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# COMPARISON OF NETWORKCODING TECHNIQUES FOR SINGLE AND MULTIHOP MULTICAST SYSTEMS

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**Abstract-** *A wireless/wired network suffers from multiple communication overheads to ensure the reliable transmission. To reduce network overhead and communication cost, a technique named Network coding is introduced in unicast, multicast and broadcast applications. Some of the transmission approaches have been specially designed for single-hop, two-hops or multi-hop networks. Starting from the use of network coding in wired networks to increases the throughput, it has also being used in wireless networks to solve the issue of link diversity. This paper explores the work in multicast network coding in both general wireless network and WSNs on the basis of their Features, Intents, applications areas, coding type and network topology.*

***Key words:*** *Network coding, wireless networks, wireless sensor networks, inter-session, intra-session, broadcast, multicast.*

## 1. Introduction

With the increasing demand of communication services, wireless networks are becoming more popular now a day. Due to the broadcast nature of wireless links, correlations and interference among the links, links diversity and their lossy behavior, the overall performance of the network decreases. To address the reliability problem, the concept of feedback messages was used by the sender to know which packets need to be retransmitted. But these messages also use network bandwidth, therefore intra session network coding is proposed in which packets of the same session (source) are coded together. To reduce redundant transmissions and to improve the network performance, multiple unicasts sessions are combined into a single broadcast. Consider an example of Fig.1, node S needs to deliver packet *ni* to each neighboring node *Di*. If each *Di* has overheard all the other packets except *ni*, node S can code (by XOR-ing) all the packets together and broadcast the resulting coded packet, from which every *Di* can recover its desired *ni*.

In general, an inter-flow coding system consists of three components: path selection, coding opportunity discovery, and packet forwarding. The path selection component is responsible for selecting data delivery paths for flows. Coding opportunity discovery is responsible for deciding, for each node on the path of one or more flows, whether the node will perform coding, decoding, or simply packet forwarding for the flow(s). Packets transmitted in the network can be either plain packets or coded packets. A plain packet is an (uncoded) packet as sent by the source node. A coded packet is a bit-wise XOR of a set of plain packets from distinct flows, denoted as $e = n1 \oplus n2 \oplus n3 \oplus \ldots\ldots nk$, where each $ni$ is a plain packet.

The rest of the paper is organized as follows. We provide the related work in Section 2. In Section 3, system mode is described in which an overview of the interflow coding system for single and multihop system is explained. Section 4 classifies the various network coding techniques and in section 5 Batch transmissions in two of the Network Coding Methods, More and Pacifier are differentiated. Section 6 concludes the paper and summarizes some Network Coding Methods especially for Multicast Applications.

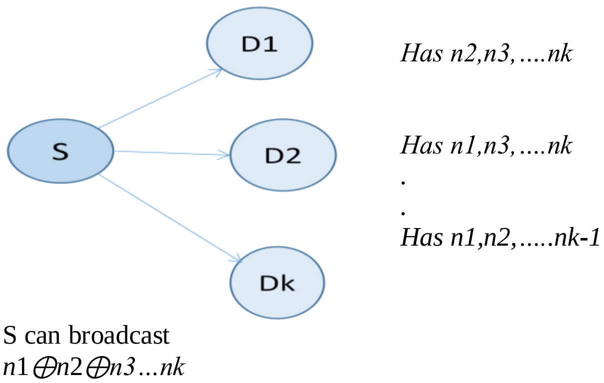
## 2. Related work

In [1] the authors proposed random linear network coding in unicast and multicast applications for multi hop networks. Although it was designed for improving the network throughput over lossy links, but was not suitable for WSNs and it creates congestion problem. In [2] solution to a unique multicast problem called crying baby is designed to handle the worst condition when the number of flows are increasing. Moreover if one of the receivers has a poor connection, then trying to satisfy reliability for this receiver may result in throughput degradation for the other receivers also.[3] limits the congestion problem of [1] by a round robin approach specially for WSNs. It reduces the forwarded nodes to the nodes of multicast tree only so that throughput can further be enhanced. In [4] the authors addressed the NC-based opportunistic routing problem for multicast in WSNs. This approach does not need any explicit knowledge about the correlation among links and channel conditions. To reduce the number of feedback messages and delayed feedback, the authors used coded feedback messages along with the coded packets. The proposed inter-sessions network coding approach in [5] is for the delay-tolerant network. In this the relay nodes immediately forward the received packets and do not postpone the transmission till the reception of more packets.

## 3. SYSTEM MODEL

In this section, a general model for inter-flow coding systems[6] is presented and details of the packet forwarding and coding component, which is the target of pollution attacks is discussed.

### 3.1 Inter-flow Coding System Overview



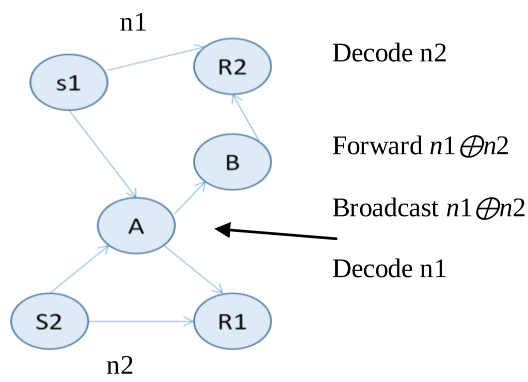




**Fig. 1 : Single Hop coding System**

**Fig.2: Multi Hop coding System**

Nodes on the path of one or more flows can be classified as forwarding, coding, or decoding nodes. A forwarding node simply forwards received coded/plain packets unmodified to its downstream node. For example, in Fig. 3 node B acts as a forwarder for the flow from source S2 to receiver R2. A coding node is a node that lies at the intersection of two or more flows. It codes received packets from the different flows into a single coded packet, which it broadcasts to the downstream nodes. For example, in Fig.2 node A is on the flows from S1 to R1 and from S2 to R2. After receiving $n1$ and $n2$, node S produces a coded packet e = $n1 \oplus n2$ and broadcasts it to R1 and B for both flows. A decoding node decodes a received coded packet by XOR-ing it with previously overheard plain/coded packets. For example, in Fig.2 node R1 decodes e = $n1 \oplus n2$ by using the overheard packet $n2$ to compute $e \oplus n2$ and recover $n1$. A decoding node may also perform partial decoding which results in another coded packet. For example, if a node receives a coded message e1 = $n1 \oplus n2 \oplus n3$ and overhears $n1$, the node can perform a partial decoding of e1 by computing $e1 \oplus n1$ to obtain another (more simple) coded packet e2 = $n2 \oplus n3$.

### 3.2 Coding Conditions

A key component of an inter-flow coding system is the coding condition being utilized, which decides the set of packets can be coded (XOR-ed) together at a node for transmission. Intuitively, in an inter-flow coding system, a node can code a set of packets for different flows to produce a single coded packet for broadcast transmission if and only if the downstream nodes will have the necessary packets to recover, from the coded packet, the respective plain packets for their flow.

***3.2.1 Single-hop coding systems.*** Single-hop coding systems represent a basic form of inter-flow coding in which the coding condition at a node is only checked among its one-hop neighbors. More formally, in a single-hop coding system, to transmit k plain packets n1,n2,…….nk to k next-hop nodes, a node can transmit a coded packet e = $n1 \oplus n2 \oplus$…... nk only if each intended next hop has all the k-1 packets $n_j$ for $j \neq i$ (see Fig.1). Although single-hop coding systems use only a subset of the possible coding opportunities allowed by the general coding condition, they have the benefit of a simple system design. Examples of single-hop coding systems include [7], [8], [10], [11], [14].

***3.2.2 Multi-hop coding systems.*** Multi-hop coding systems use coding opportunities for increasing coding performance across the multiple hops. In a multi-hop coding system, to send k plain packets, n1,n2,……nk for k flows, a node can transmit a coded packet e = $n1 \oplus n2 \oplus$…….. nk only if for each flow fi, the union of all the plain packets recoverable at the downstream nodes contains all the k-1 packets $n_j$ for $j \neq i$. For example, in Fig.2, node A can code packets n1 and n2 together, since R1 and R2 (two hops away) have overheard necessary packets to decode the coded packet. Examples of multi-hop coding systems include [9], [12].

## 4. Classification of Network coding

Network coding can be classified from different point of views depending upon the type of networks and type of transmissions required. One view is as binary coding and Random Linear (RL) coding. In binary coding, XOR operations are performed between the packets. Whereas in random linear coding, the relay nodes create coded packets. From another view, network coding can be classified as local or global coding. In local network coding, a relay node sends the coded packets such that the next hop nodes are able to decode these coded packets. Then, the next hop nodes decode the coded packets and use the same policy to code the packets. Therefore, in a multi-hop transmission, hop-by-hop coding and decoding is performed. In contrast, in global network coding, the intermediate nodes do not perform decoding; they just code the coded packets again. At the end, when the destination nodes receive enough packets, they will be able to decode them. Usually, local network coding protocols use XOR coding, and global protocols perform random linear coding.

## 5 Network Coding Methods for Multicast Applications

Opportunistic routing is an efficient way to address packet loss in wireless networks in which there is no specific path from the source to the destination, and any node that overhears the packet can relay it. The source node divides the packets to be transmitted in batches of k packets. The source node keeps on sending coded packets over a finite field. When the intermediate node receives the coded packet, it checks if the coded packet is linearly independent to the previously received packets, it adds the packet to its buffer. Each intermediate node generates linear combinations of the packets in its buffer and sends the coded packets to the next hop. The destination node can decode all of the packets of the batch when it receives k linearly independent packets. In this case, the destination node sends feedback to the source to stop sending the packets.

**5.1 MORE:** An opportunistic routing method which utilizes random linear network coding for unicast and multicast applications was proposed in [1]. Here the file is divided by the source node into batches of *k* uncoded packets, called *native packets*. Then random linear (RL) combination of the native packets in the current batch is created, and coded packets are broadcasted. MORE uses ETX (expected number of transmissions) to compute the forwarder list. The forwarder list is created by the source node. All the nodes which are closer to the destination node (in term of the ETX metric) are included in forwarder list. Innovative packets are those which contains some new information. When a forwarder node receives an innovative packet, it is accepted otherwise the packet is rejected or ignored. When the destination node receives *k* linearly independent packets, it can decode the whole batch. Some changes were made in this MORE approach for multicast applications. Firstly, the list of forwarded nodes is not selected in the same as in unicast system, rather it is the union of the forwarders of unicast flow. Also the source node proceed to the next batch after the receival of packets by all the destinations of the current batch. Along with this, the TX credit (transmissions credit) at each forwarder node is the maximum of the required transmissions for different unicast flows in the multicast group. The last modification is that the list of forwarder nodes is recomputed when the source node receives a feedback message from the destination node.
Two major problems were resulted in the modified MORE for multicast applications. First is congestion problem due to too many nodes acting as forwarder node. This results in increasing the number of flows which in turn worsens the situation. Next, throughput degradation due to satisfying the reliability of the receivers having a poor connection. This is called crying baby problem.

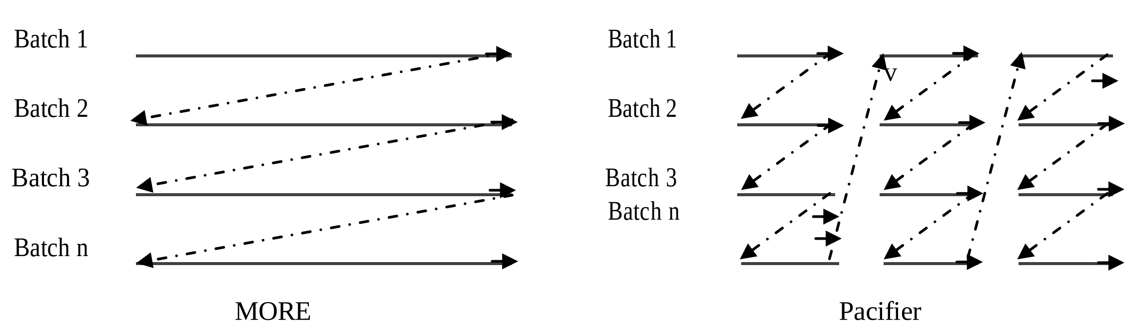



**Fig. 4: Order of batches transmission in MORE and Pacifier**

**5.2 Pacifier approach** was introduced to solve the problems of MORE approach. It is a multicast tree based opportunistic routing design. Here shortest-ETX (expected number of transmissions) is build up by the source node tree by taking the union of all of the shortest-ETX paths from the source to the receivers. The source node reconstructs this tree when a receiver node receives the complete batch. Only the nodes in multicast tree can be the forwarder nodes. Here it is different from the MORE approach where every node with a greater ETX value can be the next-hop.
The crying baby problem of MORE was solved by Pacifier approach. As we know in MORE the source node proceed to the next batch after the receival of packets by all the destinations of the current batch whereas in Pacifier approach, the source node moves to the next batch after any of the receivers send the acknowledgement of receiving the current batch. This is known as round robin pattern followed by Pacifier approach. Because of this reason pacifier is also suitable for WSNs whereas MORE was not. Figure 4 describes the order of transmitting the packets by the source node in the MORE and Pacifier approaches.

**Table 1.1 Differences among More and Pacific network coding methods**

| MORE | PACIFIER |
|---|---|
| Intra session network coding | Intra session network coding |
| Topology: Multihop | Topology: Multihop |
| Suffered from Crying Baby problem | Crying baby problem was solved |
| Congestion problem due to too many nodes acting as forwarder nodes. | Congestion problem solved by limiting the forwarder nodes to the nodes of multicast tree only. |
| Sending pattern of MORE resulted in throughput degradation. | Sending pattern of Pacifier was modified to solve the problem of throughput degradation. |
| Source node can only move to the next batch if all the destinations receive the packets in current batch. | Round robin approach was followed i.e. source node move to the next batch after any of the nodes send the acknowledgement of receiving the current batch. |
| Not suitable for WSN networks. | Suitable for WSNs networks. |

## 6. Conclusion

In this paper, we studied some of the network coding approaches for wireless and WSNs. In general, network coding methods can be classified as inter-session or intra-session network coding approaches. Some of the proposed inter-session network coding approaches allow mixing the packets from different sessions to solve the bottleneck problem. We also reviewed intra session network coding methods, which use the diversity of the links and mix the packets from the same sessions to solve the packet loss problem. These techniques are specially designed for increasing the network throughput in lossy networks by using RL and Global coding methods.

**Table 1.2 Differences among various Network Coding methods for multicasting**

| Approach | Feature | Intent | Type of Packet Mixing | Coding Type | Topology | Nature of Links |
|---|---|---|---|---|---|---|
| [1] MORE | Provides opportunist routing without network coordination, Exploits opportunism inherent in the wireless medium and mixes packet before forwarding. | Throughput increase | Linear from Same sessions | Random linear and Global | Multihop and multicast | Lossy |
| [3] pacifier | Addresses crying baby problem | Throughput increase | Linear from Same sessions | Random linear & Global | Multihop and multicast | Lossy |
| [4] distributed algorithm | Adapts to the changes in the channel conditions, Resolve the problem of | Throughput increase | Linear from Same sessions | Random linear and Global | Multihop and multicast | Lossy |

| | | | | | | |
|---|---|---|---|---|---|---|
| | delayed feedback by performing NC on feedback messages | | | | | |
| [12] CCACK Cumulative acknowledgement scheme | Enables an efficient credit based rate control algorithm, Allow nodes to acknowledge NC traffic to their upstream nodes, | Throughput increase | Linear from Same sessions | Random linear and Global | Multihop and multicast | Lossy |
| [13] IANC & IRNC | Achieves performance metrics with lower complexity | Throughput increase | RL coding from same or different sessions | Random linear & global | multihop | Perfect |

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