

RWS-230442

PHY-Aware, MAC-Layer Network Coding for Reliable, Low-Latency Communication

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Agenda: 5 (RAN1/2/3-led Rel-19 topics)

Network or Outer Coding

- Network also goes by the name outer coding or packet-level FEC and is capable of improving reliability of communication as well as latency of communication by reducing or eliminating the need for HARQ or RLC ARQ retransmissions
- However introducing an additional coding scheme can lead to a loss in spectral efficiency
- In cases where there are multiple data-link paths between transmitter and receiver, PDCP duplication can be employed to increase reliability
- Such settings create an opportunity to introduce network coding without causing a loss in spectral efficiency
- In the current presentation, we present a network coding scheme that addresses such a setting and that significantly outperform PDCP layer duplication

Overview of Presentation

- As mentioned above, an outer coding scheme is presented for settings in which two or more distinct data link paths are present
- the network coding scheme, which is a packet-level FEC scheme, operates at the MAC layer and selects the size of the sub-packets which form the symbols of the network coding to coincide with the size of the message block of an LDPC code

This has the following advantages:

- the failure domain corresponds to the erasure of a single sub-packet thereby simplifying code design and enhancing performance
- this also permits the network coding scheme to make use of LDPC codewords that are correctly decoded by the PHY layer even if not all codewords belonging to the same transport block have been correctly decoded

The outer coding scheme presented here will be shown to significantly outperform PDCP duplication.

Motivation

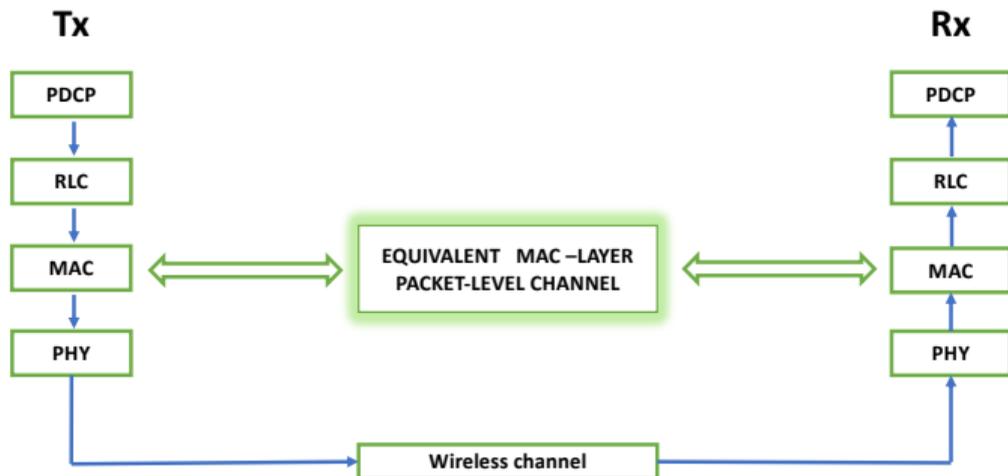
Reliable, low-latency communication is key to enabling applications such as

- V2X
- IIoT
- XR
- UAV
- Telesurgery

Existing techniques have their limitations and drawbacks:

- PHY-Layer FEC
(cannot recover from packet erasures)
- HARQ
(introduces undesirable latency)
- RLC-ARQ
(introduces undesirable latency)
- PDCP Duplication
(inefficient form of coding)

Proposed Network Coding at the MAC Layer



- We propose an outer-coding scheme at a MAC layer common to all distinct data-link paths connecting source and destination
- which provides transport blocks to the respective PHY layers

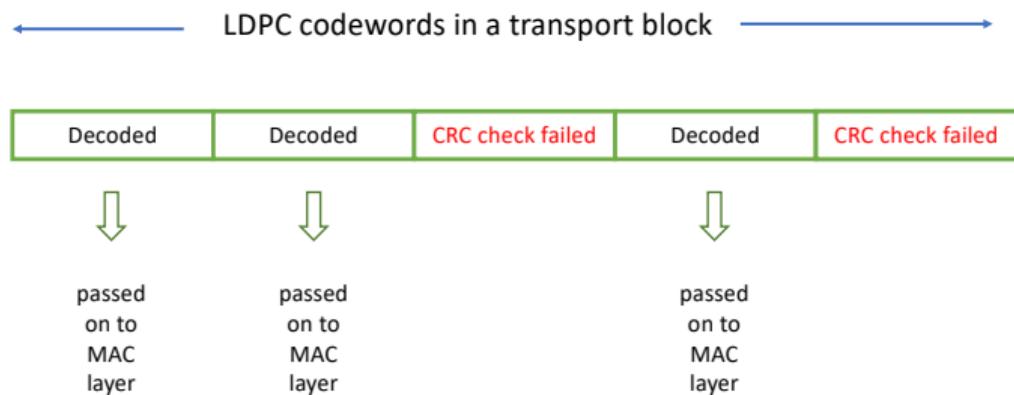
Assumptions on the Setting

- There are two or more data-link paths between transmitter and receiver
- The latency constraint does not permit more than a small number of HARQ retransmissions

Important Features of the Outer Coding Scheme

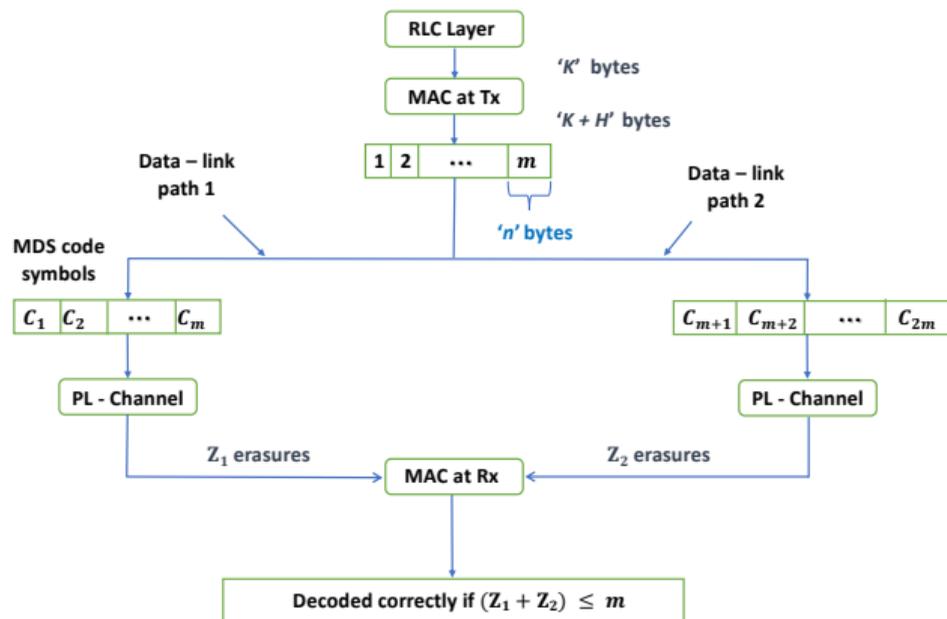
- **Appropriate selection of sub-packet size** Under the OC scheme presented here, the sizes of the sub-packets are made equal to the size of the message block of an LDPC codeword
 - ▶ thus the failure domain is a single sub-packet which is desirable
 - ▶ this is made possible as the sizes of the TBs and the LDPC codeword message-block lengths are known to the MAC layer
- **Partial TB Decoding Results Passed on to MAC Layer** The PHY layer at the receiver end, forwards LDPC codewords that have been correctly decoded to the MAC layer even when not all LDPC codewords have passed their CRC checks

Partial TB Decoding Results Passed on to MAC Layer



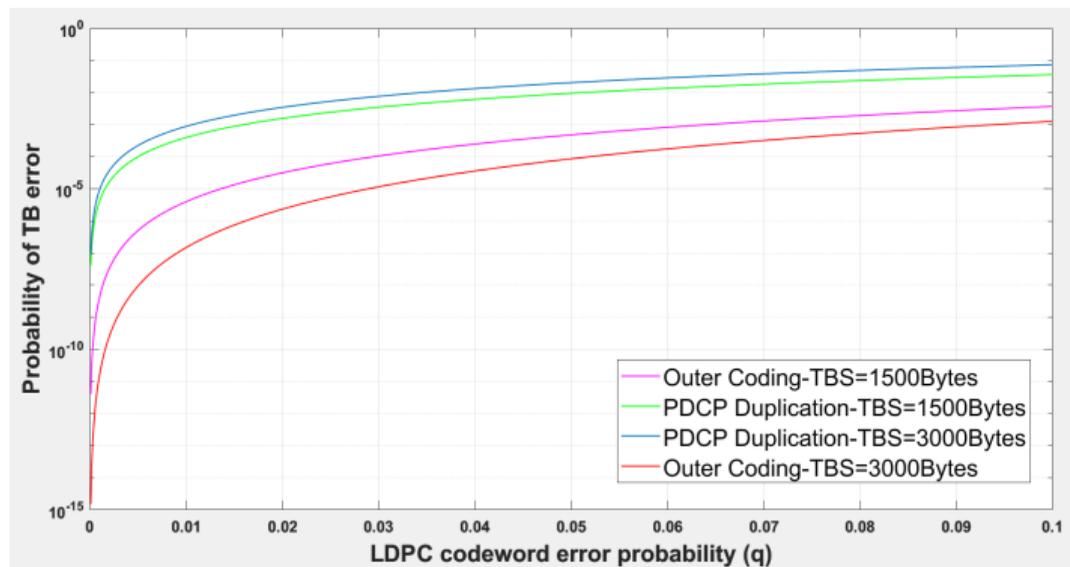
- 1 The PHY layer passes on decoded LDPC codewords to the MAC layer
- 2 even if not all LDPC codewords have been correctly decoded

Flowchart of the PHY-Aware, MAC-Layer Outer Coding Scheme



- 1 In this example scheme the data is required to be communicated over a single TTI
- 2 RLC supplies K bytes
- 3 that are fragmented into m sub-packets, each of which is a message block of an LDPC codeword
- 4 A $[2m, m]$ MDS code is used to encode the m sub-packets
- 5 m sub-packets are sent over each of the data-link paths P_1, P_2
- 6 the PHY layers at the receiver end, pass on the successfully decoded LDPC codewords (i.e., sub-packets) to the MAC
- 7 Receiver can decode if a total of m sub-packets are received over the two paths

Probability of Error Performance



- 1 The outer coding scheme presented here is shown to clearly outperform PDCP duplication
- 2 The performance difference grows as the size K of the incoming packet increases

Extensions

The scheme can be extended to other cases as well, such as for example,

- ① when a limited number of HARQ retransmissions is permissible, the outer coding scheme here can take advantage of the presence of HARQ
- ② the scheme has extensions to the case when the transport block sizes along the distinct data-link paths are distinct

Thanks!