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TCP-aware network coding with opportunistic scheduling in wireless mobile ad hoc networks

Tebatso Nage, F. Richard Yu *, Marc St-Hilaire

Department of Systems and Computer Engineering, Carleton University, Ottawa, ON, Canada

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ABSTRACT

This paper presents a scheme that employs TCP-aware network coding with opportunistic scheduling to enhance TCP throughput in wireless mobile ad hoc networks. Specifically, it considers a TCP parameter, congestion window size, and wireless channel conditions simultaneously to improve TCP throughput performance. Evaluation of this scheme is carried out by using ns2 simulations in different scenarios. The results show that the proposed scheme gives approximately 35% throughput improvement in a high mobility environment and about 33% throughput increase in no or low mobility environment as compared to traditional network coding with opportunistic scheduling. This paper also proposes a new adaptive-W (i.e., *adaptive Waiting time*) scheme whose objective is to adaptively control waiting time of overheard packets that are stored in a buffer to achieve tradeoff between throughput and overhead.

1. Introduction

Network coding (NC) is a new transmission paradigm pioneered by Ahlswede et al. [1]. In recent years, it has generated huge research interest especially in wireless communications. The main attraction of this novel concept is that it is bandwidth efficient and achieves high throughput gains [2–7]. Through experiments [8], it has been found that network coding makes it possible to perform peer-to-peer live multimedia streaming with finer granularity. Network coding can be regarded as an extension of the traditional routing protocol in which intermediate nodes store and forward packets. The basic idea about network coding is that packets are intelligently mixed (or coded) together at an intermediate node into one coded packet which is then broadcasted. This process facilitates not only the generation of a few number of transmissions in the network but also information rich transmissions. Furthermore, with network coding, more bandwidth becomes available for new data to be transmitted resulting in high network throughput [9].

Network coding comes in different forms. Some studies consider what is referred to as *random* network coding [3,4,8,9]. There are also *physical layer* network coding [10,11] and *XOR* network coding [9,12,13]. In random network coding, encoding coefficients are randomly chosen from a set of coefficients of finite field. A linear combination of packets is then performed to generate a coded packet. At the receiver, decoding becomes possible if and only if the receiver can generate a full rank transfer matrix made of coefficients extracted from received coded packets [8]. This means that if there are K encoding coefficients in a coded packet, the receiver will have to receive at least K independent versions of the coded packet for successful decoding. Physical layer network coding, on the other hand, facilitates simultaneous reception of electromagnetic (EM) waves of signals at the air interface [10] which are then aggregated. This approach achieves higher network throughput than random network coding. However, it introduces interference at the node's air interface hence high design complexity. The last form of network coding, which is the one considered in this paper, employs binary XOR operation to code packets. It is regarded as a special case of random network coding where the Galois field is of size 2. XOR network coding is simple and cheap because the same operation is used both at the sender and the receiver. Also, the implementation is less complex compared to other random network coding schemes.

Existing network coding schemes, such as COPE [6], require exchange of information among neighboring nodes in order to correctly encode and decode data packets [14]. However, this leads to high packet overhead and degrades system performance by introducing additional delay, congestion, energy consumption and inefficient bandwidth utilization. To this end, there have been several approaches to combat this problem. In [15], Chou et al. proposed a buffer model which employs traditional generation-based network coding to minimize packet overhead. Although some performance

* Corresponding author. Tel.: +1 6135202600x2978.
E-mail addresses: tebatson@sce.carleton.ca (T. Nage), richard_yu@carleton.ca (F.R. Yu), marc_st_hilaire@carleton.ca (M. St-Hilaire).

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improvements were reported in [15], this approach is susceptible to packet losses that are facilitated by flushing old generations in network coding.

In [4], Jin and Li designed an adaptive random network coding in WiMAX by adapting the number of upstream nodes and dynamically adjusting block size in response to channel conditions. Prasad et al. [14] proposed a new encoding strategy, XOR-TOP, which employs local topology to effectively estimate the available non-coded or *native* packets at neighboring nodes. They claim that their scheme, which does not employ information exchange among neighboring nodes, can always accurately identify coding opportunities according to local topology. However, wireless link conditions are unpredictable. Therefore, there is a chance of making an error in estimating available native packets at neighboring nodes and more especially in high mobility environment in which local network topology frequently changes. Katti et al. [6] employed bit-map format in packet's reception report. Even though the representation for reception reports in their approach is compact and effective, their fixed-W (i.e., *fixed Waiting time*) scheme has shortcomings. For example, if a node has many neighboring nodes, chances are that more packets from different nodes will be overheard and this could increase overhead.

Although network coding was recently introduced in the literature, substantial amount of research has been done to enhance its performance. However, to the best of our knowledge, there has not been any work reported in the literature which considers Transmission Control Protocol (TCP) dynamics and opportunistic scheduling (OS) simultaneously for network coding in wireless mobile ad hoc networks.

Therefore, this paper presents a robust and resilient TCP-aware network coding with opportunistic scheduling in wireless mobile ad hoc networks by employing the cross-layer design approach. On top of that, a new adaptive-W (i.e., *adaptive Waiting time*) scheme is also proposed to enhance the basic XOR network coding scheme. The scheme we put forward adaptively controls packet waiting time in a local buffer to achieve a tradeoff between throughput and overhead.

The motivation behind this work can be described as follows: If TCP and wireless channel information is considered simultaneously in network coding for determining transmission data rates, throughput may be maximized in wireless mobile ad hoc networks. Furthermore, it would be costly to deploy a modified version of TCP. Therefore, an efficient scheme which employs the current TCP variant (TCP Reno) as is without any changes could cut down deployment cost. Moreover, information exchange required in network coding could degrade network performance. Therefore, an adaptive scheme for controlling overhead could maximize network throughput and provide efficient bandwidth utilization.

The contributions of this paper are as follows: as a first contribution, we introduce and design a robust and resilient scheme which simultaneously considers TCP and channel information in traditional network coding to maximize TCP throughput in wireless mobile ad hoc networks. As a second contribution, we also propose an adaptive-W scheme whose aim is to adaptively control packet waiting time in the buffer called *packetPool* to achieve tradeoff between throughput and overhead.

Simulation results show that in high mobility environments, there is approximately 35% performance improvement when TCP-aware network coding is employed as compared to traditional network coding with opportunistic scheduling. When adaptive-W scheme is used in traditional network coding upon which TCP-aware network coding scheme is built, significant performance is achieved in terms of bandwidth utilization and throughput.

The rest of the paper is organized as follows. Section 2 describes the system model followed by TCP-aware network coding with opportunistic scheduling in Section 3. Adaptive-W scheme is discussed in Sections 4 and 5 presents simulation results and discussion. Finally, conclusions and future work are exposed in Section 6.

2. System models

In this section, we first present some background information about network coding. Then, the wireless channel model is described followed by the TCP model used.

2.1. Network coding

Network coding is performed at the data link layer. The following subsections will describe how information is exchanged between the nodes, how coded packet are transmitted, how to find coding opportunities and how to use the channel and TCP information in the coding process.

2.1.1. Information exchange

In order to facilitate network coding, network nodes are made to snoop on all transmissions going on in the network. They capture and store overheard packets from the network in their buffers (also known as packetPool) for a particular time interval (e.g., 0.5 s) [6]. For example, let us consider the example shown in Fig. 1 which has been taken from [12]. In this network, three packets are to be forwarded: P_1 from A to C, P_2 from C to A and P_3 from E to D. It is assumed that each node can hear the communications of its neighbors. This means that, for example, node C is within the communication range of nodes B, D and E. Initially, each node will transmit its packet to node B. At the same time, neighboring node will also

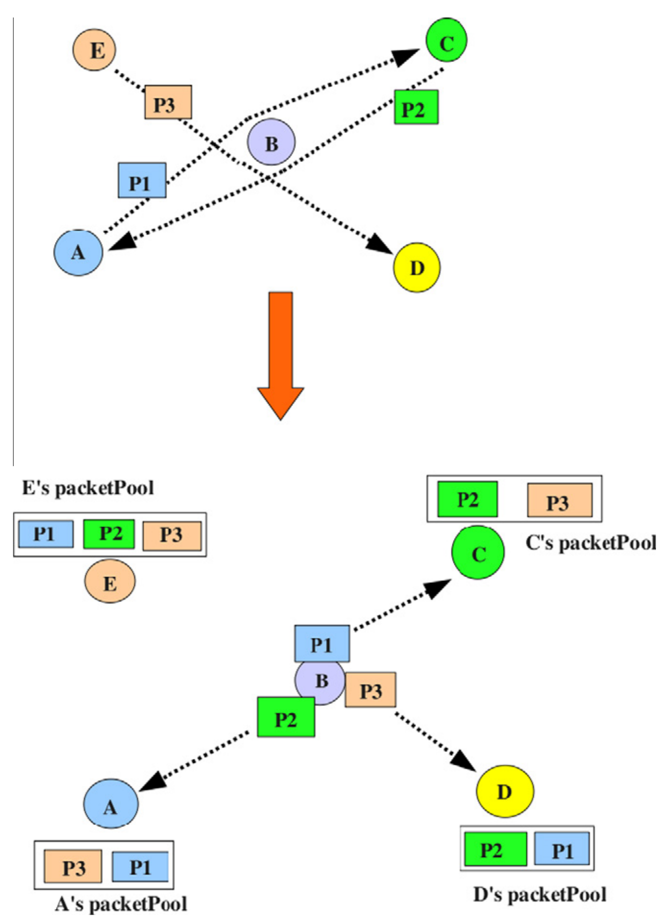

Fig. 1. XOR network coding [12].