Communication Efficient Data Exchange Among Multiple Nodes

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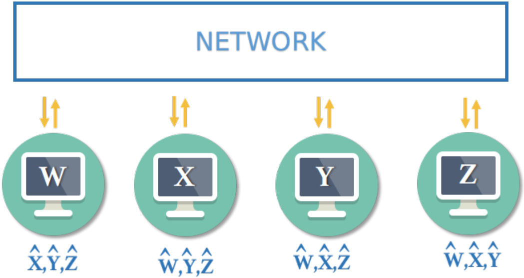
Motivation

The Data-Exchange problem

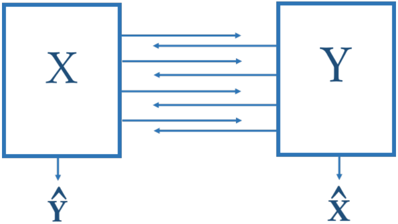


Multiple parties observing correlated data seek to recover each other's data. How can they accomplish this using minimum communication?

The Data-Exchange Problem

Two party case

- Random correlated data (X,Y) is distributed between two parties.
- The first observes X and second observes Y.
- They seek to recover each others data.
- The joint distribution of X and Y is unknown.



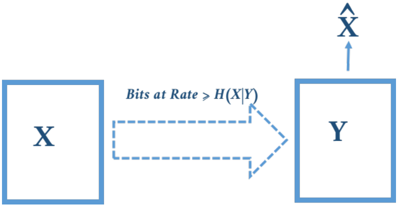
This project seeks to device a protocol which achieves this with minimal communication.

Working Solution

r-sync vs Slepian-Wolf compression

- In practice, algorithms like r-sync are used for data exchange.
  - Uses *one* guess.
  - Does not exploit the correlation between the data well.
  - Needs more communication.
  - Fast and low complexity.

- In theory, Slepian-Wolf compression is optimal.
  - Under joint decoding $H(X|Y)$ is sufficient to estimate X.



Implementation of SW compression.

Difficulties and suggested approach...

Difficulties in implementaion of SW compression

- Search is over an exponential list in decoding.
- Knowledge of $P_{X|Y}$ is required at encoder.

Suggested Approach

- Implement SW Compression using Polar Codes.
- Achieve universality using *recursive data exchange* protocol (RDE).
- Realise RDE using Rateless Polar Codes with physical layer error detection.

Outline

- Background
  - Recursive Data Exchange (RDE)
  - Brief introduction to Polar Codes
  - Slepian-Wolf compression with Polar Codes
  - Rateless Polar Codes
- Proposed implementation of RDE
  - Adaptation of Rateless Polar Code for RDE
  - PHY-Layer error detection
- Performance evaluation
- Conclusion and future work

Recursive Data Exchange (RDE)

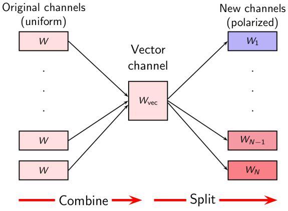
The *recursive data exchange** protocol is based on an interactive version of the SW protocol

- Here the length of communication is increased in steps until the second party decodes the data of the first.
- After each transmission second party sends ACK-NACK feedback signal, the protocol stops when ACK is recieved or some fixed number of bits have been transmitted.
- This protocol is *universal* as it does not rely on knowledge of the joint distribution.
- It uses an iterative variable length approach to reach rate optimality universally.
- The suggested decoders are theoritical constructs which use type classes to form a list of guesses for data of other parties and thus has exponential complexity.

* H. Tyagi and S. Watanabe, Universal Multiparty Data Exchange and Secret Key arrangement, *ISIT*, 2016

Brief Introduction to Polar Codes

Channel polarization



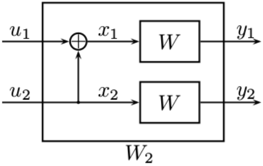
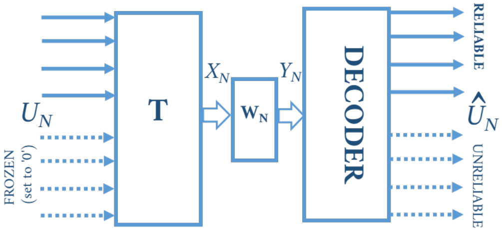


Figure: Transformation butterfly

- N independent copies of a given B-DMC (W) are combined and split into a second set of N channels $\{W_N^{(i)} : 1 \leq i \leq N\}$.
- There symmetric capacity $I(W_N^{(i)})$ tend towards 0 or 1.
- The channels with Bhattacharya parameter $Z(W_N^{(i)}) = 0$ captures the capacity of W_{vec}.

Brief Introduction to Polar Codes

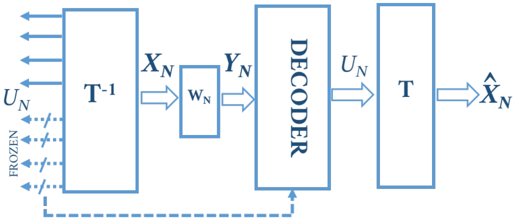
Encoding and decoding



- The encoding process[†] sends data on transformed channels with $Z(W_N^{(i)}) = 0$ (*good channels*) and treats the channels with $Z(W_N^{(i)}) = 1$ as *frozen*, sending no useful data on them.
- For our purpose, we shall be using Succesive Cancellation (SC) decoding.

[†] U_N is a uniform message vector, T is a linear transform for the butterfly.

Slepian-Wolf compression with Polar Codes



- Y_N is a corrupted version of X_N by N BSC(p) channels.
- The bits that are to be sent for estimation of X_N from Y_N are the frozen bits in U_N.
- These bits are communicated error free to the SC-decoder.
- $H(X_N) - I(W_N) = H(X_N/Y_N)$ bits are sent.

Performance

Rateless Polar Codes

Rateless code

Rateless Code

A rateless coding scheme transmits incrementally more and more coded bits over an unknown channel until all the information bits are decoded reliably by the receiver.

- A rateless code is designed for a set of channels and judged for its performance for the entire set.
- In general rateless code design is based on Hybrid-ARQ techniques and uses code puncturing.
- Rateless Polar Codes can be constructed using nesting property of Polar Codes for degraded channels.

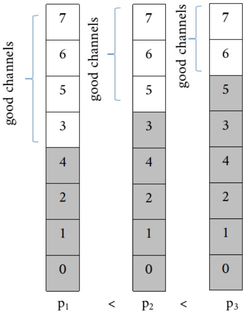
Rateless Polar Codes

Degraded channels and nesting property

Degraded channels

if X–Y–Z, and $W_1 = P_{Y|X}$, $W_2 = P_{Z|X}$ then $W_2 \preceq W_1$.

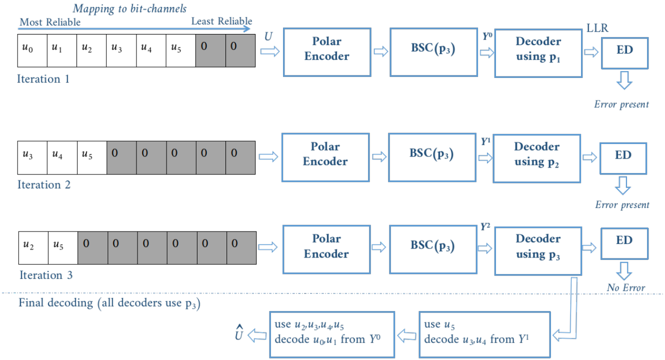
- The capacity of W_2 is lesser than that of W_1. W_2 has lesser number of good channels.
- e.g., $BSC(p_1) \preceq BSC(p_2)$ if $p_1 \geq p_2$.



- The good bit indices of W_2 is a subset of the good bit indices of W_1.
- A more reliable bit-channel is always noiseless if a less reliable bit-channel is noiseless. This leads to *reliability ordering*.

Incremental Freezing

Rateless Polar Code employing reliability ordering



- Initial transmission is done using a high rate Polar Code.
- If decoding fails then the comparatively lesser reliable channels are retransmitted.

Incremental Freezing

continued...

- Features
  - By decoding the bits from future transmissions they effectively become frozen.
  - This scheme is capacity achieving in the sense that no rate has been wasted.‡
  - A certain number of channels in this scheme is "*always available*" guaranteeing a certain rate in each transmission.
  - n iterations of the scheme is almost equivalent in performance to a R/n fixed rate Polar Code.

‡, Figure illustrates the scheme for a set of channels with rates $\{R_1 = 6/8, R_2 = R_1/2 = 3/8, R_3 = R_1/3 = 1/4\}$. After the 3^{rd} transmission u_2 to u_5 have been incrementally frozen. The final rate achieved is, $R^* = \frac{6}{8*3} = \frac{1}{4} = R_3$

Rateless Polar Codes as Hybrid ARQ

- Features
  - By decoding the bits from future transmissions they effectively become frozen.
  - This scheme is capacity achieving in the sense that no rate has been wasted.[§]
  - A certain number of channels in this scheme is "*always available*" guaranteeing a certain rate in each transmission.
  - n iterations of the scheme is almost equivalent in performance to a R/n fixed rate Polar Code.

[§], Figure illustrates the scheme for a set of channels with rates $\{R_1 = 6/8, R_2 = R_1/2 = 3/8, R_3 = R_1/3 = 1/4\}$. After the 3^{rd} transmission u_2 to u_5 have been incrementally frozen. The fi

Selective Repetition * Subset Polar Codes RB-HARQ

References

(1) S. Kumar and H. D. Pfister, Reed-Muller codes achieve capacity on erasure channels, 2015, [Online]. Available: http://arxiv.org/abs/1505.05123v2.

(2) S. Kudekar, M. Mondelli, E. Şaşŏglu, and R. Urbanke, Reed-Muller codes achieve capacity on the binary erasure channel under MAP decoding, 2015, [Online]. Available: http://arxiv.org/abs/1505.05831v1.

(3) $\equiv$ (1) $\cup$ (2) S. Kudekar, S. Kumar, M. Mondelli, H. D. Pfister, E. Şaşŏglu, and R. Urbanke, Reed-Muller codes achieve capacity on erasure channels, 2016, [Online]. Available: http://arxiv.org/abs/1601.04689v1.


What people think about
during your conference talk
Hee hee! Animated arrows!
Typo on slide 14, line 3, centre-left. Noted.
Hey! That's what I'm working on!
(RANDOM HAPPY THOUGHTS]
I'm up next I'm up next I'm up next
I'm in the wrong session.
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Thank You!

The r-sync protocol

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Polar Encoding

back

Succesive Cancellation Decoding

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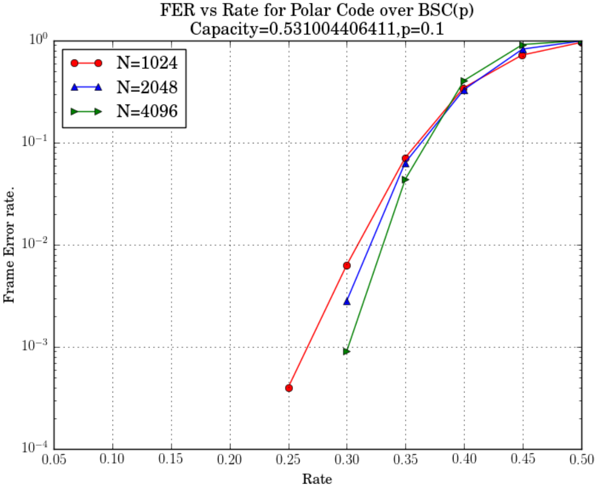
Performance of Polar Codes



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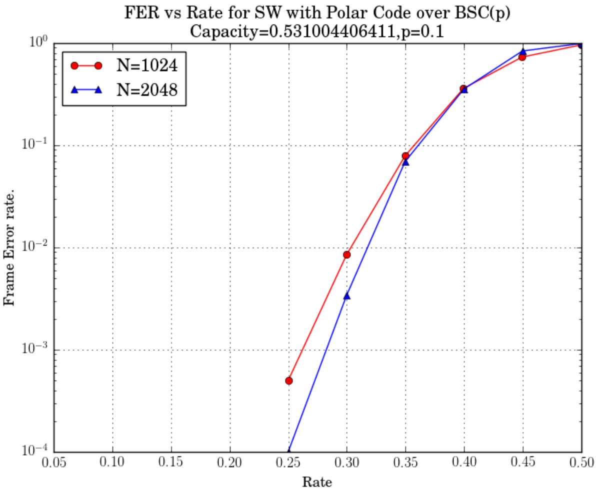
Performance of SW compression Polar Codes



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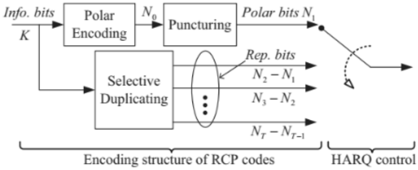
Selective Repetition H-ARQ for polar codes

- Initially, an information block of K bits is fed into a polar encoder.
- The output codeword of N_0 bits is punctured into N_1 bits and sent over the channel.



- Retransmission process
  - On decoding failure reciever sends a NACK.
  - $N_2 - N_1$ of the information bits are retransmitted.
  - The receiver tries to perform decoding with all the N_2 received bits.
  - This process continues until the transmitter receives an ACK

The retransmitted bits (RV) are chosen one at a time as the most unreliable of the K bits transmitted, reliability is calculated after choosing one bit and the process is iterated.

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Subset Polar Codes

- A Subset Polar Code can be created by greedily puncturing a low-rate mother code without re-optimizing the information bits.
- The scheme uses equivalent Subset Polar Codes as RV.
- This has the better performance compared to other HARQ methods.

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Reliability based HARQ

Reliability based HARQ technique (RBHARQ) , eliminates the use of CRC by approximating bit and word error probability from likelihood ratios (LLR). The bit error probability for the k^{th} bit can be estimated from LLR ($\tilde{u}_k$) as,

$$P_{b,k} = P(\hat{u_k} \neq u_k) = \frac{1}{1 + e^{|\tilde{u}_k|}} \tag{1}$$

then word error probability becomes,

$$P_w = 1 - e^{log\,\bar{P}_w} \tag{2}$$

where,

$$log\,\bar{P}_w = log \prod_{k=1}^{K} (1 - P_{b,k})$$

If the word error probability does not meet the requirements the bits with higher bit error probability may be retransmitted. This increases throughput, particularly evident in case of short packet lengths.

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