Matrix Network Coding based Multicast Scheme over Wireless Multihop networks

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***Abstract*—With the explosive increase of smartphone users, multimedia-sharing applications requiring a high data rate multicast scheme over several-meters coverage range, e.g., video streaming and a smart class, are also rapidly emerging. In order to support such applications, matrix network coding based wireless multihop multicast scheme is proposed. The numerical evaluation results show that the proposed multihop multicast scheme gives significant performance improvement in the multicast rate and coverage. Moreover, the proposed scheme has good scalability to the network size, which is inherited from the property of network coding.**

I. Introduction

Digital space has penetrated through our lives in several domains rapidly with the recent explosive increase of smart mobile devices. Emerging applications in one such domain are a smart class and an e-meeting, in which it is essential to provide a high data rate multicast scheme over several meters for multimedia contents sharing. In order to satisfy humans watching the multimedia contents such as streaming video, the packet error rate (PER) of the delivered contents has to be much lower than 10% in general [1], [2]. Moreover, since such applications require high data rate and several-meters coverage, it is challenging to serve them by using a legacy multicast scheme at medium access control (MAC) layer, since it cannot guarantee the successful packet delivery.

There have been some proposed algorithms for the stable wireless multicast, which can be classified into two groups: 1) feedback/retransmission (FR) based scheme, and 2) coding based scheme. The FR based schemes can efficiently deliver missing packets and recover the multicast based on the exact status of each receiver. However, it is not scalable as the number of receivers increases. As a supplementary solution, leader based FR schemes have been proposed, but they cannot still as yet overcome their inherent limitation. Meanwhile, coding based schemes are scalable for the network size and can be flexibly applicable for any network setup in terms of topology and number of nodes. Even if they might not be adaptable for a specific network change, e.g, rate adaptation, the coding based schemes have definite benefits, when a multihop topology is considered, since a coded packet transmitted from a single node can help all nodes that need more packets. In this paper, we propose a matrix network coding based multihop multicast scheme, which provides superior error correction performance with lower complexity than linear network coding.

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II. Proposed Multihop Multicast Scheme

A. Matrix Network Coding

Matrix network coding (MNC) has been introduced as a new paradigm in network coding for network error correction, where corrections of all symbol errors are performed only at destination nodes, not at relay nodes [3]. To increase error correction capability more than linear network coding, each packet P_i is divided into q subpackets as follows:

$$P_i = [P_i(1)\ P_i(2)\ \cdots\ P_i(q)], \quad i = [1:k]$$

and jth subpackets of k incoming packets are "matrix-combined" to obtain matrix network coded packet P_o:

$$P_o(j) = \sum_{i=1}^{k} A_i P_i(j), \quad j = [1:q],$$

where A_i is a $p \times p$ randomly chosen coefficient matrix in $\mathbb{F}_m^{p\times p}$. The encoding process of MNC is illustrated in Fig. 1. For decoding matrix network coded packets at the destination

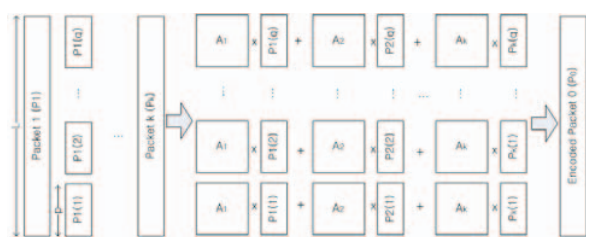

Fig. 1. Encoding process of matrix network coding.

nodes, the generalized sphere decoding algorithm described in [3] can be used, if a wireless network utilizes information from the signal level, whereas Gaussian elimination may be used, if the wireless network utilizes information only from the packet-level, e.g. WLAN.

We propose a packet-level MNC based multicast scheme as one of the optimal solutions for multicast applications over wireless multihop network by the following reasons: 1) any innovative coded packet can help all the destination nodes requiring more uncoded/coded packets for decoding, and 2) it is not necessary for the destination nodes to distinguish the coded packets transmitted by the relay nodes from the uncoded/coded packets transmitted by the source node. Thus, with a proper relay selection scheme, MNC can be extended to the multihop multicast scheme.

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B. Relay Selection for Mutihop Multicast Transmission

Rigorously the multicast rate and relay selection should be solved simultaneously for the optimal strategy. However, in this work we first consider the relay selection problem with a fixed multicast data rate based on the following reason. In general, the multicast data rate of wireless network is determined by the lowest data rate among the intended destination nodes. This simple strategy for multicast might be reasonable for the network with deterministic channel error model. However, it is not an efficient solution for the network with random channel error model corresponding a real wireless system, because random packet loss among destination nodes can generate a huge number of retransmissions. On the other hand, a coding based multicast scheme can overcome random packet erasures with a small number of redundant packets even for higher data rates. Thus, for the coding based multicast scheme, the rate selection might be relatively simple.

Our approach is as follows: 1) a source node transmits the matrix network coded packets with fixed multicast rate to the destination nodes in the single-hop range, and 2) the relay nodes within the sigle-hop range of the source node generate new matrix network coded packets and transmit to the destination nodes in the second-hop range. The said relay selection problem is formulated as follows:

$$\arg\max_i d_i$$
$$s.t. \quad p_i = P_f \quad \text{and} \quad c_i < C,$$

where d_i is the average distance from the source node to relay candidate node i which is determined by the signal measurement; p_i is the degree of freedom (DoF) of the received packets at relay candidate node i; P_f is the maximum DoF at source node; c_i is the required bandwidth by relay candidate node i; and C is the maximum bandwidth available after the transmission of the source node. Based on the proposed problem, we can select the farthest node from the source node with high probability among the nodes with the all received coded packets from the source node.

Algorithm 1 multihop multicast scheme

Input: S: source, N: destination, C: relay candidate, R: relay

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S sends relay-probe-messages to N's.
if N can decode the relay-probe-messages for all N's then
    N becomes C
S sends relay-apply-message to N's
if N is C, for all N's then
    C sends relay-response-message to S
S sends relay-selection-message to the selected C's
S starts to send data.
while Multicast data is remaining at S do
    S encodes k raw packets to m coded packets by MNC
    S multicasts m MNC coded packets to N's
    S broadcasts relay-start-message to R's
    R's re-encode and sends n MNC coded packets to N's
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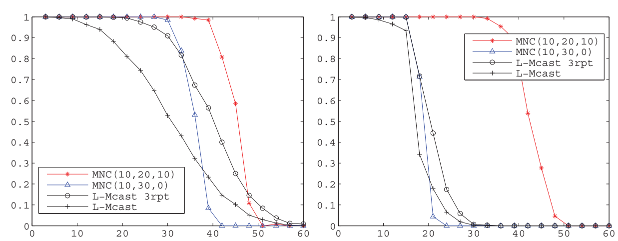
For the network operation, Algorithm 1 is proposed. First, the source node broadcasts the relay-probe-message to the destination nodes. Second, each destination node tries to decode the relay-probe-message, and the destination node that can successfully decode the message becomes a relay candidate node. Third, the source node broadcasts the relay-apply-message to the destination nodes. Fourth, each relay candidate node applies the relay node in a contention manner. Fifth, the source node selects relay nodes among the relay candidate nodes applied. Sixth, the source node starts multicast transmission and the selected relay nodes re-encode and send packets with the request from the source node. All the packets transmitted can be encoded by MNC.

III. Performance Evaluation

For the performance evaluation, IEEE 802.11g parameters are considered. Source node is located at the origin. Legacy multicast (L-Mcast), legacy multicast with three packet repetitions (L-Mcast 3rpt), MNC based multicast of code rate (10, 30, 0), and MNC based multicast with relay of code rate (10, 20, 10) are considered, where code rate (x, y, z) means that source and relay nodes send y and z MNC coded packets, respectively, which are encoded by using x original packets with coefficients over $\mathbb{F}_{2^8}^{2\times 2}$. In Fig. 2(a), line topology is considered. MNC based multicast schemes outperforms the legacy multicast with repetitions, especially for the case using relay at 18m. Much critical results can be expected for the case with Shadowing in Fig. 2(b). We assume that nodes behind 21m from the source are Shadowed with average 10dB. In such case, without relay no other scheme cannot transmit the multicast packets nodes behind 21m.



(a) Line topology (b) Line topology with Shadowing

Fig. 2. Two scenarios with four schemes: L-Mcast, L-Mcast 3rpt, MNC (10,30,0) without relay, MNC(10,20,10) with relay.

IV. Conclusion

In this paper, we propose a MNC based multihop multicast scheme, and it shows significant gain in terms of the transmission coverage compared to the legacy multicast. The proposed scheme can be efficiently applied to the emerging multimedia contents sharing applications.

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