On Error-Correction Performance and Implementation of Polar Code List Decoders for 5G

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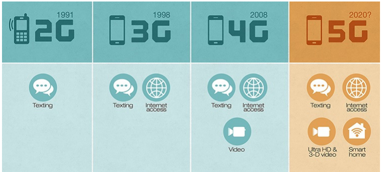
Motivation



- **Polar Codes** provably achieve channel capacity
  - Adopted in **5G eMBB** control channel
- **5G** standardization requires
  - Improved error-correction performance & throughput
  - Reduced power consumption

Motivation

- Successive Cancellation **(SC)** decoding
  - Long decoding latency
  - Mediocre error-correction performance
- Successive Cancellation List **(SCL)** decoding
  - Improved error-correction performance
  - Increased latency and power consumption
  - *Algorithms to reduce area, power and energy*

Focus

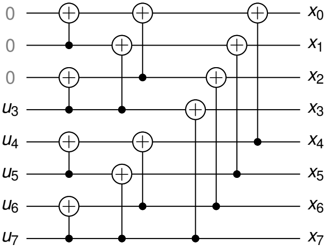
Subject decoder algorithms:

- SC-List (SCL)
- Simplified SCL (SSCL)
- Fast-SSCL
- Partitioned SCL (PSCL)

Comparison Metrics:

- Error-correction performance
- Power & energy consumption

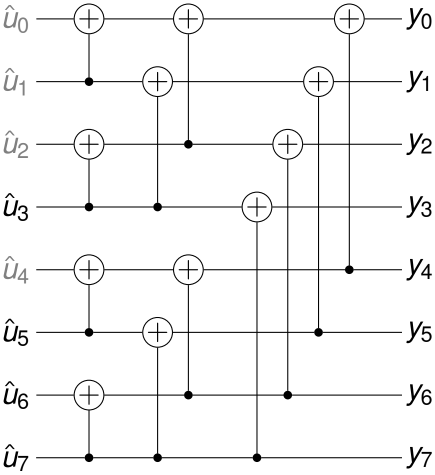
Polar Codes - Encoding



$$uG = u \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{bmatrix}$$

Successive Cancellation Tree

- View the SC decoder graph as a tree.



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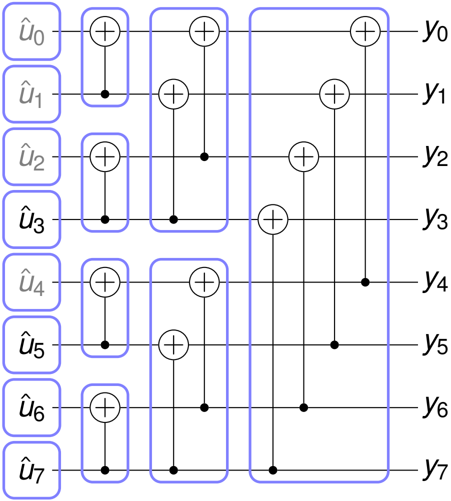

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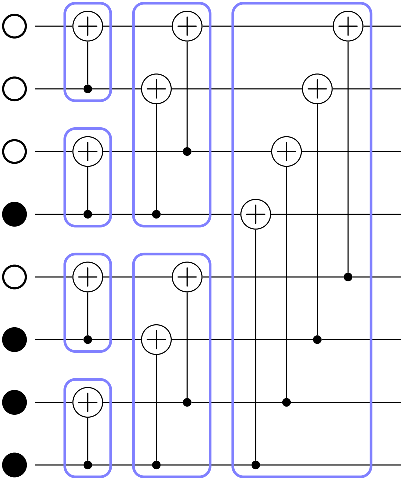

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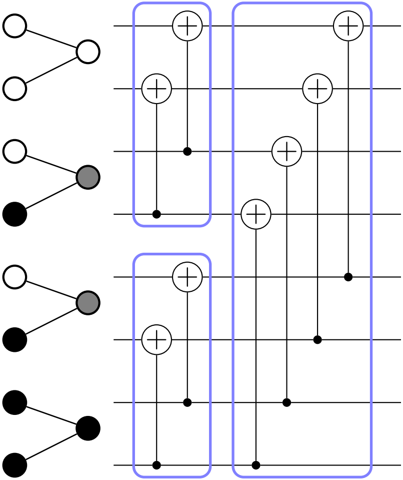

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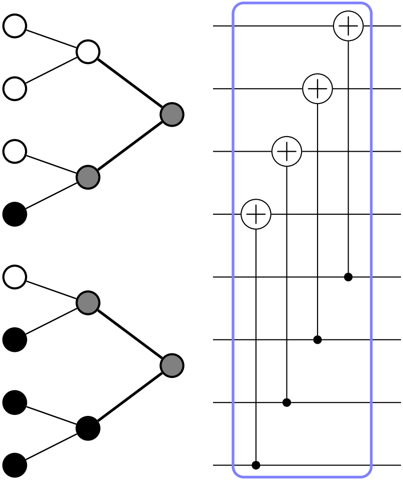

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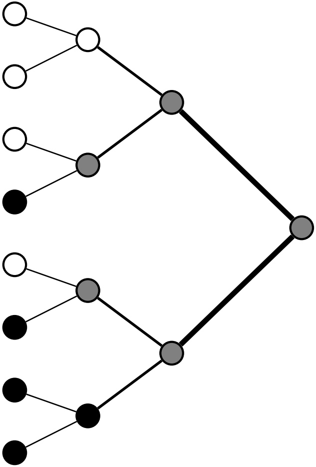
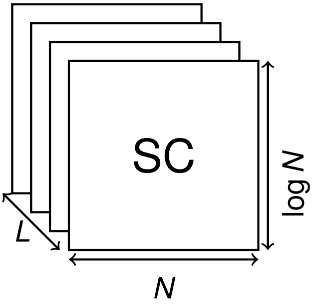


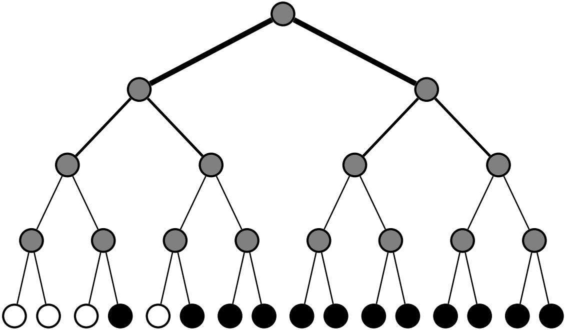
SCL Decoding

- Split path at each information bit estimation
  - Up to L paths limit complexity
  - A path metric to pick the correct codeword
  - CRC improves error-correction performance



SSCL & Fast-SSCL Decoding

- $N = 16, K = 12$



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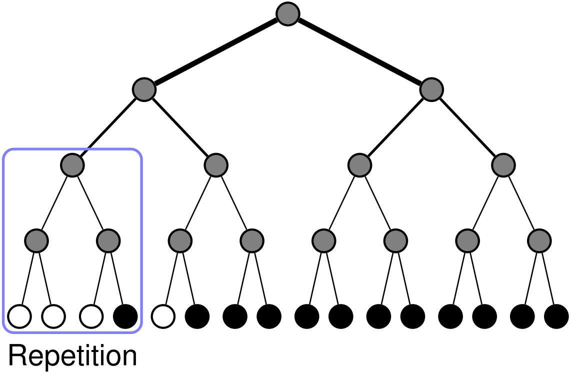

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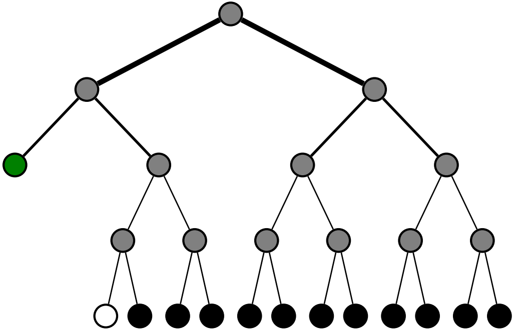

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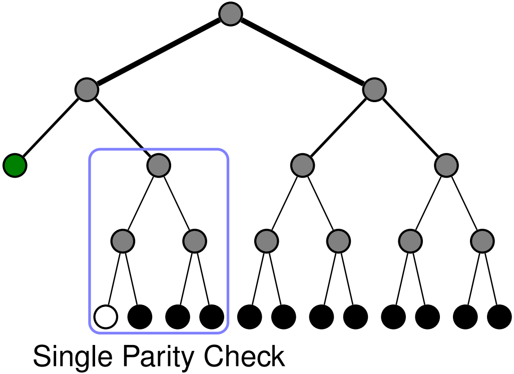

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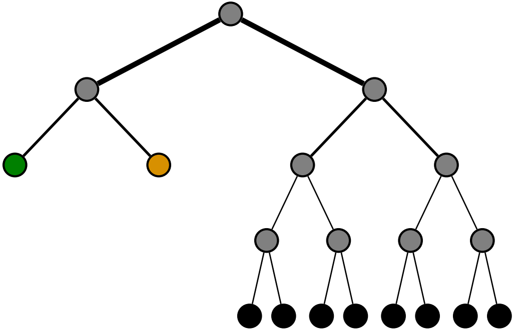

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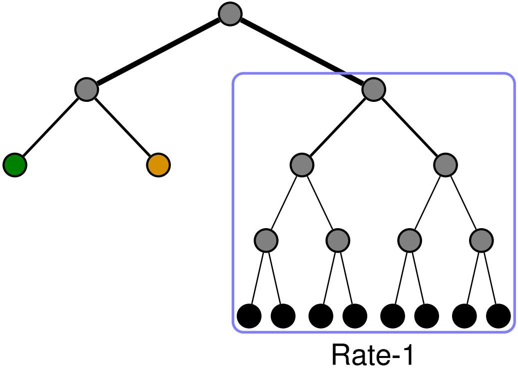

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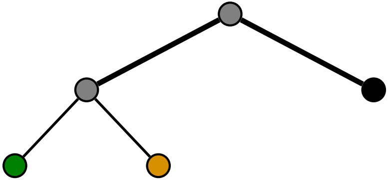

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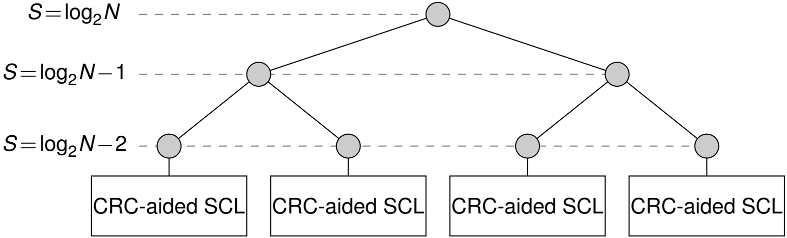
Partitioned SCL (PSCL)

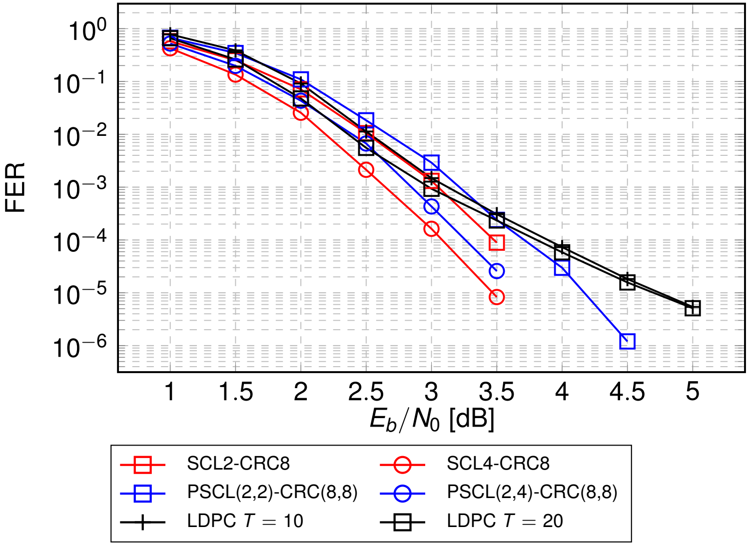
Divides polar code into P constituent sub-trees of length N/P



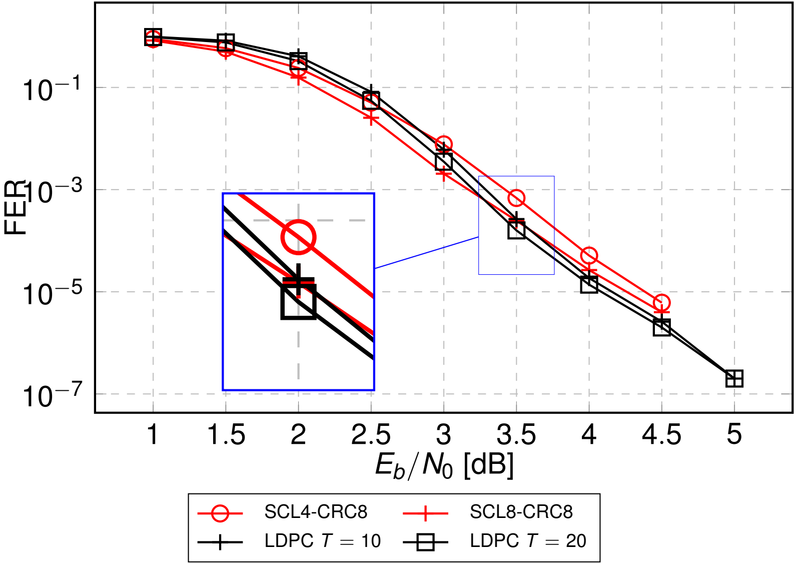
Error-Correction Performance Comparison

- Subject SCL-based decoders implemented in hardware and compared against WiMAX LDPC codes
  - Polar code length $N \in \{256, 512\}$ (included in 5G eMBB)
  - LDPC code length $N = 576$ (from WiMAX)
- Target polar code rates on 5G discussions $R \in \{\frac{1}{6}, \frac{1}{3}, \frac{1}{2}, \frac{2}{3}\}$.
- WiMAX LDPC allows $R \in \{\frac{1}{2}, \frac{2}{3}\}$.

SCL vs LDPC - $R = \frac{1}{2}$, $N_{PC} = 512$; $N_{LDPC} = 576$



SCL vs LDPC - $R = \frac{2}{3}$, $N_{PC} = 512$; $N_{LDPC} = 576$



ASIC Implementation for List Decoders

Compare H/W architectures for

- $R = \frac{1}{2}$: LDPC decoders vs. PSCL
- $R = \frac{2}{3}$: LDPC decoders vs. SCL/SSCL/Fast-SSCL

ASIC Implementation Results - $N = 512, R = \frac{1}{2}, L = 8$

Algorithm	Area [mm^2]	Power [mW]	Energy [nJ]	T/P [Mbps]
SCL	1.006	345.39	589.82	254
SSCL	1.314	421.47	356.67	860
Fast-SSCL	1.685	493.43	341.08	1164
PSCL	0.694	205.68	351.25	254

ASIC Results: LDPC vs. SCL

- Polar code decoders have 7.7×to 17.1× *less area* than LDPC decoder implementations

	SCL[a]	Fast-SSCL[a]	PSCL[a,b]	LDPC[1]	LDPC[2]	LDPC[3]
Tech. (nm)	65	65	65	90	180	90
Rate	1/2	1/2	1/2	Any	1/2	Any
Area (mm^2)	0.215	0.422	0.191	6.22	N/A	6.25
Area[d] (mm^2)	0.215	0.422	0.191	3.24	N/A	3.26
Power (mW)	75.27	119.68	63.19	528	553	264
Energy (nJ)	128.54	51.01	107.91	1368	232.9	690.6
T/P (Mbps)[d]	254	1427	254	293	1813	145

[a] $L = 2$, $C = 8$. [b] $P = 2$, $(c_0, c_1) = (8, 8)$. [d] Scaled to 65 nm.

[1] Liu et al. "Design of a Multimode QC-LDPC Decoder Based on Shift-Routing Network," *IEEE TCAS-II*, 2009.

[2] Hung et al. "A 1.45Gb/s (576,288) LDPC Decoder for 802.16e standard," *IEEE ISSPIT*, 2007.

[3] Liuet al. "An LDPC Decoder Chip Based on Self-Routing Network for IEEE 802.16e Applications," *IEEE JSSC*, 2008.

ASIC Results: LDPC vs. SCL

- Polar code decoders consume up to 8.75× times *less power* & 26.8× *less energy* than LDPC decoder implementations

	SCL[a]	Fast-SSCL[a]	PSCL[a,b]	LDPC[1]	LDPC[2]	LDPC[3]
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Concluding Remarks

- State-of-the-art SCL-based architectures are evaluated
  - Error-correction performance
  - Area, power, energy consumption
- Compared against WiMAX LDPC code decoders from literature
- Polar code decoders have reduced area, power, energy at matched FER
- Suitable for potential 5G implementations

Thank you for your attention!