EE3700/CC5901 - Exploratory Lab: From Conventional Communication to Network Coding to Physical Layer Network Coding (PLNC)

Dr Tao (Kevin) Huang tao.huang1@jcu.edu.au

Objective:
This lab aims to take you on a journey through various communication techniques, helping you explore how we can push the boundaries of network throughput by improving efficiency in message exchanges. By understanding the limitations of conventional communication and network coding, you will be inspired to delve into the advanced concept of Physical Layer Network Coding (PLNC). This lab will challenge you to think critically about how these techniques can impact real-world communication systems and motivate you to explore innovative ways to overcome their limitations. Ultimately, you will simulate PLNC and evaluate its performance, gaining insights into how this method can revolutionize communication by improving throughput in noisy environments.

I intentionally did not include any references in this lab instruction sheet, and I encourage you to do some research and try to find relevant sources first. Research for relevant and good quality references is an important skill for engineers in the real world.

Tools:

You can use MATLAB, Python, or any other programming language you are familiar with to implement the simulation in Part 3.

Journey Outline:

This lab is divided into three parts:
1. Conventional Communication (Conceptual exploration, no simulation required)
2. Network Coding (Conceptual exploration, no simulation required)
3. Physical Layer Network Coding (PLNC) (Simulation required)

Modulation Scheme:

In this lab, binary information (0, 1) will be modulated to -1 and +1 for transmission over the communication channel.

System Assumptions:

This lab assumes a Time Division Duplex (TDD) system, where the communication process is divided into distinct time slots. In other words, for each time slot, only one user can transmit its message.

Part 1: Conventional Communication (No Simulation Required)

In this part, you will conceptually explore a basic communication system where two nodes exchange messages through a relay. The process requires multiple transmissions, and you will reflect on the throughput and the limitations of this approach.

To simplify the process, we can assume that in this process, the message exchange by each user is only one bit. For example, we have two users A and B. User A wants to transmit bit b_A to User B, and User B wants to transmit bit b_B to user A. We can apply this assumption to Part 2 and Part 3.

Transmission Phases (Time Slots):

1. Time Slot 1: Node A transmits its modulated message to the relay.
2. Time Slot 2: Node B transmits its modulated message to the relay.
3. Time Slot 3: The relay forwards Node A's message to Node B.
4. Time Slot 4: The relay forwards Node B's message to Node A.

This process requires four time slots to complete the exchange of messages.

Reflection:

Reflect on the limitations of this approach. How many time slots are required to exchange information between the two users in this system? Can you think of ways to reduce the number of transmissions and increase throughput?

Note: you can draw a figure to show the data transmission process in each time slot in your report. You will need to think about how to draw the figure to clearly reflect the data transmission process. (Hint: you can find some ideas from relevant published research papers). Please show your reflection in your report as suggested in the " Report Requirements".

Part 2: Exploring Network Coding (No Simulation Required)

In this part, you will conceptually explore Network Coding at the relay, where the relay combines the messages before forwarding them. This reduces the number of transmissions, improving throughput compared to conventional communication.

Transmission Phases (Time Slots):

1. Time Slot 1: Node A transmits its modulated message to the relay.
2. Time Slot 2: Node B transmits its modulated message to the relay.
3. Time Slot 3: The relay combines the messages from Node A and Node B using network coding (e.g., XOR) and forwards the combined message to both nodes.

Note here "combines" is a broad term, which means the reply is computing a message from the message that it received from Node A and Node B. In other words, you can think the computing process is like $x_R = f_R(x_A, x_B)$, where $f_R(\cdot)$ is the computing process at the relay.

This process requires only three time slots to complete the exchange of messages.

Reflection:

Comparing to the communication process described in Part 1, what's the difference here? How can each user recover the information from another user? Can you use a math equation to describe the computing process at the user? Consider any potential trade-offs or drawbacks of network coding? Please include your reflections in your report.

Part 3: Exploring Physical Layer Network Coding (PLNC) [Simulation Required]

In this part, you will conduct a simulation of Physical Layer Network Coding (PLNC). The goal is to analyze the error rate performance when directly decoding the superimposed signal to the network-coded signal.

Transmission Phases (Time Slots):

1. Time Slot 1: Node A and Node B simultaneously transmit their modulated messages to the relay. The relay receives a superimposed signal $y_R = x_A + x_B$ + noise (Additive Gaussian Noise).
2. Time Slot 2: The relay decodes the network-coded bits from the superimposed signal and forwards the decoded network-coded message to both Node A and Node B.

This process requires only two time slots to complete the exchange of messages.

Reflection:

Comparing to the communication process described in Part 2, what's the difference here? How can each user recover the information from another user? Can you use a math equation to describe the computing process at the relay and at the user? Consider any potential challenges of physical-layer network coding? Please include your reflections in your report.

Simulation Task:

You will simulate the process where **the relay performs the computation using XOR since the message exchanged are binary bits from the superimposed signal**. The key focus is on evaluating the error rate performance under different noise conditions.

1. Mapping Table:
- Create a mapping table to decode the superimposed signal into the network-coded message (XOR).

2. Defining SNR:
- The Signal-to-Noise Ratio (SNR) is defined as the ratio of the signal power to the noise power, typically expressed in decibels (dB).

Note: you can use single user SNR, which is the same as you have done in Practical 1.

3. Generating Noise Samples:
- Generate additive white Gaussian noise (AWGN) samples using the standard normal distribution. Adjust the variance of the noise to achieve the desired SNR.

4. Error Rate Calculation:
- Simulate the transmission process for different SNR levels and calculate the Bit Error Rate (BER).

Report Requirements:

Your report should summarize your exploration and simulation results from the lab. The report is expected to be concise, well-structured, and insightful. Below is a suggested structure for the report.

Report Structure:

1. Introduction:
- Introduce the concepts explored in the lab.

2. Parts 1 and 2:
- Explain the transmission process, decoding process at the relay and the users.
- Include the "Reflections" mentioned in Part 1 and 2.
- Include any required details mentioned above.

3. Part 3:
- Include the "Reflections" mentioned in Part 3.
- Explain the system setup, mapping table, SNR definition used in simulation.
- Show the simulation result and your thoughts on the result.
- Include any required details mentioned above.

4. Results:
- Present the BER vs. SNR results and analyze the performance.

5. Conclusion:
- Summarize your key findings and discuss potential future work.

6. References:
- List any references or resources used.

7. Appendix:
- The program you wrote for this Practical with proper comments.

Submission Requirements:

1. Code: Include the code used to perform the simulation in Part 3 as Appendix.
2. Plots: Include the BER vs. SNR plot generated from your simulation.
3. Report: Submit a concise, structured report following the Report Structure provided.

Marking Criteria:

Your work will be marked based on the following criteria:

1. Conceptual Understanding (Parts 1 and 2) (30%)
- Clear explanation of conventional communication and network coding concepts.
- Accurate reflections on throughput and limitations.

Criteria	Excellent (80-100%)	Good (65-79%)	Satisfactory (50-64%)	Needs Improvement (Below 50%)
Explanation of Concepts	Thorough and clear explanations of conventional communication and network coding, demonstrating a deep understanding of how each method works.	Good explanation with minor gaps in detail or clarity. Understanding is evident, but not fully articulated.	Adequate explanation with some inaccuracies or missing details. Basic understanding is present.	Incomplete or unclear explanation, with major gaps in understanding.
Reflection on Throughput	Insightful reflections on throughput and limitations, with strong critical thinking about possible improvements.	Good reflections, though lacking in-depth critical analysis of throughput improvements.	Reflections are basic and may miss some key points regarding throughput and limitations.	Minimal or no reflection on throughput; little to no critical thinking is demonstrated.
Consideration of Trade-offs	Thoughtful consideration of trade-offs in network coding, with clear examples of where it might succeed or fail.	Some consideration of trade-offs, though not fully developed. Examples may be lacking in detail.	Basic consideration of trade-offs, but lacking depth or concrete examples.	No meaningful consideration of trade-offs, or incorrect assumptions made.

2. Simulation Implementation (Part 3) (40%)
- Correct implementation of the simulation, including noise generation and decoding.
- Accurate reflections on throughput and limitations.

Criteria	Excellent (80-100%)	Good (65-79%)	Satisfactory (50-64%)	Needs Improvement (Below 50%)
Correctness of Implementation	Simulation is implemented correctly with accurate modulation, noise generation, and decoding. Results are consistent with expectations.	Implementation is mostly correct, but with minor errors that do not significantly affect the results.	Some implementation issues, leading to inaccurate or incomplete results.	Major errors in implementation that lead to incorrect or unusable results.
Mapping Table Usage	The mapping table is used effectively to decode the superimposed signal. Clear and accurate mapping is demonstrated in the code.	Mapping table is mostly correct, but there are minor inconsistencies or errors.	Basic mapping table is used, but there are significant inaccuracies.	Little to no use of a mapping table, or incorrect mapping leading to errors in decoding.
SNR Calculation and Noise Generation	SNR is calculated correctly, and noise is generated accurately according to the specified SNR levels. Noise is added appropriately to the signal.	SNR calculation and noise generation are mostly correct, with minor errors.	Some issues with SNR calculation or noise generation, affecting the accuracy of the simulation.	Major errors in SNR calculation or noise generation, leading to incorrect results.
Code Documentation and Structure	Code is well-documented, with clear comments explaining key sections. Code structure is logical and easy to follow.	Code is mostly well-documented, with some minor gaps in comments or structure.	Basic documentation is provided, but lacks detail. Code structure is somewhat disorganized.	Little to no documentation. Code is difficult to follow or understand.

3. Results and Analysis (20%)

- Accurate calculation and presentation of BER vs. SNR results.

Criteria	Excellent (80-100%)	Good (65-79%)	Satisfactory (50-64%)	Needs Improvement (Below 50%)
Accuracy of Results	BER vs. SNR results are accurate and consistent with theoretical expectations. The plot clearly illustrates the relationship between BER and SNR.	Results are mostly accurate, with minor deviations from expected outcomes. The plot is clear but may have small issues.	Some inaccuracies in the results, with noticeable deviations from expectations. Plot may lack clarity.	Major inaccuracies in the results, with the plot failing to represent the relationship between BER and SNR correctly.
Analysis of Results	Insightful analysis of the results, identifying trends and providing meaningful interpretation. Clear understanding of how noise and SNR affect error rates.	Good analysis, though lacking in-depth interpretation. Trends are identified but not fully explored.	Basic analysis provided, but lacks depth and may miss key points in interpreting the results.	Minimal or incorrect analysis. Little to no understanding of the results is demonstrated.

4. Report Quality (10%)
- Well-structured and clear report.

Criteria	Excellent (80-100%)	Good (65-79%)	Satisfactory (50-64%)	Needs Improvement (Below 50%)
Structure and Organization	The report is well-structured, following the suggested format. Each section is clearly defined and logically presented.	The report is generally well-structured, with only minor issues in organization or flow.	The report has a basic structure, but may lack logical flow or clear sectioning.	The report is poorly structured, with sections that are disorganized or difficult to follow.
Clarity of Writing	Writing is clear and concise, with excellent grammar and vocabulary. Concepts are explained effectively.	Writing is generally clear, though there may be occasional issues with clarity or grammar.	Basic writing is provided, but may lack clarity or have frequent grammatical issues.	Writing is unclear or difficult to understand. Frequent grammar and clarity issues are present.
Use of Diagrams and Plots	Diagrams and plots are effectively used to support the explanations and results. They are clearly labeled and integrated into the report.	Diagrams and plots are used, but may not be fully integrated into the explanation. Minor labeling issues.	Basic use of diagrams and plots, but they may lack clarity or proper labeling.	Little to no use of diagrams or plots, or they are poorly presented and unclear.