Journal of Network and Computer Applications 34 (2011) 535–541

Contents lists available at ScienceDirect

Journal of Network and Computer Applications

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

A reputation system for wireless mesh networks using network coding ☆

Tingting Chen, Ankur Bansal, Sheng Zhong *

Computer Science and Engineering Department, State University of New York, Buffalo, Amherst, NY 14260, USA

ARTICLE INFO

Article history:
Received 31 March 2010
Received in revised form
19 November 2010
Accepted 17 December 2010
Available online 29 December 2010

Keywords:
Wireless mesh networks
Network coding
Reputation system

ABSTRACT

Using network coding, wireless mesh networks can significantly improve their performance. However, since many wireless mesh networks have user contributed devices as their nodes, to guarantee the cooperation of such selfish nodes is a highly challenging problem. In this paper, we study how to stimulate selfish nodes to cooperate in wireless mesh networks using network coding. We propose a simple, practical reputation system that rewards cooperative behavior in routing and packet forwarding and penalizes non-cooperative behavior. Simulation results verify that our reputation system is very efficient and that it effectively stimulates cooperation.

1. Introduction

Internet is a huge source of information today. A solution to provide universal access to the internet is to have many wireless access points at different parts of the city. Installing these many access points is expensive. Wireless mesh networks are multi-hop systems in which wireless devices (mesh nodes) assist each other in transmitting packets through the network. Mesh node provides data transport and routing functionalities and any mesh node connected to wired internet function as mesh gateway. In a wireless mesh network, only one node needs to be physically wired to an access point, this gives an advantage over traditional wireless networks where we need multiple wireless access points. However, as the number of nodes in the network increase, wireless mesh networks suffer throughput limitation.

Network coding (Ahlswede et al., 2000; Jaggi et al., 2005; Li et al., 2003; Koetter and Medard, 2003; Katti et al., 2006) can significantly improve the performance of wireless mesh networks. With network coding intermediate nodes compute and send new encoded packets from the packets that they have heard instead of forwarding the same packets as received. The most popular encoding method is random linear combination (e.g. in Chachulski et al., 2007). Intelligent linear combination of packets by nodes explores the broadcast nature of wireless networks and thus can increase throughput when multiple nodes can hear same packets in the network. But since many wireless mesh networks have user contributed devices as their nodes, the cooperation of such selfish nodes is a must.

Forwarding neighbor's messages consumes resources like bandwidth, so selfish users in the wireless mesh networks have a strong motive to deviate from the routing and packet forwarding protocols. In wireless networks with network coding, selfish nodes may report untruthful link rates so that by routing results they will be asked to transmit fewer packets than they should be. Selfish nodes may also simply skip some packets not forwarding them, even though they are required by the routing protocol.

In this paper our goal is to stimulate cooperations in network coding systems in both routing and packet forwarding procedures. Since the credit-based systems (Anderegg and Eidenbenz, 2003; Zhong et al., 2003; Buttyan and Hubaux, 2000) that involve distributing the credits (tokens or money and thus introducing much overhead to the network), we take the approach of reputation systems. Reputation systems (Buchegger and Boudec, 2004, 2005; Mundinger and Boudec, 2006) assign ratings to the participating entities (nodes in our case) in networks. Every forwarding node keeps a check on the behavior of the other forwarding nodes and assigns reputation values accordingly. Once the reputation value goes down to a certain degree, the misbehaving node is penalized based on its low reputation value. However, the existing reputation systems cannot be applied to wireless networks with network coding, because nodes cannot easily decide whether their neighbors forward packets as required since packets are all newly computed and different. In this paper, our contributions can be summarized as follows (a) to the best of our knowledge we are the first ones to stimulate cooperation of the nodes in the network coding systems by reputation systems and (b) our algorithm is very efficient and can effectively detect misbehaving nodes and prevent the system throughput from degradation.

The rest of the paper is organized as follows. The related work is described in Section 2. Section 3 describes the network model and the reputation system, we consider in the paper. The detailed design of our algorithm is described in Section 4. We verify the

☆ This work was supported by NSF CNS-0845149 and CCF-0915374.
* Corresponding author. Tel.: +1 716 645 3180x107; fax: +1 716 645 3464.
E-mail addresses: tchen9@buffalo.edu (T. Chen), abansal5@buffalo.edu (A. Bansal), szhong@buffalo.edu, szhong@cse.buffalo.edu (S. Zhong).

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doi:10.1016/j.jnca.2010.12.016

effectiveness and efficiency of our algorithm in Section 6. The last Section, Section 7 concludes the paper.

2. Related work

A simulation study presented in Michiardi and Molva (2002) showed that the performance of multi-hop wireless network severely degrades in face of selfish node's misbehavior. The previous work (Anderegg and Eidenbenz, 2003; Zhong et al., 2003; Buttyan and Hubaux, 2000; Buchegger and Boudec, 2002; Mahajan et al., 2005; Marti et al., 2000) on this problem has been studied in traditional wireless networks that do not use network coding. There are based on two main approaches, the reputation approach and the credit approach.

Reputation based algorithms to avoid misbehavior in the wireless networks have been proposed (Buchegger and Boudec, 2002; Mahajan et al., 2005; Marti et al., 2000). Marti et al. (2000) introduced two tools watchdog, which determines misbehaving nodes and pathrater, which is used to avoid the defective (selfish) nodes while forwarding messages. The simulation results show 17–27% increase in the throughput. Buchegger and Boudec (2002) proposed CONFIDANT as a solution to mitigate the routing behavior of the selfish nodes. Their solution detects and isolates misbehaving nodes. Mahajan et al. (2005) proposed anonymous neighbor verification (ANV) to isolate the selfish nodes from the network.

There exist incentive-compatible solutions in wireless networks to forward messages (Anderegg and Eidenbenz, 2003; Zhong et al., 2003; Buttyan and Hubaux, 2000). Anderegg and Eidenbenz (2003) proposed AD hoc-VCG, where misbehaving will not do any good in fact reporting true costs (for forwarding packets) will benefit nodes. Zhong et al. (2003) proposed Sprite, A Simple, Cheat-Proof, Credit-Based System, where each selfish node loses credit if it cheats. The results show an increase in throughput which overcomes the loss introduced due to the overhead involved in distributing the credit. To prevent users to misbehave in the network, Buttyan and Hubaux (2000) introduced a tamper proof hardware at each node to deduct or give credit to nodes.

The misbehavior of the nodes in the wireless mesh network using network coding, has been studied in Wu et al. (2008) and Chen and Zhong (2010). Wu et al. (2008) use a credit approach to provide incentives to honestly measure and report link loss probability and prove that their routing protocols guarantee that following the protocol is to the best of the nodes' interest. As far as we know, there is *no reputation system* proposed for wireless mesh network using network coding. In this paper, we propose a simple, practical reputation system for wireless mesh networks that rewards cooperative behavior and penalizes non-cooperative behavior. By *simple* we mean that our reputation system does not have very complicated operations and thus is very efficient (with less overhead) compared with incentive schemes. Computing resources are precious for the network users especially for mobile/wireless networks users. Consequently, it is important to remain the reputation system lightweight to make it practical in its application. Compared with the existing utility-based incentive schemes, our reputation system does not require extra cryptographic operations for each packet transmitted in the network, and thus it saves computing resources for the participating nodes. Compared with credit-based solutions such as Anderegg and Eidenbenz (2003), Zhong et al. (2003), Buttyan and Hubaux (2000) which involve significant overheads, our work is much more efficient, but still provides strong incentives for nodes to cooperate.

3. Network model and system architecture

In this section, we describe the network model that we use in this paper and the basic concepts and architecture of our reputation system.

3.1. Network model

We consider a wireless mesh network with a set of nodes. The wireless links between the nodes are lossy. For any two nodes v_j and v_i, we denote the link from v_j to v_i as (v_j, v_i), and the loss probability of (v_j, v_i) as ε_{ji}. If packets sent by v_j can be received by v_i with non-zero probability, i.e., $\varepsilon_{ji} < 1$, we say that v_j and v_i are *neighbor nodes*. We denote the set of neighboring nodes of v_i as N_{v_i}.

To be concrete, we assume that the wireless mesh network is using network coding system MORE (Chachulski et al., 2007). Note that our reputation system is not only restricted to MORE (Chachulski et al., 2007). Instead, it can be applied or easily extended to a wide variety of systems using network coding, in which loss probability is used in the routing protocol, e.g., MIXIT (Katti et al., 2008) and ExOR (Biswas and Morris, 2005). We will further explain this at the end of Section 4.2 after introducing how to calculate the reputation values in our reputation system.

The MORE system works as follows. Each node i periodically measures the ε_{ji} for each of its neighbors via ping probes. Using methods similar to link state protocols (Bicket et al., 2005), the loss probabilities are distributed to other nodes in the network. Using the loss probabilities, each node can compute a forwarder list based on the ETX distance (De Couto et al., 2003), if it wants to send a file to a destination node. The source node breaks up the files that it wants to send in batches where each batch has K native packets. For each batch the source node sends out K coded packets. Each coded packet is a random linear combination of the K native packets. Each packet header stores the batch ID, the forwarder list and the random coefficients used to generate the coded packet from the natural packets. Nodes listen to all transmissions. When hearing a message, a node v_i checks whether it is in the forwarder list and whether this packet is linearly independent from all packets v_i has received for the same batch. If so, it makes t_i (which is precomputed based on link loss probabilities) transmissions of a random linear combination of all packets for the same batch including the one just received. When the destination node has received K linearly independent packets for the same batch, it decodes them and sends an acknowledgement to the source node. For more details of the MORE system, please refer to Chachulski et al. (2007).

3.2. System architecture

In this paper, our goal is to guarantee that in wireless mesh networks using MORE, by our reputation system, the nodes are encouraged to cooperatively follow both routing and packet forwarding protocols. The overall architecture of our reputation system consists of wireless nodes in the network among which data packets are transmitted using network coding, and an offline central authority. Our reputation system is in a distributed fashion in that the central authority does not maintain real-time reputation information of each node. Instead, by offline we mean that each node can only connect to the central authority periodically. The central authority is mainly used for key setup and administrating the misbehaving node (e.g., help removing nodes that are consistently misbehaving).

4. Design of reputation system for MORE

In this section, we present our distributed reputation system for MORE. Our reputation system not only gives nodes' incentives to honestly follow the routing protocol, but also monitors the packet forwarding of the nodes, enforcing them to behave cooperatively when forwarding packets for others.