Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: A Study on Comparison of Polar and LDPC Codes above 100Gb/s Throughput Regime
Date Submitted: 15 July 2019
Source: Onur Sahin, InterDigital Europe
Address: 64 Great Eastern St, InterDigital Europe, London, UK, EC2A 3QR
Voice:+447459205055, FAX:+442077494196 , E-Mail:onur.sahin@interdigital.com
Re: n/a
Abstract: This talk will provide studies on the communication performance and implementation level comparison of LDPC and polar codes for above 100Gb/s throughputs. The comparison will focus on selected LDPC codes standardized in 3GPP 5G NR, IEEE 802.16 WiMAX, IEEE 802.15.3d standards, and state-of-the-art polar codes designed for ultra-high throughputs.

Purpose: Information of the Technical Advisory Group THz

Exceeding 100 Gb/s Barrier in Wireless Communications

- **Huge available spectrum** potential above 250GHz to achieve 100Gb/s and higher throughputs.
  - 252-325 GHz bands already considered under 802.15.3d.
  - Potential bandwidth allocations: 275-450GHz in WRC 2019 (AI 1.15).
- Substantial progress in **device-level and RF** front-end.
  - THz photonics based RF front-end solutions demonstrate ~100Gb/s ([1]).
  - 300 GHz Si CMOS transceiver solutions with >100Gb/s transmitters ([2]).
- **Novel baseband algorithms and architectures** are necessary to enable ultra-high throughputs in THz domain for a wide range of practical use-cases.
  - **FEC** is the most complex and computationaly intense component in the baseband chain → A key enabler and challenge for ultra-high throughput/THz communications.

State-of-the-Art FEC for High Throughput Wireless Systems

In existing wireless standards, 3GPP 5G NR, IEEE 802.15.3d and IEEE 802.11ad* present FEC classes with highest throughput requirements.

- 3GPP 5G NR (Target peak **TP: 20Gb/s**)
  - Flexible QC-LDPC; 20 Gb/s with rate 8/9 is supported
- IEEE 802.15.3d (Target peak **TP: 100Gb/s**)
  - Rate 14/15 LDPC (1440,1344)
  - Rate 11/15 LDPC (1440,1056)
- IEEE 802.11ad (Target peak **TP: 7Gb/s**)
  - Rate (1/2, 5/8, 3/4, 13/16) LDPC with code-word length 672

* 802.11ay amendment (Draft 3.0 stage) targets >20 Gb/s, in addition includes Rate (1/2, 5/8, 3/4, 13/16) LDPC-1344. The decoder architectures are based on 11ad LDPC-672 codes.

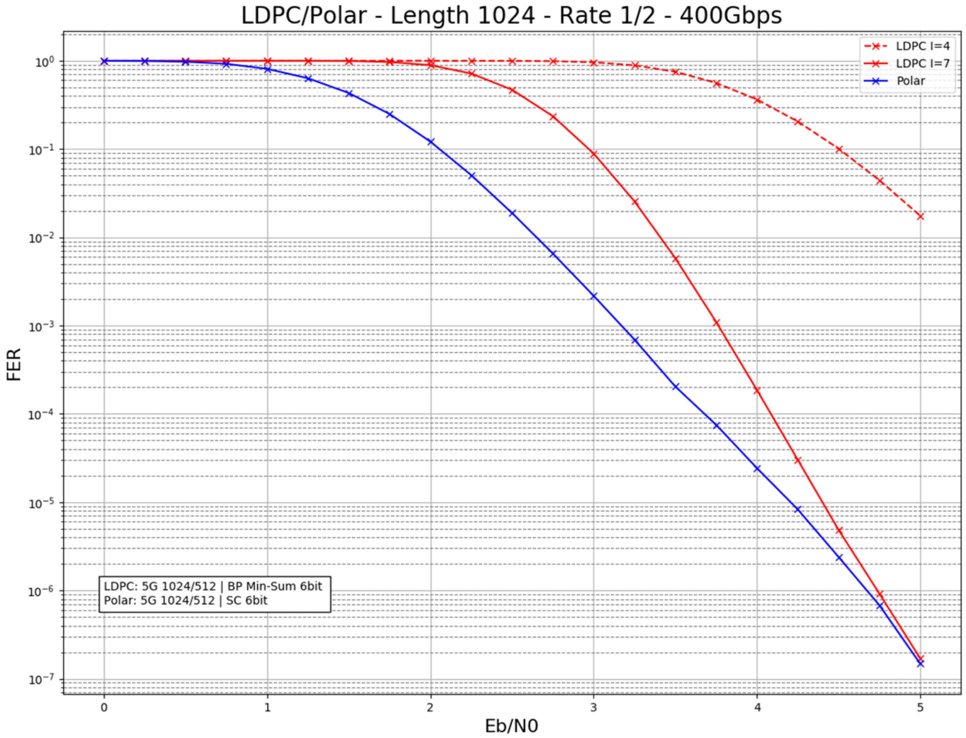
Motivation

- The feasibility of already standardized and/or state-of-the-art FEC should be assessed for practical THz use-cases, in particular for 100Gb/s and above throughput regimes.
- It is most essential to identify both communications (e.g. FER) and implementation (e.g. tput, power, area) performances to have a fair comparison among the codes.
- In this contribution, we consider selected codes from 3GPP 5G NR, WiMAX, and 802.15.3d* standards as well as polar codes designed for the target ultra-high throughputs.

* In this contribution, only communications performance of 802.15.3d codes is provided.

Study 1: 5G NR Polar Codes versus LDPC Codes - Implementation Performance

- Length=1024, Rate=1/2, 3GPP 5G NR Polar (eMBB control channel) and LDPC Codes (eMBB data channel)[3].
- Polar codes with successive cancellation decoder, LDPC with Min-Sum decoder (4 & 7 iterations).



FER 10^{-7}@400 Gbit/s

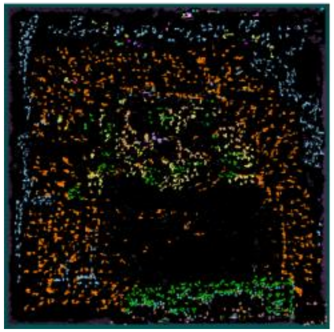
Study 1: 5G NR Polar Codes versus LDPC Codes - Implementation Performance

- Length=1024, Rate=1/2, 3GPP 5G NR Polar (eMBB control channel) and LDPC Codes (eMBB data channel)[3].
- Worst case PVT timing 28nm technology, target frequency 400MHz.
- Fully "unrolled decoder architectures" for both codes @ 400Gbit/s (200Gbit/s coded throughput).

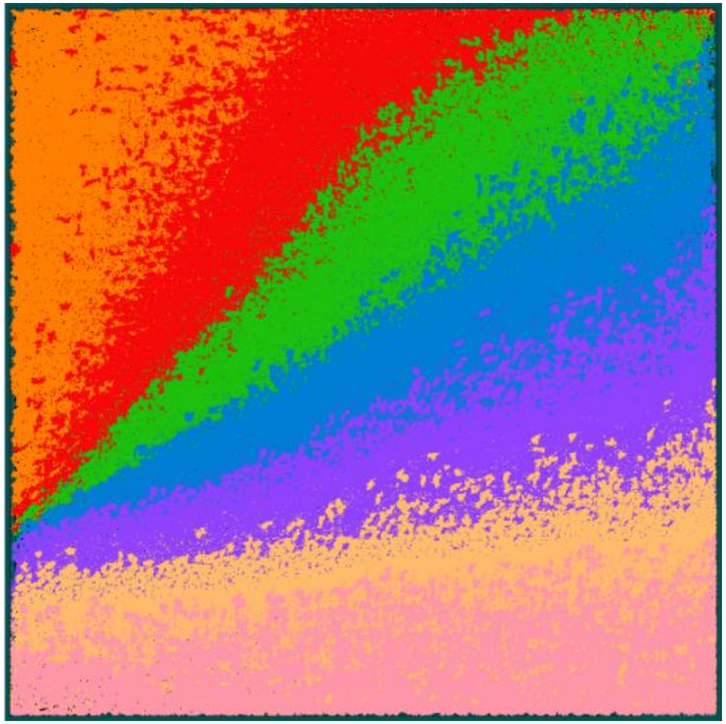
Place & Route	Polar SC	LDPC Min-Sum I=7	LDPC Min-Sum I=4
Frequency (MHz)	402	339	400
Throughput (Gbps)	411.2	347.6	409.6
Area (mm^2)	1.4349	6.9455	3.8562
Area Efficiency ($Gbps/mm^2$)	287	50	106
Utilization %	75	70	70
Power Total (W)	1.264	8.083	5.051
Power Clock (W)	0.222	1.352	0.887
Power Registers (W)	0.178	1.019	0.687
Power Comb (W)	0.864	5.713	3.477
Energy Efficiency (pJ/bit)	3.07	23.25	12.33
Power Density (W/mm^2)	0.88	1.16	1.31

Study 1: 5G NR Polar Codes versus LDPC Codes - Implementation Performance

- Length=1024, Rate=1/2, 3GPP 5G NR Polar (eMBB control channel) and LDPC Codes (eMBB data channel)[3].



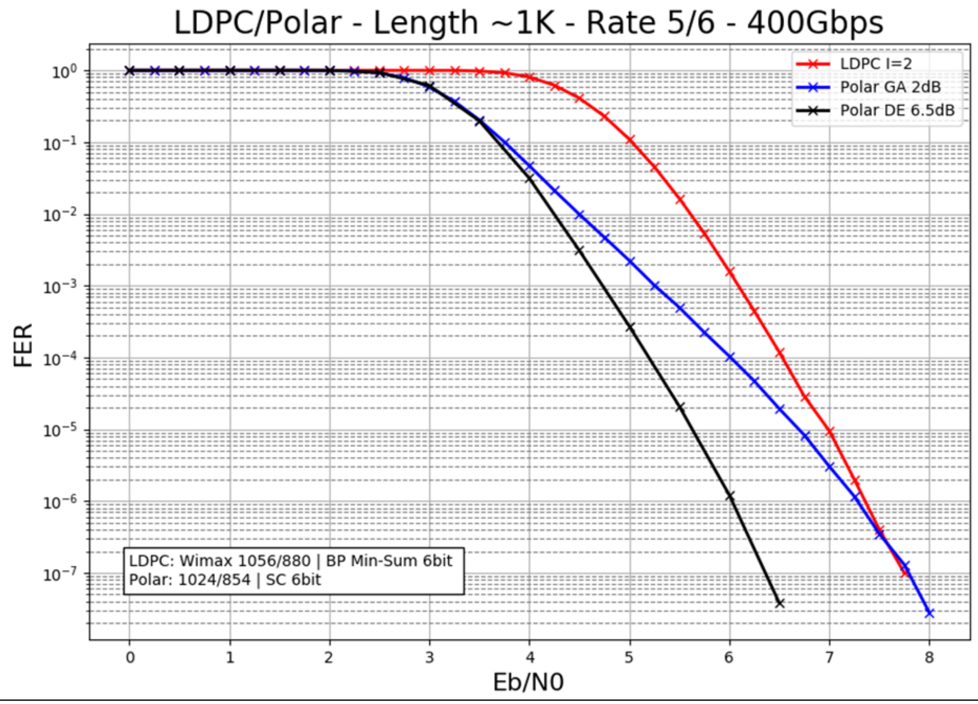
Polar decoder
1,4 mm^2 @1,2 W



LDPC decoder
6,9 mm^2 @ 8 Watt

Study 2: Polar Codes versus WiMAX LDPC Codes - Communications Performance

- Length=1024, Rate=5/6 Polar Codes generated with:
  i. 6.5dB density evolution (DE)
  ii. 2dB Gaussian Approximation (GA)
- Length=1056, Rate=5/6 LDPC codes with min-sum (2 iterations)[4]



FER 10^{-7}@400 Gbit/s

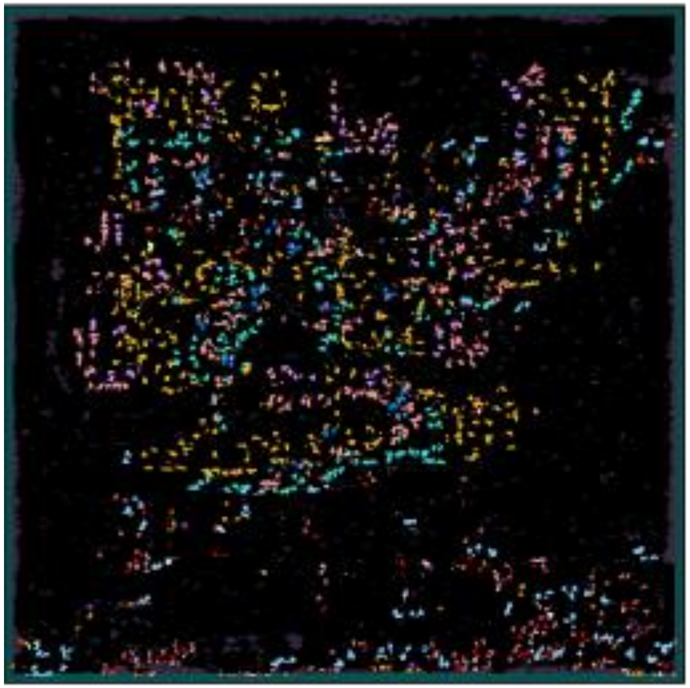
Study 2: Polar Codes versus WiMAX LDPC Codes - Implementation Performance

- Rate=5/6, Length=1024 Polar (DE 6.5dB), Length=1056 LDPC Codes[4].
- Worst case PVT timing 28nm technology, target frequency 400MHz.
- Fully "unrolled decoder architectures" for both codes @ 400Gbit/s (333Gbit/s coded throughput).

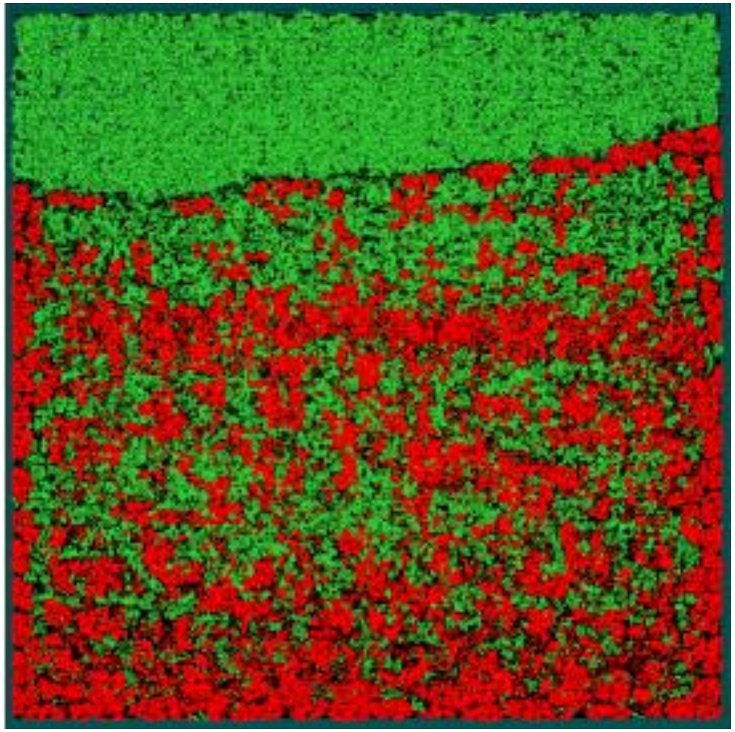
Place & Route	Polar GA	Polar DE	LDPC
Frequency (MHz)	402	402	400
Throughput (Gbps)	411.2	411.2	409.6
Area (mm^2)	1.2135	1.3816	1.6736
Area Efficiency ($Gbps/mm^2$)	339	298	245
Utilization %	73	75	70
Power Total (W)	0.892	1.147	2.037
Power Clock (W)	0.196	0.228	0.371
Power Registers (W)	0.161	0.192	0.262
Power Comb (W)	0.536	0.727	1.404
Energy Efficiency (pJ/bit)	2.17	2.79	4.97
Power Density (W/mm^2)	0.74	0.83	1.22

Study 2: Polar Codes versus WiMAX LDPC Codes - Implementation Performance

- Rate=5/6, Length=1024 Polar (DE 6.5dB), Rate=5/6, Length=1056 LDPC Codes[4]



Polar decoder DE
1,4 mm^2 @1.1 W
>1dB gain @ FER 10^{-7}



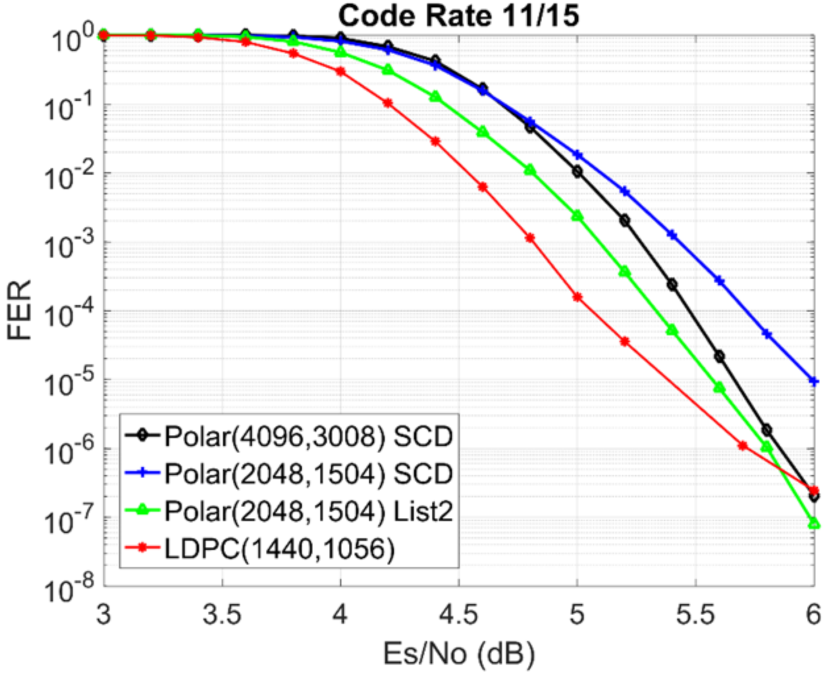
LDPC decoder
1,7 mm^2 @ 2,0 Watt

Study 3: Polar Codes versus 802.15.3d LDPC Codes - Communications Performance

- FEC classes evaluated:
  - **802.15.3d LDPC**: Length-1440, Rate=11/15[5]. I=50 iterations.
  - **Polar codes**: Length(L) = 2048, 4096, Rate=11/15. List-size=1,2 (CRC=8bits). Density (D) evolution based code design.

Observation:

- Polar code L=4096, List-size=1 and Polar code L=2048, List-size=2 are able to compete with LDPC codes at SNRs greater than 6dB.
- LDPC code experiences degraded performance at high SNRs (>6dB), a critical range for THz use-cases.



- Modulation: QPSK
- AWGN channel (BH/FH use-case in 802.15.3d study)

Conclusion

- A thorough investigation of FEC both in terms of communications and implementation performances is necessary for practical THz use-cases.
- The study demonstrates under the same technology (28nm), (frequency, quantization) constraints, and 400Gb/s throughput:
  - 5G NR polar codes with SC (Length=1024, Rate=1/2) outperforms 5G NR LDPC codes with min-sum decoder (Length=1024, Rate=1/2, iter=4,7) both in terms of implementation and communications performances (at least <10^-7 FER).
  - Polar codes with SC (Length=1024, Rate= 5/6, DE 6.5dB) outperforms WiMAX LDPC codes with min-sum decoder (Length=1056, Rate=5/6, iter=2) both in terms of implementation and communications performances.
  - In terms of communications performance only, Polar codes with Length=4096, List-size=1 and Polar code Length=2048, List-size=2 demonstrate better performance for SNR>6dB.

EPIC Grant Agreement No. 760150

"The EPIC project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 760150."

If you need further information, please contact the coordinator:

TECHNIKON Forschungs- und Planungsgesellschaft mbH
Burgplatz 3a, 9500 Villach, AUSTRIA
Tel: +43 4242 233 55 Fax: +43 4242 233 55 77
E-Mail: coordination@epic-h2020.eu

REFERENCES

- [1] Koenig, S., et al. "Wireless sub-THz communication system with high data rate." Nature Photonics, 7.12 (2013): 977.
- [2] K. Takano, et al., ISSCC2017, pp. 308–309, Feb. 2017.
- [3] 3GPP Release 15, TR 21.915 Summary of Rel-15 Work Items (Release 15), Dec. 2017
- [4] IEEE Std 802.16eTM-2005 and IEEE Std 802.16TM2004/Cor1-2005, “IEEE standard for local and metropolitan area networks part 16: Air interface for fixed and mobile broadband wireless access systems amendment 2: Physical and medium access control layers for combined fixed and mobile operation in licensed bands and corrigendum 1”, 2006.
- [5] O. Sahin, “A Preliminary 7nm implementation and communication performance study of SoA FEC classes for Tbps throughputs”, IEEE 802.15 THz IG contribution, Warsaw, Poland, May 7, 2018.
- [6] S. Scholl, S. Weithoffer, N. Wehn, “Advanced Iterative Channel Coding Schemes: When Shannon meets Moore”, in 9th International Symposium on Turbo Codes and Information Processing, pp. 406-411, Invited Talk, 2016, Brest.
- [7] C. Kestel, M. Herrmann, N. Wehn, “When Channel Coding Hits the Implementation Wall”, In the proceedings of International Symposium on Turbo Codes & Iterative Information Processing 2018, Hong Kong.