Computer Networks 57 (2013) 1488–1502

Contents lists available at SciVerse ScienceDirect

Computer Networks

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

QoS for real-time reliable multicasting in wireless multi-hop networks using a Generation-Based Network Coding

Youghourta Benfattoum *, Steven Martin, Khaldoun Al Agha

Laboratoire de Recherche en Informatique, Bât 650, Université Paris-Sud, CNRS, F-91405 Orsay, France

ARTICLE INFO

Article history:
Received 10 April 2012
Received in revised form 4 August 2012
Accepted 4 February 2013
Available online 10 February 2013

Keywords:
Network Coding
Generation
Multicast
Quality of service

ABSTRACT

Most of the works on Generation-Based Network Coding (GBNC) consider a fixed generation size. A large generation size maximizes the Network Coding benefits but leads to a long delay while a small generation size reduces the delay but decreases the throughput. This paper presents the DYnamic GEneration Size (DYGES) approach. Our network-aware method adjusts the generation size according to the network variations (network size, congestion, losses) for multicast flows to keep the delay steady. Since Network Coding and redundancy cope with data packet loss, we propose an enhancement of DYGES with ACK recovery. This method, named RDYGES, uses the opportunistic listening feature of nodes to recover the lost ACK. Our goal is to guarantee a Quality of Service (QoS) in terms of delay. The simulation results show the accuracy of our approach.

1. Introduction

Introduced in 2000 [1], Network Coding is a recent technique that mixes the flows to increase the network performance. The history of Network Coding is detailed in [2]. It was proved in [3] that for multicast traffic, linear codes are sufficient to achieve the maximum capacity bounds. Then, the authors of [4] proposed to solve the Network Coding problem in an algebraic way.

However, the coding/decoding scheme has to be agreed upon beforehand and needs full network topology. Therefore, the Linear Random Network Coding was proposed in [5] and proved to be efficient. This randomized coding guarantees robust distributed transmission and makes Network Coding easier to implement in a real network. COPE [6] was the first architecture for Network Coding in a wireless mesh network. It uses an opportunistic coding to choose the packets to XOR in order to maximize the number of neighbors that can decode them. Various approaches such as BFLY [7] and DCAR [8] propose to apply COPE with a different scheme to still increase the throughput.

In this paper we use a Generation-Based Network Coding [9] (GBNC) for multicast flows. Using this approach, the source divides the file to send into blocks called generations (also referred as batches[1]). When sending a packet, it combines only the packets belonging to the same generation using coefficients randomly and uniformly selected from a Galois Field (GF) while preventing all-zero coding coefficients.

Let us explain how GBNC works in the wireless network depicted in Fig. 1. The source node s wants to send two packets to the destination nodes y and z (multicast flow). We set the base field to $GF[2^2]$ i.e. the coefficients are chosen from the set $[0,1,2,3]$ and any operation on them is made *modulo*[4]. Node s timely[2] combines P_1 and P_2 in order to build two combinations (or combined packets) $C_1 = P_1 + P_2$ and $C_2 = P_1 + 3P_2$ which are sent to node t and node u respectively. Node t forwards C_1 to both node x and node y. Similarly, node u forwards C_2 to both node x

* Corresponding author. Tel.: +33 169156407; fax: +33 169156586.
E-mail addresses: youg@lri.fr (Y. Benfattoum), smartin@lri.fr (S. Martin), alagha@lri.fr (K.A. Agha).

[1] In the remaining of this paper, we refer to batch and generation interchangeably.

[2] Time-coding: coding a packet with previous ones.

1389-1286/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.comnet.2013.02.005

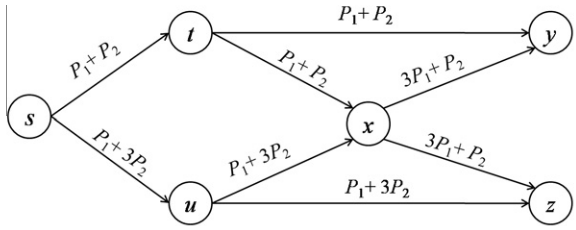

Fig. 1. A multicast network using Network Coding.

and node z. Node x combines C_1 and C_2 (space coding[3]) to build one combination $C_3 = 2C_1 + C_2 = 3P_1 + 5P_2$, and using *modulo*[4], $C_3 = 3P_1 + P_2$. This combination is then broadcast to both node y and node z. The destination node y holds two combinations C_1 and C_3. To decode the original packets, it resolves the system having two variables P_1 and P_2 and the coefficient matrix $\begin{pmatrix} 1 & 1 \\ 3 & 1 \end{pmatrix}$. A Gaussian elimination is done to recover the values of P_1 and P_2. Similarity node z uses C_2 and C_3 to recover P_1 and P_2. We notice that if Network Coding was not applied, node x would send two packets instead of one and thus would consume additional bandwidth.

In GBNC systems, the generation size is a crucial parameter, it affects both delay and throughput. Most of the works on GBNC consider a fixed generation size. The network state is not smooth, it is subject to variations such as the number of nodes, congestions and losses. A small generation size is likely the most suitable when the network load is high since it reduces the decoding delay. As for a large generation size, it is more appropriate for a low loaded network since it increases the throughput. Using for instance, a large generation size when the network is high loaded can dramatically increase the decoding delay then it becomes impossible to respect the application's requirements in terms of delay. For a given context, if the chosen generation size is not adequate, the network performance decreases in terms of delay, throughput and/or robustness.

Having this in mind, we propose DYGES which adapts dynamically the generation size according to the network load for multicast flows. Its aim is to keep the decoding delay steady around a given threshold while maximizing the throughput corresponding to that delay. A potential application of our work is to guarantee the QoS for video streaming and conferencing in either wireless or wired networks. In this context, the end-user application is required to display information within a certain delay. Moreover, video conferencing needs the display synchronization among the participants. An example of the targeted networks are limited size networks such as Home Area Networks (HANs).

This paper is structured as follows: We review the previous works relevant to Network Coding and delay in Section 2. A theoretical background about Network Coding, throughput, delay and packet loss is explained in Sections 3.1 and 3.2. We describe the principle and simulation results of our approach in Section 4. The Redundancy computation is given in Section 5. We propose an enhancement of DYGES with ACK recovery and show its accuracy by simulation in Section 7. We finally conclude in Section 8.

2. Related work

The idea of GBNC was first introduced in [9]. It uses generations and random Network Coding to reduce the coding/decoding complexity. This decentralized scheme does not need to know the network topology. However, the packets do not have the same priority and their loss is acceptable consequently there is no need for acknowledgements (ACKs).

An opportunistic coding approach inspired by COPE was proposed in [10] to minimize the delay. The packets to encode are chosen according to their delay threshold for minimizing the number of packets which miss their deadline.

A Network Coding approach with Multi-Generation Mixing for video communication is presented in [11]. It consists of combining a packet with packets of the same generation and packets of previous generations. This approach increases the decoding rate for networks with sparse connectivity and high loss rates. However, it cannot be applied for delay-sensitive applications that require a small decoding delay.

Ref. [12] investigates the throughput performance when applying GBNC to scalable multicast. It shows by simulation that the throughput is significantly dependent on the choice of the coding parameters such as generation size, redundancy (or stretch) factor, field size and topology. However, the QoS in terms of delay is not managed and the generation size for each scenario is fixed.

MORE [13] applies Network Coding on an opportunistic routing algorithm named Extremely Opportunistic Routing (ExOR [14]). For a given unicast flow, ExOR finds a multipath based on the delivery probabilities of the network links. However, a scheduling is needed to prioritize a path on another one. MORE uses random GBNC to cope with this issue. It considers a fixed generation size and does not deal with delay constraints.

For the best of our knowledge, only the approach presented in [15] adjusts the generation size in a Network Coding context. For a unicast flow, the destination estimates the Round Trip Time (RTT) using an empirical approach and sends it in the ACK packet. The source uses this information to compute the generation size and respect the probability that the block-decoding delay is below a given threshold. It is not straightforward to use this approach for multicast flows since the bottleneck is not relevant to one destination. Moreover, the relationship between the given threshold and the throughput is not obvious.

In this paper we present our approach in a lossless context and then extend it for lossy networks. Indeed, the retransmission mechanism is necessary when the delivery probability in the network is low. In the literature, many works dealing with Network Coding such as [12,9] present their schemes but do not address the retransmission issue.

An efficient Network Coding based retransmission algorithm for wireless multicast is presented in [16]. Its main

3 Space-coding: coding packets received from different links.