

# Non-Binary Joint Network and Channel Coding for Underwater Sensor Networks

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## I. INTRODUCTION

Underwater sensor networks (UWSN) have enabled various underwater applications, such as oceanographic data collection, pollution monitoring. However, researches in UWSN still face many fundamental challenges [1], [2], [3]. One critical problem is reliable communication because of the severe fading conditions in acoustic channels. Main reasons for fading include attenuation, geometric spreading and multi-path.

One important methodology to combat fading effects is using redundant information. Channel coding is a conventional error-correction technique for point-to-point communication in wireless environments with redundancy inside packets, while network coding can be treated as an erasure-correction technique with redundancy cross packets. Many schemes have been proposed in terrestrial wireless networks to jointly exploit the redundancy at both levels.

Christoph Hausl *et al.* first propose joint network coding for multi-access relay channel [4] and present iterative network and channel decoding on a tanner graph [5]. They show the benefits from jointly exploiting two levels of codes. Bao and Li propose Adaptive Network Coded Cooperation (ANCC) for multiple transmitters sending data to a common receiver through inherently unreliable and constantly changing channels [6] and extend it to GANCC [7]. They present a general framework that unifies channel coding and network coding [7]. The above schemes cannot be directly applied to general multiple hop wireless networks because they are based on binary operation and require specific topologies.

In this paper, considering the specific constraints of UWSN, we propose *Non-Binary Joint Network Channel Coding (NB-JNCC)* to seamlessly combine non-binary LDPC code and random linear network code. This non-binary operation jointly exploits the spatial diversity and coding diversity to combat severe fading effects.

## II. NON-BINARY JOINT NETWORK CHANNEL CODING

We consider a simple topology with two senders, ( $S_1$  and  $S_2$ ), two relays, ( $R_1$  and  $R_2$ ) and one sink as shown in Figure 2. This can be treated as the last hop topology in a large UWSN and the packets from senders can be of any form of network codes from the previous hops. All coding and decoding are operated on Galois Field  $GF(2^q)$ .

We use non-binary LDPC code as the channel code, which is specified by the parity check matrix  $H_{M \times N}$  and generator

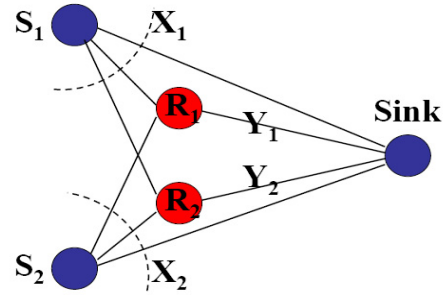


Fig. 2. Last hop topology in a large network

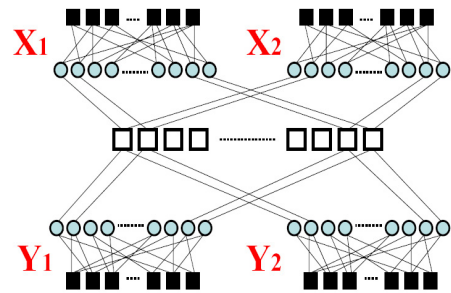


Fig. 3. Joint network channel coding on a factor graph.

matrix  $G_{K \times N}$ , satisfying  $HG^T = 0$ . Sender  $S_1$  generates a packet  $u_1$  of  $K$  symbols, each symbol  $q$  bits, then encodes it as  $X_1 = u_1G$ . The channel code rate is  $R_c = K/N$ . Correspondingly, the codeword from the other sender  $S_2$  is obtained as  $X_2 = u_2G$ . Packets  $X_1$  and  $X_2$  form a generation to be broadcasted to relays and the sink through different channels.

We assume the channels between the sources and relays are lossless. After receiving packets from the sources, the relays first decode them to obtain the original packets, then encode through non-binary LDPC encoder before generate network codes using random linear network coding. Thus the two network codes from relays  $R_1$  and  $R_2$  are:

$$Y_1 = \alpha_{11}u_1G + \alpha_{12}u_2G \quad (1)$$

$$Y_2 = \alpha_{21}u_1G + \alpha_{22}u_2G \quad (2)$$

where the coding coefficients  $\alpha_{ij}$  ( $i, j = 1, 2$ ) are chosen randomly from  $GF(2^q)$  and carried with the packets as coding vector.

The sink will receive channel codes ( $X_1, X_2$ ) directly from

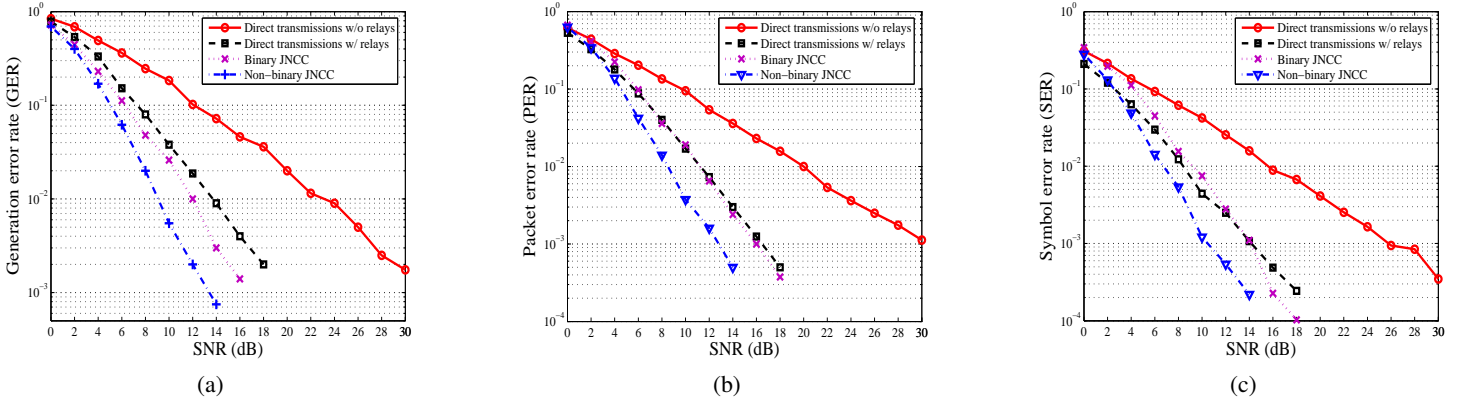


Fig. 1. Performance comparison of NB-JNCC with other schemes.

the senders and network codes ( $Y_1, Y_2$ ) from the relays, thus the network code rate  $R_n = 2/4$ . All these packets can be concatenated together to form a longer codeword as

$$\begin{pmatrix} X_1 \\ X_2 \\ Y_1 \\ Y_2 \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \\ \alpha_{11} & \alpha_{12} \\ \alpha_{21} & \alpha_{22} \end{pmatrix} \begin{pmatrix} u_1 \\ u_2 \end{pmatrix} G = M \begin{pmatrix} u_1 \\ u_2 \end{pmatrix} G, \quad (3)$$

where  $G$  is the traditional non-binary LDPC code generator matrix, which can be used for channel decoding through message passing, while  $M$  indicates the relationship cross packets on corresponding positions for information exchange among network codes. The received packets form a matrix of size  $4 \times N$ , where each row captures the relationship cross symbols in channel coding and each column captures the relationship cross packets through network coding. The integrated codes can be mapped to a factor graph as shown in Figure 3. In the factor graph, the circles and the black rectangles represent variable nodes and parity check nodes respectively in the channel codes; the white rectangles represent parity check nodes across network codes. All these nodes are connected directly or indirectly, so all information can be transferred through these links and be jointly exploited.

### III. PERFORMANCE ANALYSIS

We demonstrate the benefits of NB-JNCC through simulation. We still consider the topology in Figure 2 and  $GF(2^4)$ . The senders generate packets with packet size of  $K = 800$  symbols. We construct a non-binary irregular LDPC code, whose average column weight is 2.8 and code rate  $R_c = 0.8$ . Then the encoded channel codes have the length of 1000 symbols. The relays perform linear network coding over  $GF(2^4)$ . All packets are modulated using BPSK and all channels are modeled as rayleigh fading channels. We implement four schemes: *direct transmissions w/o relays*, *direct transmissions w/ relays*, *binary JNCC* and *NB-JNCC*.

We compare their generation/packet/symbol error rates versus SNR. The results are shown in Figure 1. We see NB-JNCC outperforms others with the highest diversity around 2.5. We observe NB-JNCC improves the performance by

around 20dB compared to direction transmission w/o relays and 4dB compared to direct transmissions w/ relays and binary JNCC. We also notice that binary JNCC provides similar packet and symbol error rates as direct transmissions w/ relays, but shows around 3dB network coding gain on generation error rate. There are two reasons behind this observation: (1) Two redundant network codes from relays are copies of the same packet and loose the coding diversity; and (2) Network coding tends to cause a whole generation of packets recoverable or unrecoverable depending on the information received.

### IV. CONCLUSIONS

In this paper, we propose non-binary joint network channel coding (NB-JNCC) to combat severe channel fading conditions in UWSN. This scheme seamlessly combines non-binary LDPC code and random linear network code for joint decoding on an integrated factor graph through message passing. Compared to other schemes, NB-JNCC fully exploits the redundancy residing in different levels of codes in the form of diversity gain and joint coding gain.

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