Minimal Coding Network With Combinatorial Structure For Instantaneous Recovery From Edge Failures

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***Abstract*-Protecting nodes against link failures in communication networks(both unicast and multicast) is essential to increase robustness, accessibility, and reliability of data transmission. The use of network coding algorithm offers, establishing reliable unicast connections across a communication network with non-uniform edge capabilities. The Proposed System addresses the task of multicast communication using using the concept of network coding in the presence of passive eavesdroppers and active jammers. Despite the complexity introduced by distributed network coding, recently, it has been shown that this rate can also be achieved for multicasting to several sinks provided that the intermediate nodes are allowed to re-encode the information they receive.**

Index Terms- Instantaneous recovery, network coding, reliable communication, unicast,multicast.

I.INTRODUCTION

In today's practical communication networks such as the Internet, end-to-end information delivery is performed by routing, i.e., by having intermediate nodes store and forward packets. Note though, routing does not encompass all operations that can be performed at a node.The issue of reliably transporting data from a single original source to multiple interested recipients, particularly when the receiver set is large, is one of growing prominence .

Recently, the notion of network coding arises as a very important promising generalization of routing.Network coding refers to a scheme where a node is allowed to generate output data by encoding (i.e., computing certain functions of) its received data. Thus, network coding allows information to be “mixed", in contrast to the traditional routing approach where each node simply forwards received data. Potential advantages of this generality of network coding over routing are many fold: resource efficiency, computational efficiency, and robustness to network dynamics.Network coding is potentially applicable to many forms of network communications. Up to now, the best understood scenario where network coding offers unique advantages is multicasting in a communication network.

A significant effort has been devoted to improving the resilience of communication networks to failures and increasing their survivability. Edge failures are frequent in communication networks due to the inherent vulnerability of the communication infrastructure. With the dramatic increase in data transmission rates, even a single failure may result in vast data losses and cause major service disruptions for many users. Accordingly, there is a significant interest in improving network recovery mechanisms that enable a continuous flow of data from the source to the destination with minimal damage in the event of a failure.

Edge failures may occur due to several reasons, such as physical damage, misconfiguration, or a human error. Networks are typically designed to be withstand against a single edge failure. Indeed, protection from multiple failures incurs high costs in terms of network utilization, which is usually not justified by the rare occurrence of such failures. we considered the problem of establishing reliable unicast (single-source single-destination) connections across a communication network with nonuniform edge capacities. Our goal is to provide instantaneous recovery from single edge failures. Here focus on two cases of practical interest:

1) Backup protection of a single flow that can be split up to two subflows; and

2) shared backup protection of two unicast flows.

The instantaneous recovery mechanisms ensure a continuous flow of data from the source to the destination node, with no interruption or data loss in the event of a failure. Such mechanisms eliminate the need of retransmission and rerouting. Instantaneous recovery is typically achieved by adding redundant packets and by routing packets over multiple paths in a way that ensures that the destination node can recover the data it needs form the received packets. Instantaneous recovery is typically achieved by adding redundant packets and by routing packets over multiple paths in a way that ensures that the destination node can recover .

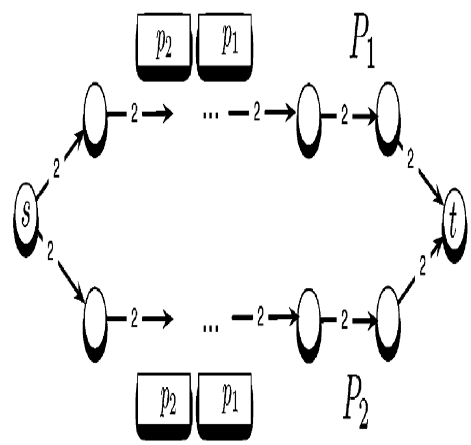

Fig.1. Dedicated path protection method

There are several techniques to achieve instantaneous recovery. A standard approach is to use the 1+1 dedicated path protection scheme . This approach requires provisioning of two disjoint paths p1 and p2 between s and t. Each packet generated by the source node is sent over both paths, p1 and p2(Fig. 1) . In the case of a single edge failure, at least one of the paths remains operational, hence the destination node will be able to receive the data without interruption. With this scheme, both p1 and p2 must be of capacity at least h . Single edge failure, at least one of the paths remains operational, hence the destination node will be able to receive the data without interruption. With this scheme, both p1 and p2 must be of capacity at least h . While the dedicated path protection scheme is simple and easy to implement, it incurs high communication overhead due to the need to transmit two copies of each packet. The dedicated path protection scheme is simple and easy to implement, it incurs high communication overhead due to the need to transmit two copies of each packet. In addition, it requires the existence of two disjoint paths, each of capacity h between s and t.

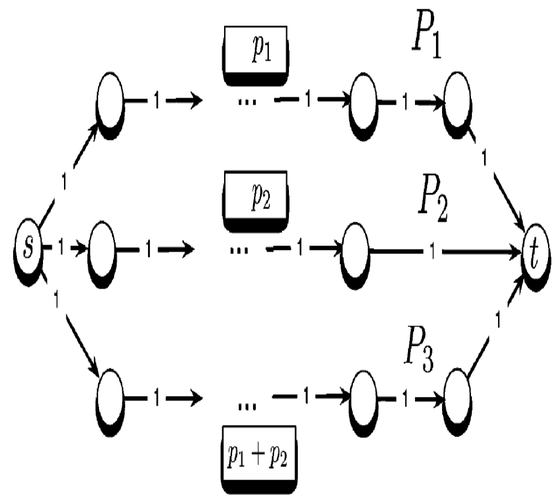

Fig.2. Diversity-Coding method for h=2.

The diversity coding technique extends the dedicated path protection scheme by using multiple disjoint paths for sending the data. This technique can be used for protecting a single unicast connection or for shared backup protection of two or more unicast connections (Fig.2). In the case of a single unicast connection, the information flow is split into two or more subflows, and each subflow uses a separate path to reach the destination.

some examples shows a diversity coding scheme that uses three disjoint pathsP1, P2, and P3 of capacity one between s and t to protect a unicast flow of rate two packets per communication round. In this example, the flow is split into two subflows that use paths P1 and P2 to send data to the destination, while path P3 serves as a shared backup protection for these subflows.

The network coding approach generalizes both the dedicated protection and the diversity coding approach. In particular, it enables shared backup protection of multiple unicast connections and does not require multiple link-disjoint paths between the source and destination nodes. The network, edges (s,v1) and (s,v2)are of capacity two, while all other edges are of unit capacity. Our goal is to establish a unicast connection that delivers two packets from s to t per communication round.

Thus this paper includes a robust network code for both unicast and multicast networks can be established through the standard network coding algorithm.by dividing the simple network into blocks ,it is possible to route the packets efficiently in the case when h=2 and also when h>2.some improvements on the existing network coding algorithm is done for efficiently handling the above mentioned functionalities. We also address the problem of efficient allocation of network resources for a robust coding network.

Related work

The network coding technique has been introduced in the seminal paper of Ahlswede et al. [3]. Initial work on network coding has focused on multicast connections. It was shown in [3] that the maximum rate of a multicast network is equal to the minimum total capacity of a cut that separates the source from a terminal. This maximum rate can be achieved by using linear network codes [8]. Ho et al. [9] showed that the maximum rate can be achieved by using random linear network codes. Jaggi et al. [10] proposed a deterministic polynomial-time algorithm for finding feasible network codes in multicast networks. They showed that if the network has a sufficient capacity to recover from each failure scenario (e.g., by rerouting) then instantaneous recovery from each failure scenario can be achieved by employing linear network codes.

A. Our contribution

In this paper we propose efficient algorithms for construction of robust network codes over small finite fields. We consider two major cases. In the first case, we assume that all edges of the network have uniform capacity, while in the second case the capacity of network edges can vary. For the first case we present an efficient network coding algorithm that identifies a robust network code over a small field. The algorithm takes advantage of special properties of Maximum Rank Distance (MRD) codes [13]. For the second case, we focus on settings in which the source node needs to deliver two packets per time unit to all terminals. We show that in this case, a special topological properties of robust coding networks can be exploited for constructing a network code over a small finite field.

II MODEL

A. Multicast Network

A multicast network N that uses a directed acyclic graph G(V,E) to send data from source s to a set T of k destination nodes {t1, . . . , tk} □ V . The data is delivered in packets. We assume that each packet is an element of a finite field Fq = GF(q). We also assume that the data exchange is performed in rounds, such that each edge e □ E can transmit c(e) packets per communication round. We assume that c(e) is an integer number and refer to it as the capacity of edge e. At each communication round, the source node needs to transmit h packets R = $(p1, p2, \ldots, ph)^T$ from the source node s □ V to each destination node t □ T. We refer to h as the rate of the multicast connection. It was shown in [3] and [8] that the maximum rate of the network, i.e., the maximum number of packets that can be sent from the source s to a set T of terminals per time unit, is equal to the minimum capacity of a cut that separates the source s from a terminal t □ T. Accordingly, we say that a multicast network N is feasible if any cut that separates s and a terminal t □ T has at least h edges. We say that a coding network N is minimal if any network formed from N by removing an edge or decreasing the capacity of an edge is no longer feasible. It is easy to verify that the capacity of each edge in a minimal network is bounded by h.

B. Coding Networks

For clarity of presentation, we define an auxiliary graph ˆG(V,A) formed by the network graph G(V,E) by substituting each edge e □ E by c(e) parallel arcs that have the same tail and head nodes as e; each arc can transmit one packet per communication round. We denote by A(e) □ A the set of arcs that correspond to edge e. In what follows we only refer to packets sent at the current communication round. The packets sent in the subsequent rounds are handled in a similar manner.

C. Robust Coding Networks

Since a failed edge e cannot transmit packets, we assume that the encoding function fa of each arc a □ A(e) is identically equal to zero, i.e., fa ≡ 0. To guarantee instantaneous recovery, it is sufficient to ensure that for each edge failure there exists a set of h linearly independent packets received by t. We distinguish between two types of robust networks codes. In strongly robust network codes the local encoding coefficients of all arcs in A remain the same, except for the arcs A(e) that correspond to the failed edge e which are assigned zero encoding coefficients. In weakly robust network codes, the arcs that are located downstream of the failed edge e are allowed to change their encoding coefficients, while all the encoding coefficients that correspond to other edges must remain the same.

III. STRONGLY ROBUST CODES FOR NETWORKS WITH UNIFORM CAPACITIES

All edges are of the network have uniform capacity c, i.e., each edge can send exactly c packets per time unit. We present an efficient algorithm that can construct a robust network code over a finite field of size O(k). We observe that without loss of generality, we can assume that the capacity of each edge is one unit. Indeed, a feasible network code for unit capacity edges can be extended into the case in which the capacity of each edges is equal to c by combining c communication rounds into a single round. In [10] it was shown that communication at rate h with instantaneous recovery from single edge failures is possible if and only if for each edge e □ E, it holds that the network G'(V',E') formed from G(V,E) by removing e, contains at least h edge-disjoint paths from source s to each terminal node t □ T. This implies that a necessary and sufficient condition for the feasibility of network N is the existence of h+1 edgedisjoint paths between s and each t □ T.

Our approach can be summarized as follows. First, we generate a special parity check packet, referred to as ph+1. This packet is a linear combination of the original packets and is constructed as described in Section III-A. Then, we use a standard network coding algorithm due to Jaggi et al. [10] for sending ˆR = {p1, p2, . . . , ph, ph+1} packets from s to T. The standard algorithm will treat the packets in ˆR as generated by independent random processes. The algorithm ensures that in the normal network conditions, each destination node receives h + 1 independent linear combination of the packets in ˆR. The following lemma shows that after a single edge failure, each destination node receives at least h linearly independent combinations of packets in ˆR.

Lemma 1: Upon an edge failure, each terminal t T receives at least h linear combinations of packets in ˆR.
Proof: Since we assume that all edges are of unit capacity, each edge in the network can be represented by a single arc. For each arc a A we define the *global encoding vector* that captures the relation between the packet pa transmitted on arc a and the original packets in ˆR:

$$p_e = \sum_{i=1}^{h+1} \mathrm{p}_{\mathrm{i}} \cdot \gamma_i^{\mathrm{e}}$$

Let t be a terminal in T. We define the transfer matrix Mt that captures the relation between the original packets R and the packets received by the terminal node t T over its incoming edges.

A. Creating parity check packet

Lemma 1 implies that in the event of any single edge failure, each terminal node receives at least h independent linear combinations of the packets in {p1, p2, . . . , ph, ph+1}. Since packet ph+1 is a linear combination of h original packets R = {p1, p2, . . . , ph}, each destination nodes receives, in fact, h linear combinations of R. Accordingly, our goal is to construct packet ph+1 in such a way that each destination node receives h independent linear combinations of R. This will allow each destination node to decode the original packets. For clarity of presentation we first focus on the case of h = 2. In this case we have two original packets, p1 and p2, and one parity check packet p3 = γ1·p1+γ2·p2. Suppose that a terminal t T receives two linearly independent combinations of p1, p2, and p3.

B. General case

We turn to consider a more general case of h > 2. Since we need to only recover from a single failure, we need to find a (h + 1, h) MRD code. For this case, we can use the parity check matrix [13]:

$$H = \alpha, \alpha^2, \ldots \alpha^h, 1$$

over the field GF(qh+1), with

$$p_{h+1} = -\sum_{i=1}^{h} \alpha^i p_i$$

We summarize our results by the following theorem:
Theorem 1: The proposed scheme achieves an instantaneous recovery from any single edge failure.
Proof: Follows directly from the properties of MRD codes [13].

IV. NETWORK WITH NON-UNIFORM CAPACITIES

The different network edges have different capacities. We focus on a special case in which only two packets need to be delivered from the source to all terminals at each communication round. The design of robust network codes for h = 2 in the context of unicast connections has been studied in [11]. In this work, we build on the results of [22] for constructing a robust network code for multicast connections. Let G(V,E) be a minimum robust coding network, i.e, a feasible robust network such that the removal of an edge or a reduction in the capacity of an edge results in a violation of its feasibility. Note that the capacity of any edge e E is at most two. For each terminal t T let Gt(Vt,Et) to be a subgraph of G(V,E) that contains a minimum coding network with respect to terminal t. That is, Gt(Vt,Et) only contains edges of G(V,E) that are necessary to guarantee the conditions defined by Equation 1 for terminal t. Furthermore, any reduction of the capacity of edges in Gt(Vt,Et) will result in a violation of this condition for at least one of the (s, t) cuts.

V. CONCLUSION

This paper addressed the problem of constructing robust network codes for unicast networks, i.e., codes that enable instantaneous recovery from single edge failures. There is need to obtain the same results for multicast connections also. But the networks where the achievable rates obtained by coding at intermediate nodes are arbitrarily larger is not allowed. An efficient network coding algorithm based on the MRD codes that requires a small finite field O(k)can be used. For the case of nonuniform capacities, we focused on a special case of h = 2 and showed that it is also possible to construct a robust code over a small field. Future research includes the construction of network codes with non-uniform capacities and transmission of more than two packets per communication round.

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