VISVESVARAYA TECHNOLOGICAL UNIVERSITY

BELAGAVI - 590018

Project Report

on

“RELAY ASSISTED PLIABLE INDEX CODING”

Submitted in partial fulfilment of the requirements for the VIII Semester

Bachelor of Engineering

in

ELECTRONICS AND COMMUNICATION ENGINEERING

For the Academic Year

2020-2021

BY

KUSHAAL R	**1PE17EC068**
PRANEETH M KASHYAP	**1PE17EC089**
PUSHKAR PRAMOD WANI	**1PE17EC093**
SAGAR RAJ N	**1PE17EC112**

UNDER THE GUIDANCE OF

Prof. Bivas Bhattacharya

Assistant Professor, Dept. of ECE, PESITBSC

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

CERTIFICATE

This is to certify that the project work entitled "**Relay Assisted Pliable Index Coding**" carried out by "**Sagar Raj N, Pushkar Pramod Wani, Kushaal R and Praneeth M Kashyap** bearing **USN's 1PE17EC112, 1PE17EC093, 1PE17EC068 and 1PE17EC089**" respectively in partial fulfillment for the award of Degree of Bachelors (Bachelors of Engineering) in Electronics and Communication Engineering of Visvesvaraya Technological University, Belagavi during the year 2020-2021. It is certified that all corrections/ suggestions indicated for internal assessment have been incorporated in the report. The project report has been approved as it satisfies the academic requirements in respect of project work prescribed for the said Degree.

Signature of the Guide	Signature of the HOD	Signature of the Principal
Prof.Bivas Bhattacharya	**Dr. Subhash Kulkarni**	**Dr.Subhash Kulkarni**
Assistant Professor	**HOD, ECE**	**Principal, PESIT-BSC**

External Viva

Name of the Examiners **Signature with Date**

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Acknowledgements

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ABSTRACT

We consider binary multi-way relaying problem with nodes having pliable demands and present algorithms to reduce the total number of transmissions compared to naive transmissions.Demands are said to be pliable when every node is satisfied with decoding/obtaining any message it does not have, but is present with other nodes. Relays are used in scenarios where direct communication is not possible.Multi-way relaying problem consists of exchanging messages amongst multiple nodes via a relay.

We consider the case where every node has a set of messages known as its side information. We consider coding at the network layer with only two nodes transmitting at a time. The relay receives the XOR of bits transmitted by the two nodes and broadcasts the same. Our goal is to minimize the total number of transmissions such that each node receives at least t messages which it does not have apriori.

Keywords: Index Coding, Pliable Index Coding, Multiway Relaying.

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Chapter 1

Introduction

To lay the groundwork for Relay assisted pliable index coding we will first briefly describe Multiway Relaying, Index Coding and Pliable index coding.

1.1 Multiway Relaying

Relaying is essential when direct communication cannot be established. For example, a computer which needs to be connected to the Internet via cellular cannot do so since it lacks the requisite cellular modem and antennas. To counteract this problem, a cellular phone can act as a relay using the Wi-Fi protocol. Another instance where direct communication is not possible is high frequency EM waves which are easily blocked by most materials. This is the case for mm wave 5G as well as next generation cellular networks operating at high data rates. This shortcoming can be overcome using relays which have line of sight communication with the base station.

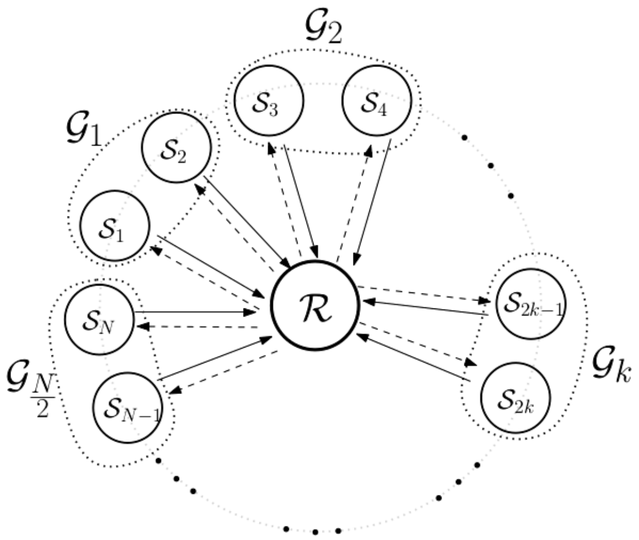

Figure 1.1: Multiway Relaying

The Fixed channel use(FCU) MultiWay relaying scheme described in [1] forms the basis of our project. It consists of N nodes having one bit messages that need to be shared with every other node. This is termed as full data exchange. This scheme guarantees full data exchange in at most N+2 channel uses(CUs) compared to 2N channel uses if conventional routing is employed. We extend this scheme to multiple packets consisting of multiple bits. We also verify through simulation that the channel use is the same for this extended scheme. Next, we discuss the motivation for relaxing the constraint of full data exchange and making the demands of the clients pliable.

1.2 Index Coding

Index coding is a scheme using which the number of transmissions by a server can be reduced. This is done by making use of a subset of the messages already present at the client known as side information. Consider the problem shown in fig 1.2. Ordinarily the server would need 3 transmissions to fulfill the requests of the client. In case of index coding, the server transmits m1+m2. Client 1 can decode m1 by subtracting m2 which it already has from the sum and obtaining m1. Client 2 can subtract m1 to obtain m2. The server then transmits m3 which satisfies client 3. Hence, the number of transmissions has been reduced to 2.

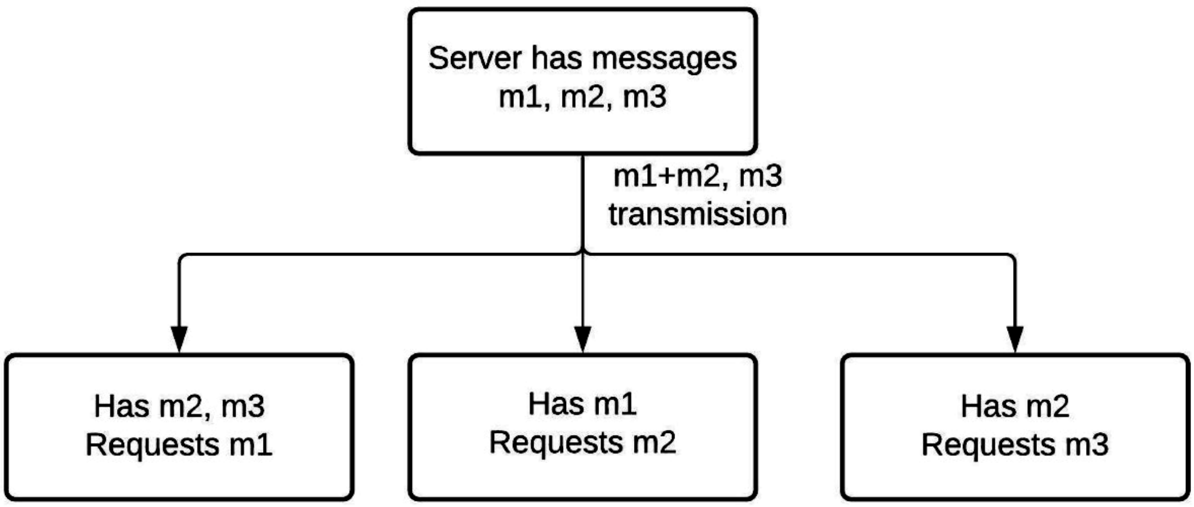

Figure 1.2: Index Coding

1.3 Pliable Index Coding

The motivation for relaxing the constraint of full data exchange is that the user generally does not request a specific file in many applications. One such example is Streaming platforms where the user might be satisfied with a movie recommendation of a similar genre which he has not already watched. Consider the problem shown in fig 1.3 where the demands of the clients have been made pliable and the clients have the same side information. The server transmits m1+m2. Client 1 can decode m1 by subtracting m2 from the sum. Similarly client 2 and 3 can decode message m2 and m1 respectively. Hence, one transmission from the server is sufficient to satisfy the three clients. This problem is termed as PICOD(t) by [2], where t is the number of packets requested by the clients.

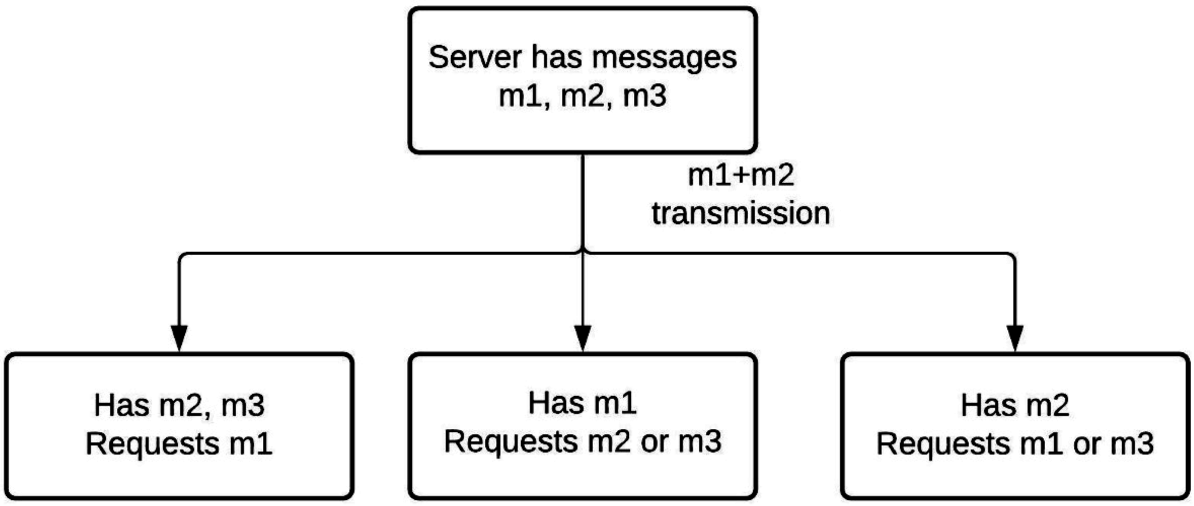

Figure 1.3: Pliable Index Coding

We make use of the FCU scheme in the relay network for the exchange of data using BPSK symbols. We apply the concept of pliable index coding introduced in [2] to a multiway relay network and analyse the performance of this network.

Chapter 2

Literature Survey

A multi stage technique for communication between multiple nodes facilitated by a relay is presented in [1]. This paper presents two schemes for full data exchange using binary multiway relaying which have lower decoding complexity, better bit error rate and are more energy efficient compared to schemes that have similar channel uses. The variable channel use(VCU) scheme reduces the number of CUs on average whereas the fixed channel use(FCU) scheme reduces the absolute number of CUs. Our project is based on the FCU scheme presented in this paper.

In [2], the concept of pliable index coding is introduced where the clients do not demand specific messages.Instead each client is satisfied if he receives any t messages that he does not already have. This results in a substantial reduction in the number of transmissions compared to full data exchange using index codes in many scenarios. The problem of finding the optimal code is proved to be NP-hard which is the same as Index coding.

In [3], a deterministic algorithm for pliable index coding is presented. This code achieves the upper bound for the code length. It is also shown that this algorithm performs better that the randomised algorithm presented in [2].

The overview of multiway relaying is presented in [4]. This paper explores the various relay models that are applicable for a wide range of applications like cellular communication, satellite communication, etc. It also presents the summary of various studies on capacity analysis and performance metrics. Unsolved problems and challenges in multiway relay networks are also presented in this paper.

Chapter 3

Hardware and Software Requirements Specification

3.1 MATLAB 2020

We use matlab to model the selection of packets as a graph in order to gain familiarity with the side information matrix and understand what it means to satisfy the clients in terms of graph.

- **Graph and Network Algorithms toolbox :** The generation of the graph using side information and manipulation of graph such as adding and removing nodes is performed using this toolbox.

3.2 Python 3.6.9 on Google Colaboratory

We realised that running our code on Google Colab is faster than running it locally, so we chose to run our simulation on Colab.

- **Numpy package:** NumPy is a general-purpose array-processing package.Data packets, side information matrix, clients' has sets, number of phases counted, and graph plot inputs are all stored as numpy arrays. Modulo 2 addition, element wise addition or subtraction, averaging, transpose, and a few other operations are common on them.

- **Matplotlib package:** Python visualisation library for 2D array plots.

  The FCU scheme described in the paper[1] was validated by plotting the channel use ratio (CUR) against the number of clients. Matplotlib is also used to plot the results of our implemented scheme. The resulting graph is used to compared with simulations in the paper[2].

Chapter 4

System Design

4.1 Architecture

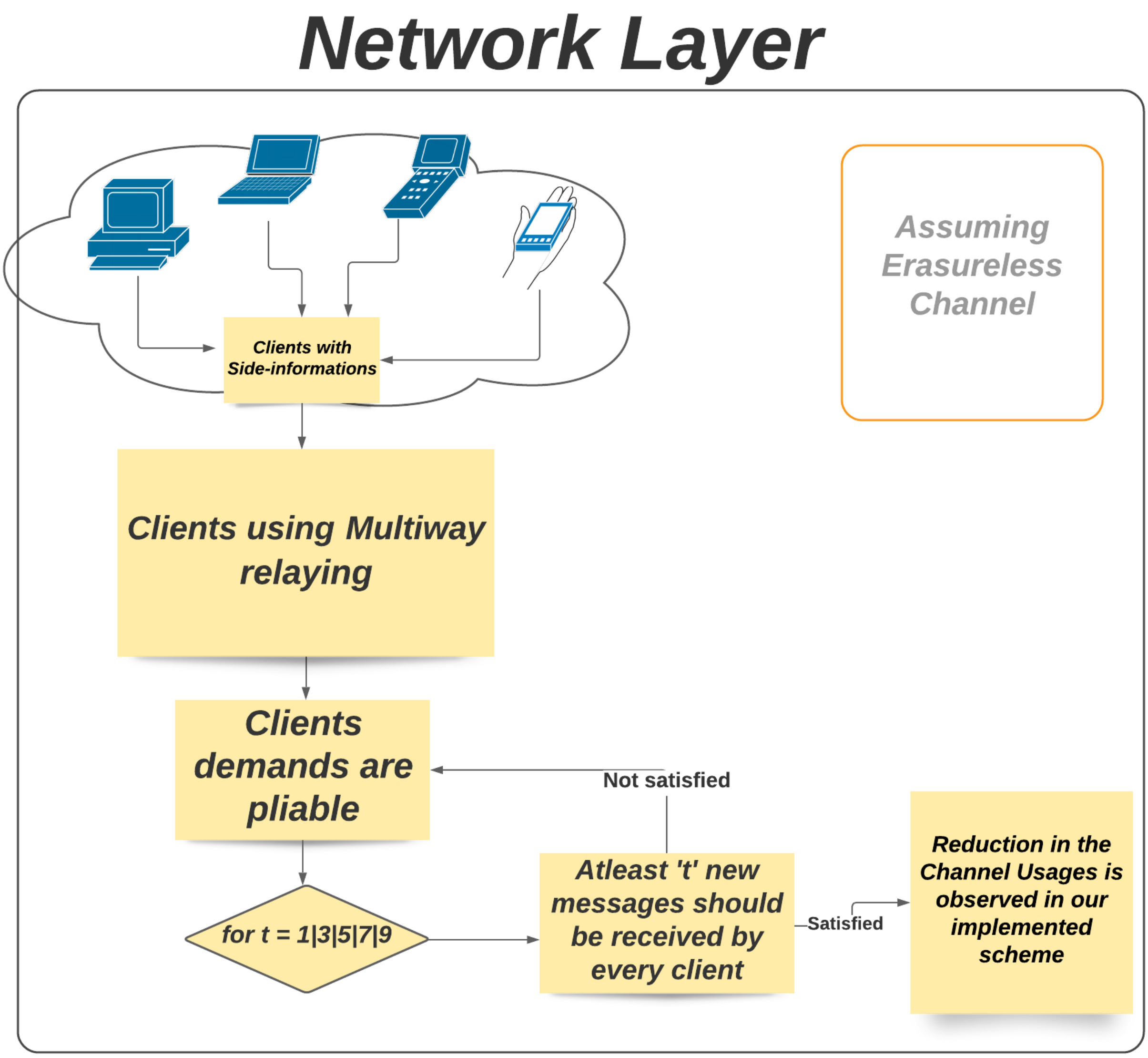

Figure 4.1: System Design Architecture

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Communication can be viewed from two perspectives: Physical and Network layer. In our case, we are only concerned with the network layer, assuming an erasure less channel, but the similar idea can be extended to AWGN, fading and other channels provided appropriate demodulating schemes are employed for respective channels. Our scheme combines the multiway relaying and Pliable index coding concepts. Considering the binary multiway relaying problem with pliable demands of nodes/clients . In our project the specific pliable demand is atleast t new messages should be received by every client. Relays are used when direct communication is not possible. The multiway relaying problem consists of exchanging messages between multiple nodes via a relay. Upon obtaining the simulation results, we observe a reduction in Number of channel uses in the implemented scheme.

4.2 Problem Formulation

We consider a MWR problem having a set of messages $\mathcal{B} = \{b_1, b_2, ..., b_m\}$, set of clients are $\mathcal{C} = \{c_1, c_2, ..., c_n\}$ and a single relay $\mathcal{R}$. $|\mathcal{B}|$=m,$|\mathcal{C}|$=n. Multiway relaying problem consists of exchanging messages amongst multiple nodes via a relay. We consider a case where each node has a set of messages known as its side information set denoted by $\mathcal{S}$ and the side information present at the i^{th} client is represented as $\mathcal{S}_i$ where $\mathcal{S}_i \subset \mathcal{B}$.For client C_i its wants set is represented as $\mathcal{W}_i = \mathcal{B} \setminus \mathcal{S}_i$, $|\mathcal{W}_i| = t \; \forall \; i$.Where t is number of new messages requested by each client.We consider coding at the network layer with only 2 nodes transmitting at a time. The relay receives the bits transmitted by the two nodes and broadcasts the same after processing , assuming an erasure-less channel. The relay receives feedback after each phase of transmission,hence it ensures demands of the nodes are satisfied.

4.3 Assumptions

- We work at the network layer since this is the lowest layer that gives access to the packets without dealing with flow control , Error control and frame synchronisation. This allows us to directly model the flow of data in terms of packets and rapidly simulate and analyse the performance of the network.
- Additionally this analysis can be translated to firmware quickly since routers and WiFi access points primarily work at the network layer. We assume that the overhead caused by node feedback after each phase is not greater than the overhead caused by conventional index coding.

Chapter 5

Implementation

5.1 Overview

The Multiway Relaying technique is implemented as shown in Fig 1.1 using Fixed channel usage scheme described in the paper[1], and similar results are obtained to validate the performance of the channel usage ratio for varying node counts.

The index coding concept was to generate the graph based on two conditions applied to the side information matrix. And then use the maximal clique algorithm to find the set of cliques that will reduce the graph and thus the number of transmissions. In order to verify the same ,in MATLAB we generated a graph for a given side information matrix and used the maximal clique algorithm to find the set of cliques needed to solve the index coding problem.

We have combined the index coding with pliable demands and the multiway relaying scheme for data transmission. The Nodes can only communicate through the Relay, which is the key component that performs binary operations, PAM signalling, Broadcasting, receives acknowledgement feedback, and checks for Nodes demand satisfaction. All functions are defined as sub blocks and integrated in the algorithm as explained in the following section.

5.2 Index Coding

Index coding is a canonical problem in network information theory that studies the fundamental limit and optimal coding schemes for broadcasting multiple messages to receivers with different side information. The index coding problem provides a simple yet rich model for several important engineering tasks such as satellite communication, content broadcasting, etc.

The index coding concept used in this work is to generate the graph based on two conditions applied to the side information matrix. The maximal clique algorithm is then used to find the set of cliques that will reduce the graph and thus the number of transmissions.

5.2.1 *C*ondition 1 for IDNC:

$j = l$ implies that the two vertices are induced by the loss of the same packet j by two different receivers i and k.

5.2.2 *C*ondition 2 for IDNC:

$j \in H_k$ and $l \in H_i$ implies that the requested packet of each vertex is in the Has set of the receiver of the other vertex.

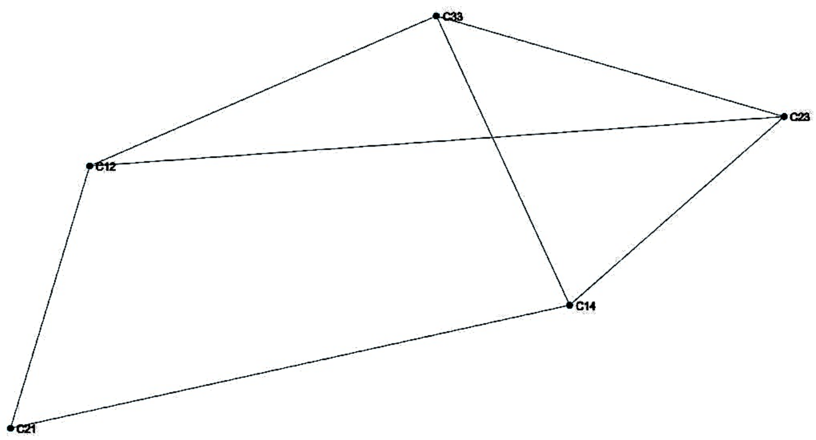

Figure 5.1: IDNC graph

As previously stated for the IDNC condition, we consider the Full data exchange case. Cliques formed between nodes in the above graph, which is generated after satisfying the two conditions mentioned in Subsections 5.2.1 and 5.2.2 are $[C_{12}, C_{21}]$, $[C_{21}, C_{14}]$, $[C_{14}, C_{23}, C_{33}]$ and $[C_{12}, C_{33}, C_{23}]$. The one with the maximum number of cliques in the following IDNC graph will be satisfied at the earliest, At the receiver/client-end, information will be decoded at a faster rate, and the total number of transmissions will be reduced. In the above example either the pair $[C_{14}, C_{23}, C_{33}]$ followed by $[C_{12}, C_{21}]$ can be selected to complete data exchange or the pair $[C_{12}, C_{33}, C_{23}]$ followed by $[C_{21}, C_{14}]$ can be selected. Either case overall number of transmissions is only two.

5.3 Relay Assisted PIC Algorithm

5.3.1 Sub Blocks of the Algorithm

The algorithm executes the following Blocks of Steps multiple times. When these blocks are called in the Algorithm, their operation is clear.

Part One

- The relay transmits the sign of the received sum during the first phase of the FCU scheme. If the sum is negative or zero, it broadcasts 1, otherwise it broadcasts +1.
- Using this, each node considers whether it is a majority or minority node.
- Nodes in any given group transmit symbols in accordance with Table I.

Part Two Phase

- The relay detects the received noisy sum signal and maps it to the broadcast symbol x_R in each phase, according to Table II.
- According to Tables I and II, each node will detect x_R and thus know the majority and minority status of the pair of nodes belonging to each group.
- If N is odd, the ungrouped node sends its symbol on its own.

Packets Selection

- In the k_{t_h} phase, the following steps are taken to select one packet from each client.
- Get the list of packets available at each client from the most recent side information matrix.
- Except for the $2k_{t_h}$ and $(2k-1)_{t_h}$ clients, choose a random packet from the list of available packets for each client.
- Check the respective columns in the side information matrix for each packet contained by the $2k_{t_h}$ client.
- Choose the packet with the greatest number of ones in the aforementioned columns.

- Steps 3 and 4 must be repeated for the $(2k-1)_{th}$ client.
- Return an array containing the indices of all clients' selected packets.

Pliable Demand Satisfaction Check

- At the end of each phase, the following steps are taken to indicate whether the clients are satisfied.
- Get the most recent side information matrix in the form of client feedback.
- Take the updated matrix and subtract it from the initial side information matrix.
- If the difference is greater than the value 't' for each client, return true; otherwise, return false.

TABLE I
COMPUTING THE SYMBOL s_i

Node Type	Index (i)	s_i
Majority	Odd	1
Majority	Even	No transmission (denoted as 0)
Minority	Odd	-1
Minority	Even	-1

Figure 5.2: Table I

TABLE II
SIGNAL RECEIVED AT THE RELAY IN $(k+1)$TH-PHASE

s_{2k-1}	s_{2k}	$y_{\mathcal{R}}$	$x_{\mathcal{R}}(PAM)$	$x_{\mathcal{R}}(QPSK)$
1	0	1	-3	$\frac{1}{\sqrt{2}} + \frac{j}{\sqrt{2}}$
-1	0	-1	-1	$-\frac{1}{\sqrt{2}} + \frac{j}{\sqrt{2}}$
1	-1	0	1	$-\frac{1}{\sqrt{2}} - \frac{j}{\sqrt{2}}$
-1	-1	-2	3	$\frac{1}{\sqrt{2}} - \frac{j}{\sqrt{2}}$

Figure 5.3: Table II

5.3.2 Algorithm

The algorithm returns a matrix of the number of phases required for various values of the number of clients and t. For different contours of t, the graph is plotted as the number of clients on the abscissa and the number of phases on the ordinate.

```
t_var = number of different values of t
n_var = number of different values of number of clients
mat[][] of dim(t_var,n_var)
for t in range 1:9:2:
  for n in range 25:1000:25:
    numOfphases = []*200
    for iter over 200 iterations:
      ~ Phase_count = 0
      ~ fix the number of packets
      ~ fix the packet length
      ~ Generate Random Packets
      ~ Generate Random Side Info Matrix
      ~ Based on Matrix,Update clients` packets
      ~ Convert bits to BPSK scheme
      ~ Call Pliable Demand Satisfaction Check block
      ~ Until it returns true:
        - Access 2 clients at a time:
          ~ Call Packets Selection Block.
          ~ Phase_count += 1
          ~ for each bit in packet:
            - Execute Part 1 Block
            - Execute Part 2 Phase Block.
            - Update Clients` packet.
          ~ Update the Side Info Matrix
      ~ numOfphases[iter] = Phase_count
    - Avg = avg(numOfphases)
    - mat[t][n] = Avg
```

Figure 5.4: Algorithm

Chapter 6

Result Analysis

6.1 Multiway Relaying FCU scheme

The channel use ratio is used to evaluate multiway relaying schemes. The channel use ratio (CUR) for N-way relaying is defined as the ratio of the number of Channel uses by a given scheme to those required if routing is used.
The CUR of the Fixed Channel Use (FCU) scheme is not dependent on the exact realisation of messages at the nodes. Furthermore, the average BER of the FCU scheme is better due to the lower cardinality transmit constellation used in the first phase and the absence of error propagation. As expected, the results obtained are the same as that of the paper's implementation[1].

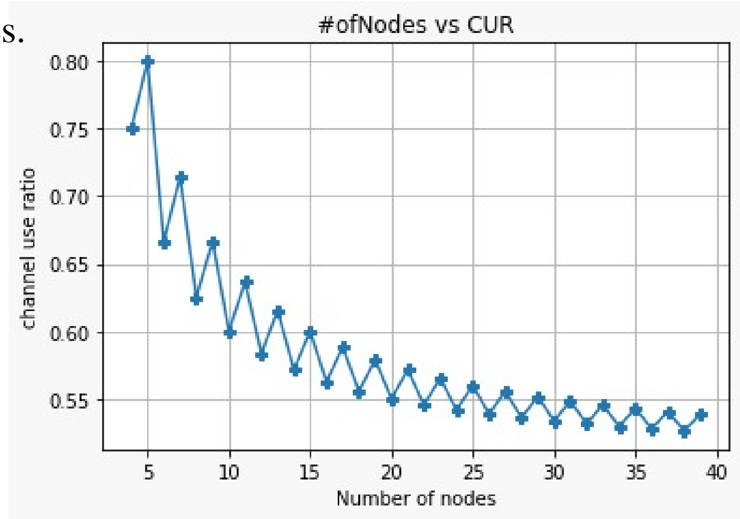

Figure 6.1: Channel Use Ratio of FCU scheme.

6.2 Relay Assisted Pliable Index Coding

For general PICOD(t), the performance of the algorithm(GRCOV) in the paper[2] is shown in the Figure 6.2, the average side of code does not change substantially for different values of t, with curves essentially getting translated upwards for higher values of t. In our scheme, the number of phases attribute is similar to the behaviour of average side of codes in the algorithm of [2], and similar upward translation of curves for higher values of t is observed , as shown in the Figure 6.3.

The Benefits of Multiway relaying FCU scheme combined with pliable index coding provides an improvement over the GRCOV algorithm for all values of t.

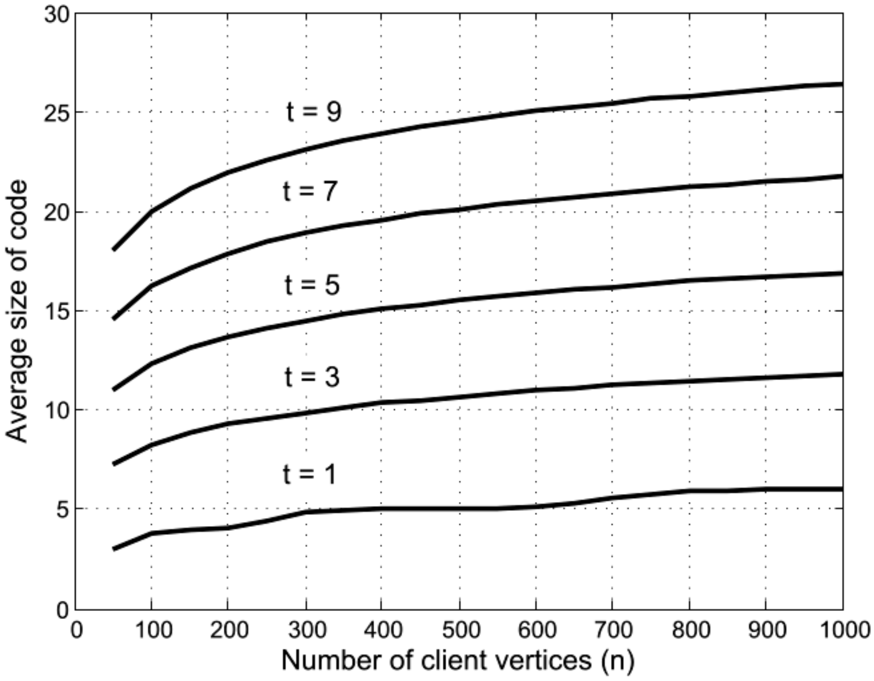

Figure 6.2: Average code size of GRCOV as a function of n as contours over t

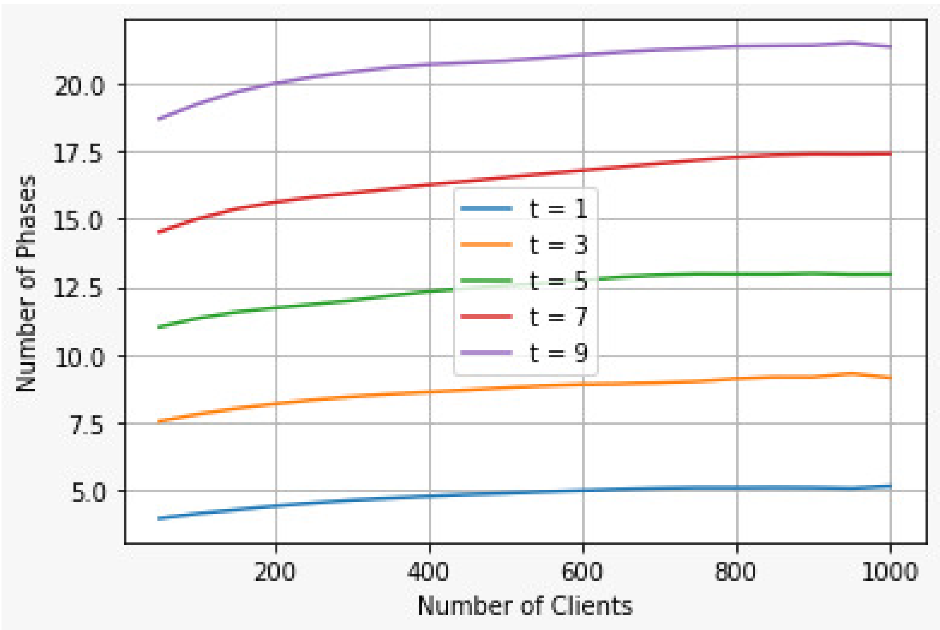

Figure 6.3: Number of Phases for Relay Assisted Pliable Index Coding

Chapter 7

Conclusion and Future Scope

7.1 Conclusion

This scheme combines two network-coding concepts namely multiway relaying and pliable index coding. Binary transmissions from nodes with pliable demands are exchanged via a relay that employs Network Layer Network Coding.Data exchange is completed in fewer number of phases compared to only using picod scheme mentioned in the paper[2]. We considered the case of noiseless and erasure free channel, but can be extended to other type of channels for future work along with other works mentioned in the next section.

7.2 Future Scope

- To evaluate the efficiency of an algorithm and to substantiate the obtained results, asymptotic analysis can be performed using mathematical derivations and statistical analysis.
- The concept of combining two nodes can be extended to higher order, taking into account the resulting trade-off between bits per symbol and BER as a result of higher order combining, which results in a denser constellation.
- With an increasing number of devices connecting to the internet, particularly IoT devices, it is not feasible to add base stations to cover smaller and smaller areas, hence the concept of relaying is a better option.
- Relaying reduces the number of transmissions, thereby saving power and contributing to greener communication. Furthermore, there is no need for additional infrastructure or a redesign of existing architecture to implement the relaying concept.

References

[1] *A Throughput Efficient Multi-Stage Technique for Binary Multiway Relaying*: Saket D. Buch, Chinmayananda Arunachala, and B. Sundar Rajan

[2] *Pliable Index Coding*: Siddhartha Brahma and Christina Fragouli

[3] *A Deterministic Algorithm for Pliable Index Coding*: Linqi Song and Christina Fragouli

[4] *An Overview on Multiway Relay Communications: Fundamental Issues, Recent Advances, and New Challenges*: Rui Wang and Xiaojun Yuan

Appendix A

Review Process

A.1 Phases of Review

Project was evaluated at phases with major checkpoints as follows :

A.1.1 Pre-Review : *Defining Problem Statement & Feasibility analysis*

1. Understanding of the problem statement.
2. Technical understanding of domain.
3. Identification of differentiating features.
4. Feasibility of conversion to a research paper.

A.1.2 1st Review : *Literature survey and Project plan Review*

1. Clarity in understanding of the problem/project.
2. Completion of Literature Survey.
3. Implementation of index coding using maximal cliques
4. Timeline for completion of project using Gantt chart.

A.1.3 2nd Review : *Project Progress Review*

1. Adherences to project plan.
2. Implemented a multiway relay with 1 bit message cache clients and simulated the fixed channel use scheme.
3. 50% implementation.

4. Demonstration of completed modules using primitive interfaces

A.1.4 3rd Review : *Project Progress and Finishing plan Review*

1. 70% Module level implementation
2. Extended the multiway relay client cache from 1 bit to ambiguous packets.
3. Applied pliable index coding to the relay, where at least 't' messages are needed by each client
4. Final demonstration plan.

A.1.5 4th Review : *Module completion and Integration Review*

1. 100% Module implementation.
2. Completion of Integration.
3. Presentation of test data as per test plan.
4. Adherences to project plan.