Computer Networks 57 (2013) 228–242

Contents lists available at SciVerse ScienceDirect

Computer Networks

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

Fairness-related challenges in mobile opportunistic networking

Abderrahmen Mtibaa *, Khaled A. Harras

School of Computer Science, Carnegie Mellon University, Doha, Qatar

ARTICLE INFO

Article history:
Received 28 November 2011
Received in revised form 24 May 2012
Accepted 29 August 2012
Available online 21 September 2012

Keywords:
Fairness
Mobile opportunistic networks
Social networks
Rank-based opportunistic forwarding
Fairness efficiency trade-off

ABSTRACT

The fundamental challenge in opportunistic networking, regardless of the application, is when and how to forward a message. Rank-based forwarding techniques currently represent one of the most promising methods for addressing this message forwarding challenge. While these techniques have demonstrated great efficiency in performance, they do not address the rising concern of fairness amongst various nodes in the network. Higher ranked nodes typically carry the largest burden in delivering messages, which creates a high potential of dissatisfaction amongst them. In this paper, we adopt a real-trace driven approach to study and analyze the trade-offs between efficiency, cost, and fairness of rank-based forwarding techniques in mobile opportunistic networks.

Our work comprises three major contributions. First, we quantitatively analyze the trade-off between fair and efficient environments. Second, we demonstrate how fairness coupled with efficiency can be achieved based on real mobility traces. Third, we propose FOG, a real-time distributed framework to ensure efficiency–fairness trade-off using local information. Our framework, FOG, enables state-of-the-art rank-based opportunistic forwarding algorithms to ensure a better fairness–efficiency trade-off while maintaining a low overhead. Within FOG, we implement two real-time distributed fairness algorithms; Proximity Fairness Algorithm (PFA), and Message Context Fairness Algorithm (MCFA). Our data-driven experiments and analysis show that mobile opportunistic communication between users may fail with the absence of fairness in participating high-ranked nodes, and an absolute fair treatment of all users yields inefficient communication performance. Finally our analysis shows that FOG-based algorithms ensure relative equality in the distribution of resource usage among neighbor nodes while keeping the success rate and cost performance near optimal.

1. Introduction

Mobile opportunistic networks interconnect nodes with heterogeneous contact rates, unpredictable mobility, and limited resources. These mobile nodes communicate relying on both the transport of messages as well as multi-hop forwarding. Current forwarding techniques [3,28,19,21,9] are generally designed to efficiently select the most likely relay nodes to deliver a message to its destination. Within those techniques, rank-based forwarding [5,7,8] represents one of the most promising methods for addressing this message forwarding challenge. This method differs in the type of information used (e.g., information acquired during contacts [7,8], or social interaction between users [5,26,25]), as well as how it is used to rank nodes in the network. A node with a lower rank will forward messages to nodes with higher ranks. This solution, however, creates a high potential of dissatisfaction among high ranked nodes that carry a heavier burden compared to others.

Ensuring fairness in mobile opportunistic networks is a crucial goal if rank-based forwarding algorithms are to be adopted in the future. In such networks, nodes can behave selfishly and try to only maximize their own utility

* Corresponding author. Tel.: +974 3315 9831.
E-mail addresses: amtibaa@cmu.edu (A. Mtibaa), kharras@cs.cmu.edu (K.A. Harras).

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http://dx.doi.org/10.1016/j.comnet.2012.08.019

without considering the global system-wide performance. Previous studies have considered absolute fair allocation of user resources [1,18,20]. They have shown that absolute fairness results in higher end-to-end delivery delays. They did not, however, investigate trade-offs between the three metrics in mobile opportunistic networks: fairness, end-to-end delay, and cost.

Throughout this paper, we adopt a real-trace driven approach to quantitatively analyze those trade-offs, and propose a real-time distributed framework for fairness in opportunistic networking. Our initial conference version compromises three major contributions [23]. First, we quantitatively analyze the impact of an absolute fair and efficient environment on the overall network performance. We show that in an unfair environment, selecting preferential or popular relay nodes in forwarding decisions is efficient and yields enhanced forwarding performance. We also show that absolute balancing across nodes causes significant end-to-end delay and severe performance degradation. Second, we study the trade-off between fairness, cost, and efficiency in opportunistic forwarding. Relying on our experimental datasets, we consider an offline approach to construct forwarding paths while ensuring both fairness and efficiency, and keeping the cost near optimal. Finally, we adopt a distributed real-time approach in order to efficiently discover these paths while utilizing only local information. We call our distributed real-time framework FOG (*F*airness-based *O*pportunistic networkin*G* framework).

This journal paper adds the following contributions beyond the conference version [23]:

- We address fairness in opportunistic forwarding more generally. While [23] focuses mainly on a trade-off between fairness and success delivery ratio, this paper extends that work to quantitatively study different trade-offs between fairness, cost and success rate. Cost metric is addressed after identifying the best performing algorithms with respect to the other two metrics. We look then at the cost within those nominal values. We investigate fairness issues of social-based forwarding algorithms such as PeopleRank [25] and Simbet [5] and contact-based forwarding such as *Frequency* (FR) [8] and *Last_Contact* (LC) [7].
- We propose two real-time distributed algorithms to maximize the overall user satisfaction; Proximity Fairness Algorithm (PFA) and Message Context Fairness Algorithm (MCFA). While the main advantage of PFA is its simplicity which allows any rank-based forwarding algorithm to ensure minimum fairness without using additional network information, MCFA uses local information to make better forwarding decisions. MCFA enables cost performance aware message delivery in mobile opportunistic networks taking into account the number of message replicas in the network and user satisfaction of each message. We model the satisfaction a node derives from sending and receiving messages as a utility function. MCFA uses such utility in order to avoid overwhelming the popular nodes with many messages when other nodes can deliver them to theirs destination in a bounded delay.
- Our real-trace analysis includes additional results that rely on a modified San Francisco [27] dataset that we synthesize. We show that FOG uses the two fairness algorithms PFA and MCFA to ensure relative equality in the distribution of resource usage among neighbor nodes while maintaining a high delivery success rate, and cost performance close to optimal. While the simplicity is considered as one of PFA algorithm strengths, we show that MCFA uses fewer message replicas compared to PFA and achieves a better success delivery ratio.

The remainder of this paper is organized as follows. Section 2 provides a brief overview of rank-based forwarding techniques and the experimental datasets used throughout the paper in our analysis. Section 3 discusses the fairness vs. efficiency vs. cost trade-offs. In Section 4 we adopt an offline approach to construct forwarding paths while ensuring both fairness and efficiency. In Section 5, we propose a real-time distributed framework for fairness in opportunistic networking, and implement two distributed algorithms that enable existing rank-based forwarding algorithms to be both fair and efficient. We then present the related work in the field of fair and efficient mobile opportunistic forwarding in Section 6. Finally, Section 7 concludes the paper.

2. Background and datasets

In this section we provide a brief overview on rank-based forwarding algorithms, and present the experimental datasets used in our analysis to improve the fairness of these forwarding algorithms. We also briefly describe our evaluation methodology used throughout the whole paper.

2.1. Rank-based forwarding algorithms

Rank-based forwarding techniques represent one of the most promising methods for message forwarding in opportunistic networks. They differ in the type of information used, as well as how it is used, in order to rank nodes in the network. We distinguish between two type of rank-based forwarding techniques; contact-based ranking techniques, where information learned during contact, are used to rank nodes, and social-based ranking techniques, where social interactions between users are used to rank the nodes.

2.1.1. Social-based ranking algorithms

There are three well-known social-based ranking techniques that differ in the type of social metric used:

- *Degree-based forwarding*: Consists of forwarding messages to socially well connected nodes. Paths are then constructed according to a non-decreasing social node degree rule (more details in [22]).
- *Centrality-based forwarding*: The main idea behind this technique is that central nodes in social graphs are more likely to socialize with other people and therefore more likely to forward messages (more details in [5,22]).