improve TCP performance.

Keywords: mobile ad hoc networks, wireless networks, transport protocols, performance evaluation, explicit feedback, TCP

1. Introduction

With the proliferation of mobile computing devices, the demand for continuous network connectivity regardless of physical location has spurred interest in the use of mobile ad hoc networks. A mobile ad hoc network is a network in which a group of mobile computing devices communicate among themselves using wireless radios, without the aid of a fixed networking infrastructure. Their use is being proposed as an extension to the Internet, but they can be used anywhere that a fixed infrastructure does not exist, or is not desirable. A lot of research of mobile ad hoc networks has focused on the development of routing protocols (e.g., [10,11,13,16,18,20,22, 25,27,29–35]). Our research is focused on the performance of TCP over mobile ad hoc networks.

Since TCP/IP is the standard network protocol stack on the Internet, its use over mobile ad hoc networks is a certainty. Not only does it leverage a large number of applications, but its use also allows seamless integration with the Internet, where available. However, earlier research on cellular wireless systems showed that TCP suffers poor performance in wireless networks because of packet losses and corruption caused by wireless induced errors. Thus, a lot of research has since focused on mechanisms to improve TCP performance in cellular wireless systems (e.g., [2,3]). Further studies have addressed other network problems that negatively affect TCP performance, such as bandwidth asymmetry and large round-trip times, which are prevalent in satellite networks (e.g., [4,12]).

In this paper, we address another network characteristic that impacts TCP performance, which is common in mobile ad hoc networks: link failures due to mobility. We first present a performance analysis of standard TCP over mobile ad hoc networks, and then present an analysis of the use of explicit notification techniques to counter the affects of link failures.

2. Simulation environment and methodology

The results in this paper are based on simulations using the *ns* network simulator from Lawrence Berkeley National Laboratory (LBNL) [14], with extensions from the MONARCH project at Carnegie Mellon [5]. The extensions include a set of mobile ad hoc network routing protocols and an implementation of BSD's ARP protocol, as well as an 802.11 MAC layer and a radio propagation model. Also included are mechanisms to model node mobility using precomputed mobility patterns that are fed to the simulation at run-time. For more information about the extensions, we refer the reader to [5]. Unless otherwise noted, no modifications were made to the simulator described in [5], beyond minor bug fixes that were necessary to complete the study.

All results are based on a network configuration consisting of TCP-Reno over IP on an 802.11 wireless network, with routing provided by the Dynamic Source Routing (DSR) protocol and BSD's ARP protocol (used to resolve IP addresses to MAC addresses). These are wildly used and studied protocols, and are likely candidates for implementation in commercial ad hoc networks. Hence, understanding how they work together, and with TCP, can lead to modifications that improve performance. Since we frequently refer to details of the DSR protocol, in the next paragraph we give a brief primer on DSR to familiarize the reader with its characteristics and terminology.

The Dynamic Source Routing (DSR) protocol was developed by researchers at CMU for use in mobile ad hoc networks [6]. In DSR, each packet injected into the network contains a routing header that specifies the complete sequence of nodes on which the packet should be forwarded. This route is

* Corresponding author.