Computer Networks 130 (2018) 134–144

Contents lists available at ScienceDirect

Computer Networks

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

On the goodput of flows in heterogeneous mobile networks

Anand Seetharam*, Arti Ramesh

Department of Computer Science, SUNY Binghamton, USA

ARTICLE INFO

Article history:
Received 8 June 2017
Revised 2 October 2017
Accepted 24 November 2017
Available online 2 December 2017

ABSTRACT

In practice heterogeneous networks comprising of diverse nodes need to operate efficiently under a wide range of node mobility and link quality regimes. In this paper, we propose algorithms to determine the goodput of flows in heterogeneous mobile networks. We consider a scenario where some network nodes operate as routers while others operate as flooders, based on the underlying forwarding policy. When a node operates as a router, it forwards packets based on the routing table as determined by the underlying routing algorithm and when it operates as a flooder, it broadcasts packets to all its neighbors. We begin with the case of a single network flow and demonstrate that the problem of determining the goodput is challenging even for this simple setting. We construct a Bayesian network, and propose an algorithm based on the sum-product algorithm to determine the exact goodput. We extend the proposed Bayesian network model for exact goodput calculation to feed forward networks with multiple flows. For a general network with multiple flows, the problem becomes more challenging. The difficulty of the problem stems from the fact that node pairs can forward traffic to one another, resulting in cyclical dependencies. We propose a fixed-point approximation to determine the goodput in this case. Finally, we present an application scenario, where we leverage the fixed-point approximation to design a forwarding strategy *adaptive-flood* that adapts seamlessly to varying networking conditions. We perform simulations and show that *adaptive-flood* can effectively classify individual nodes as routers/flooders, achieving performance equivalent to, and in some cases significantly better than that of network-wide routing or flooding alone.

© 2017 Elsevier B.V. All rights reserved.

1. Introduction

The emergence of the Internet of Things has seen rapid growth and deployment of heterogeneous networks comprising of diverse nodes (e.g., mobile nodes, static nodes, sensor nodes) with varying capabilities to connect to the Internet (e.g., WiFi, 4G). Uncertainty and change in network connectivity due to node mobility and wireless link quality are fundamental characteristics of such networks. Analytically determining the *goodput* of flows in heterogeneous networks is an important, yet unsolved problem. A quick search yields plethora of research papers that determine the throughput of wireless networks, each subject to its own set of assumptions and constraints [1–3]. However, limited attention has been devoted to determining the goodput of flows in a mobile and wireless setting. In comparison to throughput, goodput only takes the number of unique packets reaching the destination into account.

In wireless networks, a variety of forwarding strategies have been proposed, ranging from stateful routing protocols [4] to flooding [5,6]. The pros and cons of maintaining state in dynamic wireless networks has also been investigated [7,8]. Manfredi et al. [9] show that in mobile networks with *homogeneous* node mobility and link characteristics, stateful routing protocols such as OLSR [10] perform well in dense and stable networks, whereas flooding is preferable in sparse and rapidly changing networks. However, mobility and connectivity characteristics observed in real-world measurements are often *heterogeneous*: while some nodes may have highly dynamic links, there are also well-connected nodes forming sizable connected components [11,12]. In heterogeneous networks with both stable and dynamic components, it is likely that neither routing nor flooding alone may perform particularly well in a given scenario. In such scenarios, performance can be improved by operating nodes as routers or flooders, depending on the network characteristics. However, flooding by network nodes can result in duplicate packets reaching the destination, thus making it necessary to analyze goodput instead of throughput to evaluate performance.

In this paper, an extension of our prior work [13], we consider a heterogeneous network where some nodes operate as routers

* Corresponding author.
E-mail addresses: aseethar@binghamton.edu (A. Seetharam), artir@binghamton.edu (A. Ramesh).

https://doi.org/10.1016/j.comnet.2017.11.008
1389-1286/© 2017 Elsevier B.V. All rights reserved.

while others operate as flooders, as specified by the underlying forwarding policy. *Our objective is two-fold in this paper. We propose algorithms to compute the goodput of flows in a heterogeneous network based on local link characteristics as well as the forwarding behavior of particular nodes (i.e., router or flooder). Secondly, we leverage this goodput calculation to design a forwarding strategy that seamlessly adapts itself to changing network conditions (i.e., mobility, connectivity) and provides superior performance.*

Our first goal is to design algorithms that determine the overall goodput based on network characteristics such as connectivity and mobility, given that a subset of nodes operate as routers, while others operate as flooders. This problem is challenging primarily due to two reasons - *i)* flooding can result in duplicate copies of a packet reaching the destination along multiple overlapping paths, *ii)* when there are multiple flows in a general network, nodes can forward traffic to each other, thereby influencing their incoming and outgoing rates. For networks with a single flow and feed forward networks with multiple flows where we only encounter the first challenge, we adopt a Bayesian network model and perform exact inference to determine the goodput. For general networks with multiple flows, the second challenge complicates exact inference and therefore, we propose a fixed-point approximation to determine the overall network goodput.

Having determined the overall network goodput for a given set of routers and flooders, our next objective is to leverage this calculation to design a forwarding strategy that classifies individual nodes as routers or flooders to maximize the overall network goodput. Our work in driven by the intuition that in a wireless network with heterogeneous mobility and connectivity characteristics, neither routing nor flooding alone may perform well. Despite its apparent simplicity, this router/flooder classification is a challenging problem. While it is tempting to think that classifying a node as a router or flooder only requires local information, flooding at one node increases network traffic at downstream nodes and may ultimately reduce overall goodput due to congestion. In addition, one node operating as a flooder may affect the usefulness of turning another node into a flooder, implying subtle dependencies in the decision process.

Our contributions in this paper are as follows.

- We demonstrate via an example of a four node network that determining the goodput exactly, even for a network with a single flow, is non-trivial. We construct a Bayesian network and design an algorithm that leverages the sum-product algorithm to infer the exact goodput for a network with a single flow. We extend the Bayesian network model for inferring the exact goodput to feed forward networks with multiple flows. For a general network with multiple flows, the problem becomes more challenging as node pairs can forward traffic to one another resulting in cyclical dependencies. For this scenario, we propose a fixed-point approximation for determining the goodput.
- We leverage the goodput calculation to design a forwarding strategy that determines which nodes should operate as routers and which ones should operate as flooders so as to maximize overall network goodput. Our approach *adaptive-flood* assumes that an underlying native routing protocol is available and greedily selects those nodes as candidate flooders that maximize the overall network goodput. The algorithm picks nodes as flooders in decreasing order in which they contribute to maximizing network-wide goodput; it stops when converting any of the remaining routers into a flooder would result in a decrease in goodput. From an implementation perspective, this means that each node needs to determine only one piece of information, namely whether to unicast packets to the next-hop neighbor specified in its forwarding table, or to locally flood each packet to all neighbors.
- We show via simulation that *adaptive flood* outperforms network-wide routing or flooding. In particular, at low network loads flooding outperforms routing, while at high network loads, performance is reversed. In contrast, *adaptive flood* matches or outperforms both approaches over most or all of the range of loads in both homogeneous as well as heterogeneous scenarios. From these results, we conclude that *i)* the proposed fixed-point algorithm is an effective way for determining the overall network goodput, and *ii)* routing combined with adaptive flooding is a promising solution to solve the challenges inherent in mobile networking.

The rest of this paper is organized as follows. We discuss related work in Section 2. We formalize the problem and the underlying network model in Section 3. We first demonstrate the inherent challenges involved in exact goodput calculation via a simple example and then propose a Bayesian network model based algorithm for exact inference in Section 4. For general networks with multiple flows where exact inference is difficult, we propose a simple fixed-point approximation technique for determining the goodput in Section 5. We describe the *adaptive-flood* algorithm for classifying nodes into routers and flooders and present simulation results evaluating the performance of *adaptive-flood* in Section 6. We conclude the paper and provide an outlook at future work in Section 7.

2. Related work

In this section, we list some of the most influential work studying the capacity of wireless networks and highlight how this paper differs from existing work. A significant amount of past research has been devoted to demonstrate the capacity scaling of both flat and hybrid mobile networks [1,2,14,15]. Gamal et al. study the delay-throughput scaling in mobile wireless networks [16]. In comparison to research on throughput analysis and measurement, there is minimal work on goodput in wireless networks [17–19]. In contrast to prior work, we propose algorithms for computing the goodput (and not throughput) of flows in wireless networks. We also utilize this goodput calculation to design a forwarding strategy that adapts seamlessly to changing network conditions.

We next present work related to network classification in wireless networks. Several past research efforts [9,20,21] have addressed the challenge of classifying mobile wireless networks based on connectivity and predictability. For example, Manfredi et al. [9] propose a framework for organizing the decision space of communication strategies (i.e., determining whether the network as a whole should operate by flooding, routing, or store-carry-and-forward) in a homogeneous network based on connectivity and unpredictability so as to maximize goodput. In contrast to Manfredi et al. [9], where classification has been done for the network as a whole, the *adaptive-flood* algorithm developed in this paper adopts a per-node classification strategy (route or flood) in order to maximize goodput.

Additionally, number of past efforts have sought to exploit characteristics such as connectivity, predictability and mobility of wireless networks to design forwarding protocols that enhance performance [4,22–25]. Epidemic routing [5,26] and multicopy routing [27] are designed for sparsely-connected networks and use a store-carry-and-forward mechanism and packet replication to battle poor connectivity. Balasubramanian et al. [23] and Demmer and Fall [28] make assumptions on the mobility pattern and network topology to design forwarding protocols for intermittently connected networks. Tie et al. [12] propose a routing protocol, R3, that provides robust performance in diverse and varying connec-

Download English Version:

https://daneshyari.com/en/article/6882816

Download Persian Version:

https://daneshyari.com/article/6882816

Daneshyari.com