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Minimizing Transmission Cost and Efficient Routing for Third-Party Information Exchange with Network Coding

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***Abstract*— Generally in wireless network, it is lucrative for the node to have the knowledge about channel gain or the link loss probability known as channel state information (CSI). The knowledge of CSI not only comprise all the needful information required for the network design but also enhances the performance of the system and mitigate network optimization to a great extend. The main aim of third-party information exchange is to create standard and effective algorithms to equip all the nodes to gain complete global information by exchanging packets between them. To improve the efficient routing, we can implement AODV routing protocol. So that every node is provided with a pair of public and private keys. These modes must exchange and verify the keys before the commencement of transmission. If the key exchange between nodes fails, then the transmission should be terminated. In this work we propose a network-coded third-party information exchange scheme, which stress on reducing the total cost for exchanging CSI among the nodes and improve efficiency.**

Index Terms— Channel State Information, Cooperative Data Exchange, Wireless Networks, Network Coding,

I. INTRODUCTION

Wireless networks are computer networks that are not connected by cables of any kind. The use of a wireless network enables enterprises to avoid the costly process of introducing cables into buildings or as a connection between different equipment locations. The basis of wireless systems is radio waves, an implementation that takes place at the physical level of network structure. Wireless networks use radio waves to connect devices such as laptops to the Internet, the business network and applications. When laptops are connected to Wi-Fi hot spots in public places, the connection is established to that business's wireless network.

Network coding is a networking technique in which transmitted data is encoded and decoded to increase network throughput, reduce delays and make the network more robust. In network coding, algebraic algorithms are applied to the data to accumulate the various transmissions. The received transmissions are decoded at their destinations. This means that fewer transmissions are required to transmit all the data, but this requires more processing at intermediary and terminal nodes. In traditional routing networks, packets are cached and forwarded downstream. Therefore, if a routing node receives two packets from two sources it forwards them one after another, and queues the others in the meantime, even if both are headed for the same destination. This requires separate transmissions for each and every message delivered, which decreases network efficiency. In network coding, algorithms are used to merge those two messages and the accumulated result is forwarded to the destination. After receiving the accumulated massage, it is decoded at the destination using the same algorithm..

The problem, referred to as "third-party information exchange", was first proposed in [1], [2]. The objective of third-party information exchange is to develop deterministic and efficient algorithms to enable all the nodes to obtain the complete global information by exchanging packets among themselves. Closely related to the problem of third-party information exchange is the problem of cooperative data exchange [3], [4]. In cooperative data exchange, each node is assumed to initially hold a subset of packets, and the objective is to ensure all the Helpful nodes will eventually obtain the whole set of packets by cooperatively exchanging data between themselves, over a lossless common broadcast channel [3]. The only difference between cooperative data exchange and third-party information exchange is the initial information held by the nodes. In the former, the initial subsets can be arbitrary, with or without much overlapping between nodes. In the latter, the information initially possessed by each node must and will only include the channel information from all of its neighbors to itself, and, with the assumption of channel reciprocity, each pair of neighboring nodes share only one piece of common information, and the shared information is different for every pair. Hence, the problem of third-party information exchange presents a special case of the general problem of cooperative data exchange.

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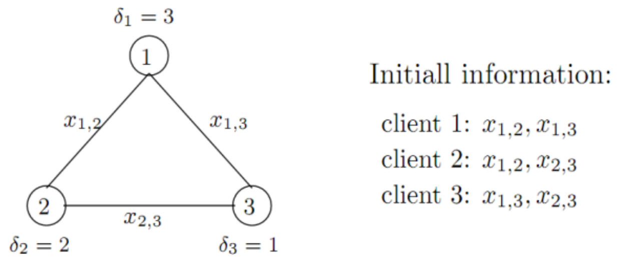

Fig. 1 Third-party information exchange among three clients

The rest of the paper is organized as follows. Section II presents the related works and problem description. Section III proposed the third-party information exchange problem as an integer linear programming problem. Section IV proposes an implementation and evaluates its performance of the proposed transmission schemes. Finally, we conclude the paper in Section V.

II. Related Works

Network coding, a cross-layer technology that was initially developed for static (wire line) networks [5], [6], has received extensive research attention in wireless community, due to its significant benefits in improving wireless performance [7], [8] including throughput, reliability and etc. Recent studies show that network coding can also help reduce the number of transmissions or the transmission delay/cost for general cooperative data exchange [9], [10], [11]. However, finding the deterministic code design to achieve these limits for cooperative data exchange can be non-trivial as it needs very high field size, and the complication comes, in part, from the very general setup of cooperative data exchange. In comparison, instances of third-party information exchange present better opportunities for analytical and algorithmic tractability.

An earlier study of third-party information exchange [1] demonstrated the existence of optimal solutions, where the optimality is measured in terms of minimizing the total number of transmissions. Since each node/device may be associated with a different transmission cost, e.g., different battery cost at the nodes, our previous work [12] extended the study by adding "weights" to transmissions, and tried to minimize the total transmission costs consumed for third-party information exchange.

The third-party information exchange was studied in [1], [12]. Specifically, the work in [1] presents an optimal solution with minimum number of transmissions, and designs a deterministic coding based on GF (2). Our previous work [12] extends the study by adding "weights" to transmissions of each node, and tries to minimize the total transmission costs consumed for third-party information exchange. An optimal solution based on ILP is designed and the performance of random linear network coding is analyzed. However, the solution based on ILP needs to know the global information of transmission costs of the nodes. Based on the previous work, in this paper, we further propose two deterministic transmission schemes, which can be implemented in a distributed manner and are optimal under two specific settings. In addition, a deterministic code is designed to support the proposed schemes.

A. *Problem Description*

Consider a network with N nodes in C = [c_1; c_2; ... ; c_N] g, where each node c_i = C is associated with a transmission cost d_i for sending a single packet over a lossless common broadcast channel [1], [3]. Let $x_{i;j}$ be the CSI (e.g., channel gain, link loss probability or delay) of the link between node ci and node c_j.

The network-coding-based information exchange scheme involves distributed encoding and distributed decoding at all the nodes. To facilitate packet exchange, each node c_i generates a set of y_i encoded packets over a finite Galois field (GF) based on its initial information possession X_i.

III. Centralized Optimal Solution For Third-Party Information Exchange

This section will first formulate the problem of third-party information exchange with minimum transmission cost as an integer linear programming problem. Then, we derive some theoretical results which will be used in the following sections.

A. *Mathematical Formulation of the Proposed Problem*

Based on our previous work [12] and the work in [13], we can get the necessary and sufficient condition of third-party information exchange problem as follows.

Theorem 1. There exists a code design that enables any node to decode all of its desired packets, if any cardinality k subset there exists

$$\sum_{Ci\in C} yi \geq (k/2)$$

Based on Theorem 1, we can obtain the following three corollaries, which will be used in the following proofs. Corollary 1. To minimize the total transmission cost, the number of packets sent by the node with a lower transmission cost should be no less than the node with a higher transmission cost. The proof follows directly from the symmetry of the network. Suppose in a feasible coding scheme, node c_i has a higher transmission cost than node cj and transmits more packets than cj. Then we can transform this coding scheme by interchanging the index i with the index j. The results are a new feasible coding scheme with a reduced total transmission cost.

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Since we have assumed an ascending order for the transmission cost, to minimize the total transmission cost, and will get a descending order for the number of transmitted packets also confirms Corollary 1, i.e., a node with a lower transmission cost must transmit no fewer packets than the node with a higher transmission cost.

B. Deterministic Algorithms with Minimum Transmission Cost for Two Special Cases

The ILP formulated in the previous section allows us to determine the optimal number of packets to be exchanged between nodes for any solution to be feasible, but the formulation is a centralized optimization problem that requires complexity to solve it. In addition, the centralized algorithm needs the knowledge of each node's transmission cost. In what follows, we present two deterministic transmission schemes that can be performed in a distributed manner without the knowledge of the exact transmission cost of each node. We will show that these two schemes are optimal, i.e., capable of achieving the minimum transmission cost, in two specific cases.

C. The Fair Load (FL) and Proportional Load (PL) Transmission Schemes

The first transmission scheme developed here is termed the FL transmission scheme, where all the nodes will send the same number of packets, with the possible exception for the last node if there are odd numbers of nodes.

1. Definition 1 (The FL Scheme).

- Suppose the cost of transmission satisfies $\delta_1 \leq \delta 2 \leq \ldots \leq \delta_N$.
- When N is odd, any of the first (N-1) nodes, send (N-1)/2 packets, and the last mode c_N sends nothing.
- When N is even, every node send (N/2)-1 packets
- The FL scheme in Definition 1 provides a feasible solution to the third-party information exchange problem.

2. Definition 2 (The PL Scheme).

- Consider N nodes with none decreasing per node transmission cost $\delta_1 \leq \delta 2 \leq \ldots \leq \delta N$. In the PL scheme, the node c_i will transmit y_i packets
- The PL scheme in Definition 2 is a feasible solution to our third-party information exchange problem

3. Deterministic Code Design Based on GF (2)

In this section, we design a deterministic encoding strategy (based on XORs coding over GF (2)), which can be performed locally at each node and can be used in combination with the proposed FL and PL schemes to ensure the successful deduction of all the desired packets by all the nodes.

4. Definition 3 (Encoding Strategy)

Each node *ci* ϵ sends yi encoded packets. The nodes generate the encoded packets according to the following points.

- For the FL scheme with odd N and the PL scheme, the jth packet sent by ci is generated.
- Note that the above encoding operation is based only on XORs coding over GF (2). Take a network with N nodes as an example. The encoded packets, where y_i is determined by either the FL or the PL scheme.

The encoding strategy described in Definition 3 makes sure that with the FL or the PL transmission scheme, each node can finally get/decode the complete packets in X.

5. Optimality Analysis of FL, PL Transmission Scheme

From the above theorem, we can see that irrespective of the number of nodes, the condition depends only on the first two nodes c_1; c_2, and the last node c_N (assuming non-decreasing order of nodes' transmission costs). This condition has advantage of the scalability of the network in terms of its size, e.g., if a new node joins the network, and its transmission cost is more than the previous second node, then the transmission scheme need not change. It also applies if some nodes walk away from the network.

D. Distributed Transmission

The proposed distributed transmission protocol does not require the knowledge of the exact transmission costs of the nodes. Only the knowledge of the order of the transmission costs suffices. The distributed transmission protocol can be operated with FL or PL scheme as follows:

A synchronization timer is first generated independently at every node according to a predefined function, the transmission cost, and f is a strictly decreasing function that ensures that a higher transmission cost will lead to a smaller synchronization timer.

- The exact form of f may be flexible, and may be determined according to the specific system settings.
- Initially, each node sends its first packet as soon as its synchronization timer times out.

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- After the above step, every node will know the order of their transmission costs.

IV. Implementation and Performance Evaluation

evaluate the performance of the proposed transmission scheme used in combination with FL (in Definition 1) and PL (in Definition 2) in a realistic network scenario.

1. Implementation of wireless network

In this module, a wireless network is created. All the nodes are configured and randomly deployed in the network area. Since our network is a wireless network, nodes are assigned with mobility (movement). A routing protocol is implemented in the network. Sender and receiver nodes are randomly selected and the communication is initiated. All the nodes are configured to exchange the third-party information among all the nodes.

2. Performance analysis

In this module, the performance of the network after exchanging Third-Party Information is analyzed. Based on the analyzed results X-graphs are plotted. Throughput, delay, energy consumption are the basic parameters are considered here and X-graphs are plotted for these parameters.

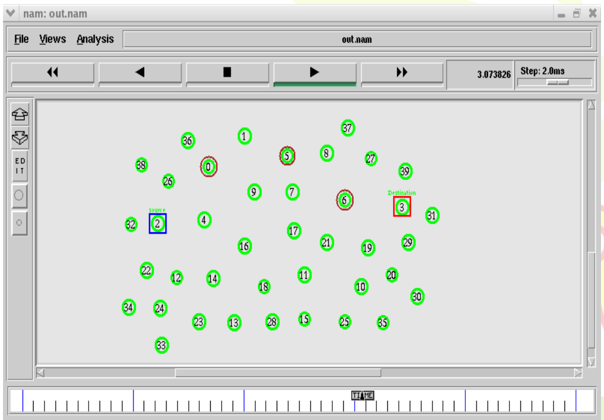

Fig. 2 NAM Window

3. Implementation of Network coding scheme

In this module, to enable all the nodes to get the global CSI, we propose a network-coded third party information exchange scheme, with an emphasis on minimizing the total transmission cost for exchanging the CSI among the nodes. The proposed encoding strategy is based on XORs coding which has very low complexity. The network-coding-based information exchange scheme involves distributed encoding and distributed decoding at all the nodes.

Table-I Transmission cost analysis

Throughput	151971.91packets/s
Delay	0.788ns/node
Energy (Used)	54% joules
Traffic with data "HELLO" packets	204 packets/ms

4. X-graph analysis

In this module, the performance of the proposed network coding method is analyzed. Based on the analyzed results X-graphs are plotted. Throughput, delay, energy consumption are the basic parameters considered here and X-graphs are plotted for these parameters. Finally, the results obtained from this module is compared with previous results and comparison X-graphs are plotted. Form the comparison result, final RESULT is concluded.

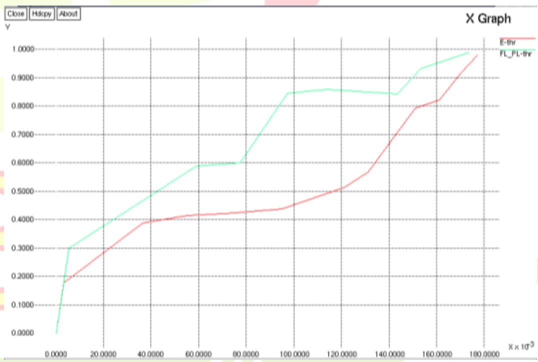

Fig. 3 Comparison of Transmission Cost of proposed Energy Minimization

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Fig. 4 Comparison of Transmission Cost of proposed Throughput

Fig. 5 Comparison of Transmission Cost of proposed Delay.

V. CONCLUSION AND FUTURE ENHANCEMENT

The network-coded cooperative information exchange scheme to minimize the total transmission cost for exchanging third-party information. A necessary and sufficient condition is first developed for the existence of the feasible solution. Formulating the problem of minimizing the total transmission cost as an integer linear programming problem, and develop useful results for feasible and optimal solutions. To have further designed two efficient transmission schemes, FL and PL schemes, and evaluated their performances for specific and randomized networks. We also construct a deterministic encoding strategy, which is based only on XORs coding over GF (2), to support FL and PL transmission schemes. A distributed transmission protocol is proposed that enables FL and PL schemes to be operated in a decentralized manner. Simulations show that the proposed PL scheme can in general perform very close to the optimal solution in practical wireless contexts.

In order to enhance the efficient routing and security further, we can employ AODV and dynamic encryption algorithms like ECC (Elliptic Curve Cryptography). Every node is provided with pair of public and private keys. Nodes must exchange and verify the keys before start the transmission. If any node exchanges false key, then it should be terminated.

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