EE7330: Network Information Theory	**2021**

NETWORK CODED MULTIPLE ACCESS - II

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0.1 INTRODUCTION

This paper presents a first real-time network-coded multiple access (NCMA) system that jointly exploits physical layer network coding (PNC) and multi-user decoding (MUD) to boost the throughput of a wireless local area network (WLAN). NCMA is a new design paradigm for multi-packet reception wireless networks, in which the access point (AP) can receive and decode several packets simultaneously transmitted by multiple users.

Conventionally, multi-packet reception is realized using MUD only, while the key idea of NCMA is to use PNC together with MUD to realize multi-packet reception. The current investigation makes the following state-ofthe- art contributions towards NCMA:

1. NCMA system with integrated real-time PHY-layer and MAClayer.
2. A new unified framework for MAC-layer decoding that yields higher throughput with faster decoding – the faster decoding is one of the key enablers of our real-time implementation decoding.
3. Design new PHY-layer decoding techniques that overcome the poor performance of the first generation NCMA prototype at low SNR.

Experimental results show that, compared with the previous NCMA prototype, the new NCMA prototype improves real-time throughput by more than 100% at medium-high SNR ($\geqslant$ 8dB).

0.2 OUTCOMES OF PAPER

Using the techniques proposed in the reference papers,

1. Throughput of the system is increased for about 100%.
2. System performance at low, mediummedium-high SNR regimes was increased.

0.3 NCMA-I (EARLIER SYSTEM)

In NCMA-I,

1. PHY - layer decoding was not integrated with MAC Layer decoding.

2. PHY - layer decoding was performed online while MAC Layer decoding was performed offline. This affects the performance of system while decoding.
3. A Three Equation System was proposed of which two equations are defined for decoding native messages of two users independently and one equation for decoding a network-coded message of two users combined.
4. Performance of System was evaluated at mid-range SNR.

0.4 Definitions

1. NCMA - NETWORK CODED MULTIPLE ACCESS. In WLAN, AP can receive and decode several packets simultaneously transmitted by multiple users. It is given in below figure.

Figure 0.1: WLAN Communication System

Multi-packet reception is realized using MUD in generally. The Key idea of NCMA is to use PNC decoding together with MUD decoding. The block diagram of NCMA system is given below.

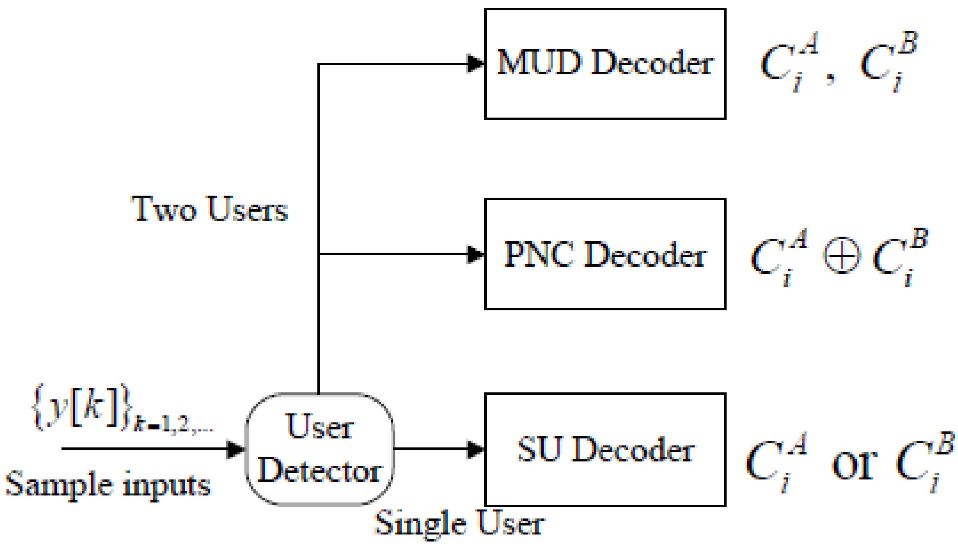

Figure 0.2: NCMA Block Diagram

2. PNC - PHYSICAL LAYER NETWORK CODING. It is a technique to exploit wireless interference by turning the superimposed electromagnetic waves into useful network-coded information.The process of decoding for the network-coded information based on the superimposed signals is referred to as PNC decoding.Instead of forwarding the original information of the source nodes, the relay nodes forward the network-coded information to destination nodes, where self-information or side information obtained by overhearing, is used to extract the original source information.

3. MUD - MULTI-USER DECODING. In NCMA, at the sender end, each message is partitioned and channel-coded into multiple packets at the MAC layer. These packets are then forwarded to the PHY layer, where another layer of channel coding is performed before the packets are transmitted over the air. At the receiver end, two PHY-layer decoders are used: a PNC decoder attempts to decode the signals simultaneously transmitted by several senders into network-coded packets; at the same time, a conventional MUD decoder attempts to decode the signals into the individual native packets of the two users. The PHY-layer packets collected from different time slots, network-coded as well as native, are then used to decode the MAC-layer messages from the users.

0.5 Mathematical Statement

0.5.1 MAC Layer Bridging

Here the equations are from NCMA-I since they provide a better version of equations than in NCMA-II paper. The codes used here are Reed- Solomon codes in MAC layer and Convolutional Code in PHY layer.Since they are non cyclic binary codes, they will have a generator polynomial in matrix form for generating codewords. Let M^A and M^B be the messages from users A and B respectively. Their codewords are generated using the following equations.

$$\begin{aligned} C^A &= G^A M^A \\ C^B &= G^B M^B \\ &\text{These codewords are transmitted and received at the receiver end and indicated by } \tilde{C}^A, \tilde{C}^B. \\ &\text{Whenever the decoding is being performed, then message} \\ \hat{M}^A &= \tilde{G}^{A-1}\tilde{C}^A \\ \hat{M}^B &= \tilde{G}^{B-1}\tilde{C}^B \end{aligned} \tag{0.1}$$

Here the AP will perform a XOR on the packets received and broadcast them to both the users. Depending on number of packets received i.e.L(here) and depending on from which user the packets received by using above equations missing packets in case of user A and B. If number of packets received are of XORed ones then the MAC bridging equations are used. They are given as below case wise.

Case - I and II: When L packets of user A or user B are received first than B or A and A $\oplus$ B, then following equations are used to decode

$$\begin{aligned} \tilde{G}^A M^A &= \tilde{C}^A \\ \tilde{G}^B M^B &= \tilde{C}^B \\ \bar{G}^{A\oplus B} M^B &= \bar{G}^{A\oplus B}(G^A)^{-1}C^A \oplus \bar{C}^{A\oplus B} \end{aligned} \tag{0.2}$$

Case - III: When L packets of AP i.e. A⊕B are received first than B or A, then following equations are used to decode

$$\begin{aligned} &\text{For decoding packets of A} \\ \tilde{G}^A M^A &= \tilde{C}^A \\ \bar{G}^B M^A &= \bar{C}^B \oplus (\bar{G}^B((\tilde{G}^{A\oplus B})^{-1}\tilde{C}^{A\oplus B})) \\ &\text{For decoding packets of B} \\ \tilde{G}^B M^B &= \tilde{C}^B \\ \bar{G}^A M^B &= \bar{C}^A \oplus (\bar{G}^A((\tilde{G}^{A\oplus B})^{-1}\tilde{C}^{A\oplus B})) \end{aligned} \tag{0.3}$$

The above equations are formulated as a part of NCMA-I i.e. Triple Equation System. In NCMA-II, they have been modified as Unified Equation System as below.

$$\tilde{G}\begin{pmatrix} M^A \\ M^B \end{pmatrix} = \begin{pmatrix} \tilde{G}_A^A & 0 \\ \tilde{G}_A^X & \tilde{G}_B^X \\ 0 & \tilde{G}_B^B \end{pmatrix}\begin{pmatrix} M^A \\ M^B \end{pmatrix} = \begin{pmatrix} \tilde{C}^A \\ \tilde{C}^{A\oplus B} \\ \tilde{C}^B \end{pmatrix} \tag{0.4}$$

where $\tilde{G}_A^A, \tilde{G}_B^B, \tilde{G}_A^X, \tilde{G}_B^X$ can be found out using equations as given above with slight modifications as explained in NCMA-II reference paper.

0.5.2 PHY Layer Bridging and Decoding

In PHY Layer, PNC decoder and MUD decoder are employed with convolutional coding on BPSK modulated superimposed signals. This NCMA-II uses reduced constellation demodulation that facilitates soft decision decoding using Viterbi decoding algorithm. The soft information is determined by log likelihood ratio as per the equation below.

$$\log\frac{P_0}{P_1} = \log\frac{Pr\{x_A = 1, x_B = 1|y\} + Pr\{x_A = -1, x_B = -1|y\}}{Pr\{x_A = 1, x_B = -1|y\} + Pr\{x_A = -1, x_B = 1|y\}} \tag{0.5}$$

As per the constellation scheme, the MUD decoder also demodulates and decodes the message at PHY Layer. Since the data decided on these log likelihood values, a max function is used to decide the output, they are error prone and depending on SNR values, their P_e is calculated that gives the system performance.

0.5.3 Notations

1. ndicate received codewords
2. ndicates decoded codewords
3. C indicates codeword at sender side.

0.6 REFERENCES

1. http://personal.ie.cuhk.edu.hk/ lulu/paper/NCMA2.pdf
2. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.707.8209rep=rep1type=pdf