Network Coding vs. Erasure Coding: Reliable Multicast in Ad hoc Networks

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Abstract — Providing reliable and efficient networking services in wireless ad hoc networks is very challenging due to high mobility and unstable wireless nature. Network coding (NC) and erasure coding (EC) are such coding schemes considered to be able to provide excellent ammunition against erasure networks. However, “the jury is still out” regarding which scheme is suitable in ad hoc networks. We present information on the performance of both schemes which may be useful for selecting the better coding scheme.

I. INTRODUCTION

In ad hoc tactical networks, multicast communications are prevalent due to the group oriented actions undertaken by the military. Such environments always require high reliability because messages communicated in tactical networks contain critical information. However, reliability support in mobile ad hoc networks (MANETs) is very challenging due to high mobility and unstable wireless nature: a significant number of packets can be corrupt or lost. To improve reliability in packet erasure networks, automatic repeat request (ARQ) has been employed in unicast communications; however, ARQ is not useful in multicast due to the so-called feedback implosion problem. Instead, various coding schemes have been proposed and studied for the past several years. Network coding (NC) and erasure coding (EC) are such coding schemes which can increase reliability in multicast communications.

NC and EC essentially share a common concept: both schemes can potentially encode original packets into an infinite data stream of encoded packets and receivers reconstruct the original packets once they have collected a certain number of encoded packets. By exploiting the sufficient redundancy in the network, the receivers can successfully recover packets from huge packet losses. The main difference of both schemes is that NC allows intermediate nodes to encode packets they have received so far whereas only sources encode packets in EC. Both schemes are considered promising to improve reliability in packet erasure networks; we compare performance of NC and EC to provide characterized information on reliability and efficiency. Recently, the advantage of coding over ARQ in a single-path tree or one hop topology has been presented [4]. However, it has yet to be identified which coding scheme is more suitable in wireless ad hoc networks, where multi-path redundancy is naturally provided. Hence we employ a grid topology as a multi-path topology and we also extend the work to a random topology to provide insights in realistic scenarios.

II. SIMULATION METHODS

Random linear coding [1] is the key technique which makes NC practical (e.g., [2]), and is applied to both coding schemes. When packets are encoded, coefficients are randomly drawn from a finite field, which is $\mathbb{GF}(2^q)$ in our simulations. A set of coefficients, which shows how the original packets are mixed, is called encoding vector. In both schemes, a source splits the stream of original packets into batches of $k$ packets; we call $k$ generation size which is 8 in this paper. We define code rate as $c=k/n$, when $k$ packets in the same generation are encoded into $n$ packets ($n \geq k$) at the source, which is specifically considered for EC. Upon overhearing a packet, each node stores the packet with its encoding vector into the local buffer. The vectors form a matrix, and the dimension of the sub-space spanned by the vectors is defined as rank. The incoming packet is considered to be innovative if the encoding vector can increase the rank of the local matrix. Each receiver is able to reconstruct the original packets once the rank reaches $k$. We assume that every node has enough local buffers, and a node forwards at most $n$ packets for one generation. In both schemes, we adopt probabilistic routing [3]. With NC, we assume that an intermediate node forwards re-encoded innovative packets with a certain probability, called forwarding probability $f(1 \geq f \geq 0)$, after receiving innovative packets. With EC, a node relays encoded packets with $f$ as long as they are not duplicates. We implement our protocols in QualNet network simulator with default 802.11b settings. To realize an erasure channel, each node drops received packets with packet drop probability $d (1 \geq d \geq 0)$.

III. PERFORMANCE COMPARISON

First, we show the results in the grid topology. As shown in Fig. 1 (a), every node except the source has $r$ redundant paths; $r$ is 3 in our simulations. The number of hops from a source to receivers is defined as $h$, i.e., $h = 3$ in the figure. Fig. 2 shows the simulation results: (a) delivery ratio with $h = 5$; (b) normalized overhead with $f = 1$; and (c) (d) delivery ratio varying $h$ and $d$. NC requires much less overhead to achieve the same delivery ratio as EC. Furthermore, since the normalized overhead grows in proportion to $h$, large multi-hop networks with EC can be easily filled up with lots of unnecessary packets. As $h$ increases, EC delivery ratio becomes worse while NC

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we briefly illustrate the results in the random topology, where the number of innovative packets depends on the code rate. Lastly, we discuss how the growth rate of innovative packets changes with the maximum number of innovative packets in the case of NC. It means that redundant paths exist, forwarding less than $k$ packets.

In (1), we find that redundant paths can directly increase the number of innovative packets. In NC, since packets are re-encoded with randomly drawn encoding vectors at intermediate nodes, we approximately consider NC to be an asymptotic model having multiple senders, each of which could generate innovative packets. In the case of EC, the redundant paths are utilized to improve the reliability, hence a parallel reliability model fashion. Let $N_{NC}$ and $N_{EC}$ denote the number of innovative packets each node can potentially receive in NC and EC respectively. Given the single-hop models, we can arrive at

$$N_{NC}(h) = \begin{cases} r(1-d)N_{NC}(h-1) & \text{if } N_{NC}(h-1) \leq k, \\ r(1-d)k & \text{if } N_{NC}(h-1) > k, \end{cases}$$

$$N_{EC}(h) = \begin{cases} (1-d)k, \\ (1-d)(1-f) \left[ 1-(1-d)N_{EC}(h-1) \right], \\ (1-d)k, \end{cases}$$

In (1), we find that redundant paths can directly increase the number of innovative packets in the case of NC. It means that each intermediate node can save network bandwidth when adequate redundant paths exist, forwarding less than $k$ packets. In addition, (2) shows that redundant paths give EC the benefit in the growth rate of innovative packets though the maximum number of innovative packets depends on the code rate. Lastly, we briefly illustrate the results in the random topology, where the number of innovative packets in the case of NC and EC respectively. Given the single-hop models, we can arrive at

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IV. CONCLUSION

In this paper, we have compared NC and EC in wireless multicast scenarios over the mobile ad hoc networks. The simulation results and the theoretical analysis demonstrated that NC can significantly save network resources to achieve the same reliability as EC. Joint coding scheme of NC and EC based on the characteristics shown in this paper is an extension of our work and under investigation.

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