Pseudo Random Network Coding Design for IEEE 802.16m Enhanced Multicast and Broadcast Service

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***Abstract*—Applying network coding on broadcasting service is known to reduce times of transmission in the process of recovering the loss packets. In previous design, coding coefficients are put in the packet headers so that MSs can decode the coded packets. However, it causes extra overhead. Moreover, since many mechanisms depend on feedback information to encode packets, they may cease operating once they are out of feedback support. To address these problems, we propose a codebook-based network coding scheme, Pseudo Random Network Coding (PRNC). The codebook defines the coding coefficients of the transmission packets; therefore, we only need to put the index of the codebook in the packet header to decode packets. The simulation result shows that PRNC decodes more packets and has higher all-perfect decoding ratio compared with other network coding schemes.**

Keywords: multicast, broadcast, network coding, codebook

I. INTRODUCTION

IEEE standard 802.16, also known as WiMAX, shows great promise in the development of WirelessMan for providing high bandwidth and long distance radio link access as well as offering a wide range of applications, which draws a lot of attention from the related fields. The standard 802.16e[1] provides Multicast Broadcast Services (MBS), allowing base station (BS) to send data packets to multiple mobile stations (MS) simultaneously. Such characteristic renders it highly suitable for data distributions in wireless transmission. However, the 802.16e MBS only provides basic multicast and broadcast functionality. For instance, the rate of data transmitting is limited to a fixed rate in BPSK.

IEEE 802.16m[2] is the promising next-generation WiMAX standard. Enhanced MBS(EMBS) is defined to provide better capability, flexibility and mobility support, thereby adding new function to WiMAX system and granting more options to MBS operations. For example, the idea of Multicast Broadcast Single Frequency Network(MBSFN) allows multiple BSs to form a larger multicast group to serve more MSs. In this work, we provide a network coding scheme for EMBS retransmission. The work presented in this article, Pseudo Random Network Coding(PRNC) mechanism, differentiates from our previous work focusing on offering a network coding scheme for EMBS, and transcends other network coding mechanisms for one-hop multicast, makes further improvements.

The major breakthrough of PRNC is putting an index instead of a full coding coefficient matrix in a packet header. In the previous network coding mechanisms, BS generates coding coefficients in response to the lost packets, and then puts the coefficients in the packet header, while in PRNC, both BS and MS have their predetermined codebook each with their own corresponded coding coefficient, therefore, BS simply needs to send an index in the packet header to decode packets, which resolves the problem of wasting header overheads. Another contribution PRNC makes is to help mechanisms operating without feedback information. By deciding the quantity of necessary transmission slots, BS excludes the necessity of feedback information.

II. RELATED WORK

Network coding is required to achieve the higher capacity in multicast[3][4]. In addition, Katti et al. propose a network coding transmission scheme for the scenario where nodes transmit through relay nodes[5]. This is different from our scenario where both BS and MS existed. Apart from that, Jin, Li, and Kong propose network coding to improve the throughput in WiMAX[6]. After that, Jin and Li also design an adaptive random network coding in which coding coefficients are randomly generated to be put in packet headers so that MS can decode coded packets[7]. As for other mechanisms in terms of network coding one-hop multicast and broadcast, Nguyen et al., for example, adopt XOR network coding on broadcast transmission to efficiently reduce the transmission times[8]. Another work of theirs combines channel coding with network coding[9]. In these two works, coding coefficients are generated relying heavily on feedback information of lost packets which is put in packet headers. Wang et al., similarly, propose a network coding mechanism on broadcast transmission[10][11] that also relies on feedback to generate coefficients to packet headers.

In this paper, we propose the Pseudo Random Network Coding (PRNC). Compared to [7], PRNC uses the pseudo random coding generated from codebook, and we only put the index of the codebook's row in the packet header. Because the coefficient is from codebook, the MS can decode the coded packet by the index instead of the full coding coefficient. Compared to [8][9][10][11], PRNC can operate without any feedback information. The detail of PRNC mechanism is described in the next section.

III. PSEUDO RANDOM NETWORK CODING

PRNC aims to solve two major problems:

1. Extra overheads caused by coding coefficient in packet headers: In previous work, coding coefficients are generated

randomly from the BS or decided by the BS according to feedback information. Therefore, coding coefficients have to be included in packet headers so that MSs can decode the coded packets. But it causes the extra overhead.

2. Dependence on feedback information: Mechanisms [8][9][10][11] share a characteristic that MSs have to inform lost packets to the BS so that the BS can encodes the packets according to the feedback information. However, if there is no feedback support in the system, the mechanism are paralyzed. For example, the network coding mechanism designed for WiMAX EMBS, where sets no feedback channels, must be able to operate without feedback information.

To solve the first problem, we try to use a set of coding coefficients for all transmissions. By the pre-determined coefficients, packet headers only include the index rather than full coding coefficients, thereby reducing the overheads. To realize the mechanism, we have to make sure that coding coefficients decided by the codebook stay the same decode performance as the ones generated by random network coding. To achieve that, we uniformly distribute the original packets into the coded packets. Further description is presented latter.

AS for the second problem, since the original packets are uniformly distributed into the coded packets, the lost packets can thereby be recovered with high probability, which excludes the necessity of feedback information.

Further details of codebook are explored as follows. First, we assume that:

1. There are N packets, P_1, P_2, ..., P_N, to be transmitted to several MSs.

2. The BS transmits coded packets which are coded according to code book.

3. The coded packets are the XOR of the original packets.

4. BS determines the number of transmission packets without any feedback information from MSs.

$$C = \begin{pmatrix} C_{1,1} & C_{1,2} & C_{1,3} & ... & C_{1,N} \\ C_{2,1} & C_{2,2} & C_{2,3} & ... & C_{2,N} \\ ... & & & ... & \\ C_{i,1} & C_{i,2} & & ... & C_{i,N} \\ ... & & & ... & \\ C_{T,1} & C_{T,2} & & ... & C_{T,N} \end{pmatrix}$$

The row in code book C represents the coding coefficients of one coded packet. The i_{th} coded packet is $C_{i,1}P_1$+$C_{i,2}P_2$+...+$C_{i,N}P_N$.

We design two type of codebook: Diagonal codebook and triangle codebook.

A. *Diagonal Codebook*

For row 1 to N,

$$C_{i,j} = \begin{cases} 1, & \text{if } i = j \\ 0, & \text{otherwise.} \end{cases} \tag{1}$$

It means that N original packets are transmitted first, and then the following packets are used to recover the possible loss of the first N packets.

For row N+1,

$$C_{N+1,j} = 1, \text{which j = 1 to N} \tag{2}$$

For row > N+1, positive integers a and k,

$$a \geq 2, 0 \leq k \leq a-2, \text{such that } i = N+2+\frac{(a-1)(a-2)}{2}+k$$

$$C_{i,j} = \begin{cases} 1, & \text{if } j \text{ mod } a = k \\ 0, & \text{otherwise.} \end{cases} \tag{3}$$

For example,

$$a = 2, k = 0, C_{N+2} = 1, \text{ if } j \text{ mod 2 = 0} \tag{4}$$

$$a = 3, k = 0, C_{N+3} = 1, \text{ if } j \text{ mod 3 = 0} \tag{5}$$

$$a = 3, k = 1, C_{N+4} = 1, \text{ if } j \text{ mod 3 = 1} \tag{6}$$

$$a = 4, k = 0, C_{N+5} = 1, \text{ if } j \text{ mod 4 = 0} \tag{7}$$

This part can be seen as redundancy, in order to recover the probably lost in the first N packets. In this part, the original packet is uniformly distributed in the coded packet. The density of packets is from high to low when the index increases. It starts from mod 1 (row N+1). The row N+2 is j mod 2 = 0,

$$1 \quad 0 \quad 1 \quad 0 \quad 1 \quad 0 \quad 1 \quad 0 \quad ...$$

Then the row N+3 is j mod 3 = 0. The reason why we don't use j mod 2 = 1 is that this row, previous row (j mod 2 = 0), and row of mod 1 is linearly dependent.

$$\begin{matrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & ... \\ 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & ... \\ 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & ... \end{matrix}$$

Therefore, we don't use j mod 2 = 1, j mod 3 = 2, j mod 4 = 3, ..., etc. The simulation result also shows that adding these rows will decrease the number of recovery packets. An example of N=10 is shown here.

$$C = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 \\ ... & & & & & & & & & \end{pmatrix}$$

B. Triangle Codebook

For row 1 to N,

$$C_{i,j} = \begin{cases} 1, & \text{if } i \leq j \\ 0, & \text{otherwise.} \end{cases} \tag{8}$$

The main distinction between triangle and diagonal codebook is the first N packets of triangle codebook are coded packets, while the ones of diagonal code are original packets. In addition, the simulation result shows that triangle codebook has higher probability of decoding all the packets by MSs compared with diagonal codebook.

For row > N, positive integers a and k,

$$a \geq 2, 0 \leq k \leq a-2, \text{such that } i = N+1+\frac{(a-1)(a-2)}{2}+k$$

$$C_{i,j} = \begin{cases} 1, & \text{if } j \bmod a = k \\ 0, & \text{otherwise.} \end{cases}$$

For example,

$$a = 2, k = 0, C_{N+1} = 1, \text{ if } j \bmod 2 = 0$$

$$a = 3, k = 0, C_{N+2} = 1, \text{ if } j \bmod 3 = 0$$

$$a = 3, k = 1, C_{N+3} = 1, \text{ if } j \bmod 3 = 1$$

$$a = 4, k = 0, C_{N+4} = 1, \text{ if } j \bmod 4 = 0$$

We can see an example of N = 10.

$$C = \begin{pmatrix} \mathbf{1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \mathbf{1} & \mathbf{1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \mathbf{1} & \mathbf{1} & \mathbf{1} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & 0 & 0 & 0 & 0 & 0 & 0 \\ \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & 0 & 0 & 0 & 0 & 0 \\ \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & 0 & 0 & 0 & 0 \\ \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & 0 & 0 & 0 \\ \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & 0 & 0 \\ \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & 0 \\ \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} & \mathbf{1} \\ 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ \cdots & & & & & & & & & \end{pmatrix}$$

IV. COMPARISON SCHEME

We will compare PRNC with Arulselvan's scheme[12] in the simulation part. In Arulselvan's scheme, the BS also transmits the original packets first. After the N_{th} transmission, the original packets will be grouped into same size groups, and the number of group is the same as the remain transmission times. The detail of Arulselvan's scheme is described in their document. For example, if the original packets is 8 and the transmission times is 13, the transmission packets (TP) will be

i_{th} TP	content	i_{th} TP	content
1	P_1	8	P_8
2	P_2	9	$P_1 \oplus P_2$
3	P_3	10	$P_3 \oplus P_4$
4	P_4	11	$P_5 \oplus P_6$
5	P_5	12	P_7
6	P_6	13	P_8
7	P_7		

In fact, the Arulselvan's scheme is also pre-decided coding coefficient, and it can be formulated to a codebook. The difference between Arulselvan's scheme and PRNC is the content of codebook. In the simulation part, we will compare the different performance due to the different codebook design.

V. SIMULATION RESULT

We compare Pseudo Random Network Coding (PRNC) with random network coding, Arulselvan's scheme, and no network coding scheme. We use C++ code for simulation. In the code, a BS transmits N original packets in T transmission packets (coded packets). The packet loss probability distribution is Bernoulli with parameter p. The MSs decode coded packets after transmission, and we calculate the number of decoded packets. The data batch size N = 50 or 100 in simulations. The number of transmission in each batch T = N+1 to N+25. There are 10 MSs in an EMBS group. Notice that the rows with the index greater than N in the coding coefficient matrix are used for retransmission. If the number of retransmission packets is k, the number of transmission packets is N+k.

A. decoded packets and all perfect ratio

Fig.1 shows the result that when N=50 and p=0.05, which indicates that dia-PRNC (using diagonal codebook) decodes more packets than Arulselvan's scheme and No NC scheme. On the other hand, the tri-PRNC (using triangle codebook) decodes less than others when the number of transmission packets is small, which is because it transmits coded packets instead of the original packets from row 1 to row N. If a packet in the range of row 1 to row N is lost, two packets are unable to be decoded. Other than that, we also find that random network coding has the same or even better performance than dia-PRNC. However, it costs more packet overhead. We will calculate the goodput which excludes the overhead in the next subsection.

The all-perfect-ratio is also calculated in our simulations, in which we consider that all MSs decode all packets by a single trial is a successful trial, and the all-perfect-ratio is the ratio of the times of successful trials to the total number of trials. All-perfect-ratio is an important metric for some application. Assume that the data of the application needs to be complete ,otherwise, it have to be retransmitted. All-perfect-ratio is important in such situation.

Fig. 2 shows the all-perfect-ratio of N = 50 and p = 0.05. We can see that the all-perfect-ratio of tri-PRNC is high while Arulselvan's scheme and no NC scheme are low. Moreover, the dia-PRNC is relatively low compared to tri-PRNC. In fig. 1, the number of decoded packets of tri-PRNC is also found very close to dia-PRNC when the retransmission packets is larger than 8. Therefore, when the number of retransmission packets is larger than 8, tri-PRNC is considered a better choice due to its higher all-perfect-ratio.

On the other hand, both Fig.3 and Fig.4 show that when N=100, the random coding has higher decoded packets and all-perfect-ratio than the other schemes, which is due to its relatively high randomness when the batch size (N) is larger.

Overall, we conclude that tri-PRNC is the best choice when the number of transmission is larger than the threshold; by contrast, when it is smaller than the threshold, dia-PRNC is better. The value of threshold differs from various given N.

B. goodput excluding overhead

We calculate the goodput as the part of actual payload in the packet. In random network coding, the header size is N bits, since each bit represents a coded original packet. The ratio of payload is payload/(header+payload), so when the ratio payload is L bits, the ratio of payload is L/(N+L). Since PRNC only includes indexes, the header size is 1 byte, and the ratio of payload is L/(8+L).

We assume the traffic is constant bit rate with payload 500 bytes and 1000 bytes in the simulation. Fig. 5 shows the goodput of L = 50 and payload = 500 bytes. We can see that the goodput of random network coding is lower than PRNC, and even Arulselvan's. When the payload is 1000 bytes (fig. 6), which is large, the goodput of random network coding is still lower than PRNC. When N = 100 (the figure is not here due to space limitation), the goodput of random network coding is still lower than PRNC. Therefore, we can see that PRNC effectively reduces the overhead, and increases the goodput.

C. different loss rate

Different schemes with various packet loss rates are also compared. We set N=50, and the number of transmission packets is 60. Fig.7 shows that when the number of transmission packets is 60 and the packet loss rate is lower than 0.08, tri-PRNC decodes more packets than Arulselvan's scheme and remains almost equal decoded packet number as dia-PRNC. On the other hand, when the packet loss rate is rising, the decoded packet number of tri-PRNC drops. Therefore, we conclude that the packet loss rate is also a threshold to decide which type of PRNC we will use.

D. Discussion

If the system operates in better situation which has large number of transmission packets, small loss rate, we can use tri-PRNC. The reason is that it has higher all-perfect-ratio, and its decode number is close to dia-PRNC in such situation. Otherwise, if the number of retransmission is forced to be small, we use dia-PRNC.

VI. CONCLUSION

Pseudo Random Network Coding is a network coding scheme with reduced overhead. PRNC stores coefficient index instead of the complete coding coefficient matrix in the data

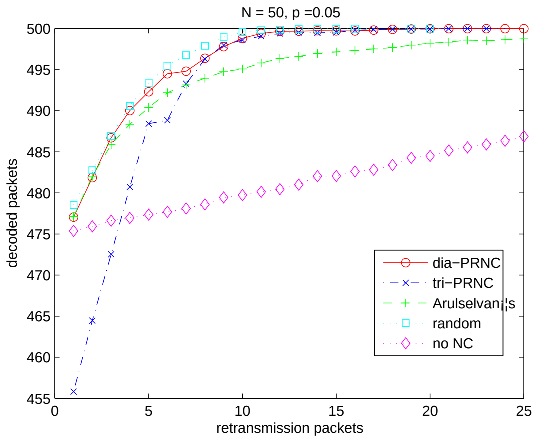

Fig. 1. decoded packets - N = 50, p = 0.05

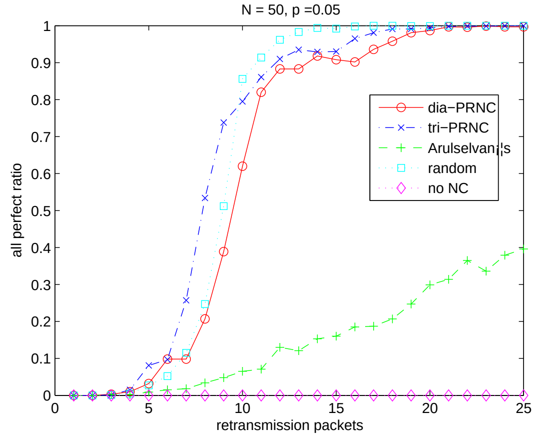

Fig. 2. all perfect ratio - N = 50, p = 0.05

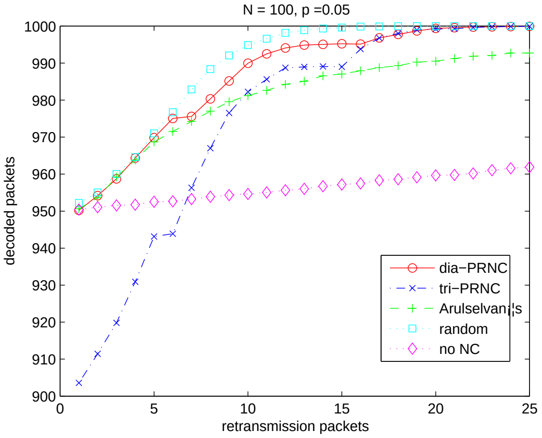

Fig. 3. decoded packets - N = 100, p = 0.05

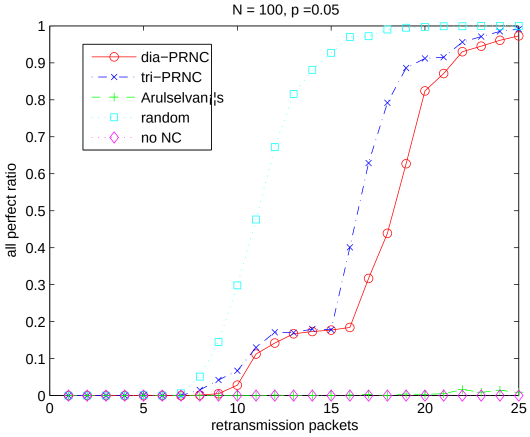

Fig. 4. all perfect ratio - N = 100, p = 0.05

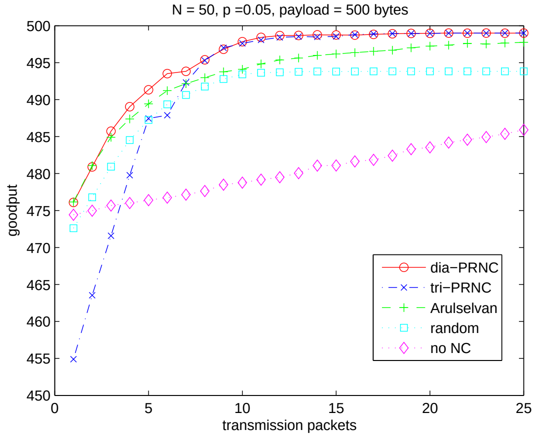

Fig. 5. goodput - payload = 500 bytes, N = 50, p = 0.05

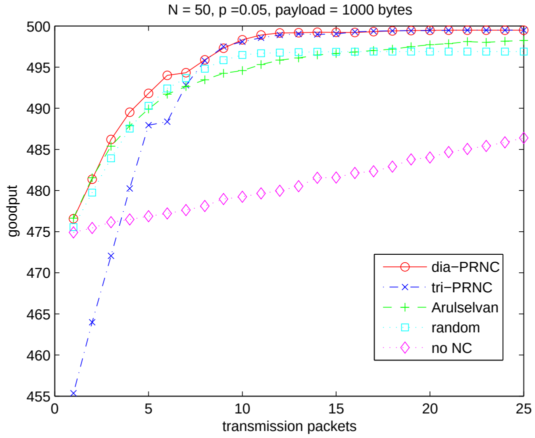

Fig. 6. goodput - payload = 1000 bytes, N = 50, p = 0.05

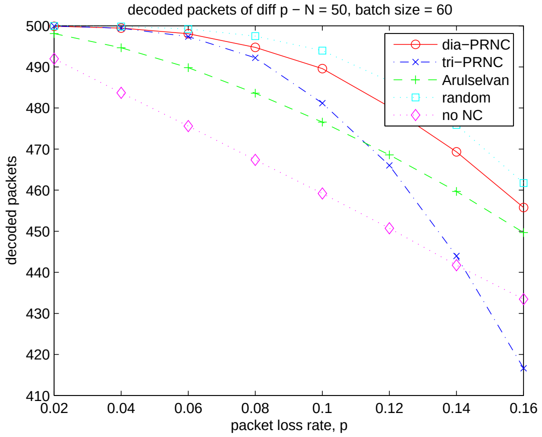

Fig. 7. decoded packets of diff p - N = 50, transmission packets = 60

packet header. The simulation results show that PRNC decode more packets and has a higher probability for perfect decoding such that all MS decode all packets. In summary, the proposed scheme provides higher throughput, higher reliability, and less overhead to WiMAX Enhanced Multicast and Broadcast Service.

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