Polar Coding for Selector-less Resistive Memories

Marwen Zorgui, Mohammed E. Fouda, Zhiying Wang, Ahmed Eltawil, and Fadi Kurdahi

University of California, Irvine

Non-Volatile Memories Workshop, Mar 11, 2019
Agenda

• Varying Sneak Path in Resistive Memory
• Polar Codes for Varying Channels
• Application to Crossbar Arrays
• Conclusion
Emerging Memory Technologies

Parameter | FeRAM | STTRAM | PCRAM | ReRAM
---|---|---|---|---
Maturity | Product | Product | Product | Product
Feature Size | F>45nm | 10n<F<45n | F< 10 nm | F< 10 nm
3D Integration | Difficult | Possible | Feasible | Feasible
Endurance | < $10^{10}$ | $>10^{10}$ | $< 10^{5}$ | $>10^{10}$
Retention | <10 years | <10 years | <10 years | >10 years
Latency | <100ns | <100ns | <100ns | $\leq 5\,\text{ns}$
Power | Low | Medium | Medium | Low
Variability | low | Reasonable | Reasonable | Reasonable

Crossbar One-Step Reading

Sneak Path

Feature size $F$ | Wire resistance $R_w$
---|---
50nm | 5Ω
5nm | 90Ω
Varying Sneak Path

\[ R_w = 30\Omega \]
Varying Channels

- Threshold per cell, per row, per column, or per array
- Training: Logistic regression-based
- => Binary symmetric channels (BSCs) with varying error probabilities
Polar Coding

• Low complexity encoding and decoding: $O(N \log N)$

• Provably capacity-achieving

• Adaptable to different scenarios, including varying channels
Basic Polar Transformation & Properties

Channel combination

Channel splitting

\[ W'_0 : U_0 \rightarrow (Y_0, Y_1) \]

\[ W'_1 : U_1 \rightarrow (Y_0, Y_1, U_0) \]

Capacity conservation & Extremization

\[ I(W'_0) + I(W'_1) = I(W_0) + I(W_1), \]

\[ I(W'_0) \leq I(W_i) \leq I(W'_1), i = 0, 1. \]

Recursive Application of Polar Transformation

Size 4 polar code construction

\[
\begin{align*}
U_0 & \rightarrow X_0 \\
U_1 & \rightarrow X_1 \\
U_2 & \rightarrow X_2 \\
U_3 & \rightarrow X_3 \\
W_0 & \rightarrow Y_0 \\
W_1 & \rightarrow Y_1 \\
W_2 & \rightarrow Y_2 \\
W_3 & \rightarrow Y_3 \\
\end{align*}
\]

Size 8 polar code construction

\[
\begin{align*}
U_0 & \rightarrow X_0 \\
U_1 & \rightarrow X_1 \\
U_2 & \rightarrow X_2 \\
U_3 & \rightarrow X_3 \\
U_4 & \rightarrow X_4 \\
U_5 & \rightarrow X_5 \\
U_6 & \rightarrow X_6 \\
U_7 & \rightarrow X_7 \\
W_0 & \rightarrow Y_0 \\
W_1 & \rightarrow Y_1 \\
W_2 & \rightarrow Y_2 \\
W_3 & \rightarrow Y_3 \\
W_4 & \rightarrow Y_4 \\
W_5 & \rightarrow Y_5 \\
W_6 & \rightarrow Y_6 \\
W_7 & \rightarrow Y_7 \\
\end{align*}
\]
We have $N$ channels of different reliabilities

Polarization theory extends to this setup [1]

Fraction of good polarized channels approaches the average of the channels’ capacities [2]

Moreover, systematic codes have better empirical bit error rate (BER) [3]

Question: Can we reorder the channels to get better BER?

Proposed Ordering of the Channels

• Assume the channels are such that $I(W_0) \leq I(W_1) \leq \cdots \leq I(W_{N-1})$

• We propose the use of the bit-reversal permutation $\Psi$

• Example: $N = 8$; $\Psi = (0, 4, 2, 6, 1, 5, 3, 7)$

• Bit-reversal permutation has been proposed in the context of rate-compatible polar codes [1]

• Binary symmetric channels (BSCs).
• Raw BER (p) are linearly spaced with maximum deviation of 0.045.
• Bit-reversal permutation performs empirically good.
• Systematic encoding gain.

Example for Synthetic Channels

Rate = 0.5, N=1024
Application to the Crossbar Array

• Transform the read cells into BSC’s:
  • Estimate a threshold for each row (wordline) by logistic regression
  • Estimate the raw BER for each cell

• Apply proposed polar codes with the estimated raw BER
  • Encode each row separately
32 × 32 array, $\mathcal{R} = 0.5$, $R_w = 30\Omega$, $LRS = 1K\Omega$, $HRS = 1M\Omega$
Conclusion and Future Work

- Applied polar codes to the sneak path problem in resistive arrays
- Proposed channel ordering method to improve the performance
- Enhanced performance compared to regular polar codes

Future directions:

- Modeling and soft-information decoding
- Encoding the entire array for storage systems
- Enhanced successive-cancellation list decoding