Efficient Structured Rate Adaptive Codes for 5G mmWave Communications

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5G – Vision & Challenges for Channel Coding

Vision	Challenges for Channel Coding
- Migration to New mmW Spectrum - GHz of Spectrum at Higher Frequencies	• Relatively Unstable Channel • Robust Modulation and Coding
- 1000x Capacity over current cellular systems (LTE). - 10Gb/s Peak Throughput User Experience - < 1ms Latency	• Very High Throughput PHY Processing • Spectrum & Power Efficient Channel Decoder
- Mobile Services for >100b devices - Highly Heterogeneous Apps & Devices	• Greater Flexibility in Code Block Sizes & Rates • Fast and Highly Adaptive MAC Operation

References:
"5G Radio Access," Ericsson, 2014,
"Requirement analysis and design approaches for 5G air interface," METIS Deliverable D2.1, 2013,
"Millimeter-wave Mobile Broadband: Unleashing 3-300GHz Spectrum," F. Khan & J. Pi, Samsung, 2011.

Migration to mmWave

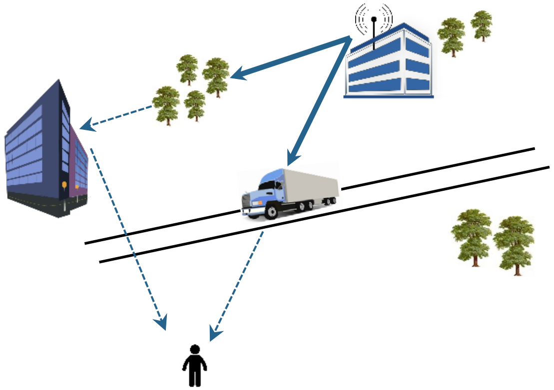


Fig. Scenario (in a cellular system) with a finite outage probability.

Challenges

- Directional (LOS) communication
- Shadowing
    - Buildings (40-80 dB)
    - Human body "Handheld Effect" (20-35 dB)
    - Foliage
- Fast fading (~3kHz @60GHz, 60km/h)

Solutions

- Large antenna arrays
- Highly-adaptive beamforming
- Massive MIMO
- Robust and adaptive modulation and **coding**.

Ref: S. Rangan et al, "Millimeter-Wave Cellular Wireless Networks: Potentials and Challenges," Proceedings of the IEEE, Vol, 102, No. 3, March 2014.

High-Throughput and Latency

Throughput: Number of bits processed per unit time.

- Channel decoder is one of the most computationally intensive modules of PHY.
- Complexity is a limiting factor at high throughputs (several Gb/s for 5G).
- 1st commercial rollout: Samsung: 5Gb/s (mobile) by 2020 (4G's 1st was 75Mbps).[1]

Latency: Processing time between the 1st input bit and the 1st output bit.

- End-to-end latency (<1ms) is (1/10)th of 4G. (latency budget for 802.11n (2012) is ~ 6μs).
- HARQ (which is very likely to be used) will contribute to latency due to inherent feedback.
- "Modern coding" (probabilistic codes) perform well at moderate to large block lengths, impacting latency directly.

Encoding needs rethinking due to an almost symmetric UL-DL ratio envisioned in 5G.

[1] W. Roh, DMC R&D Center, Samsung Electronics Corp, "Performances and Feasibility of mmWave Beamforming Prototype for 5G Cellular Communications," ICC 2013.

Rate Flexibility

Code Rate (measure of redundancy): Number of parity bits per information bit.

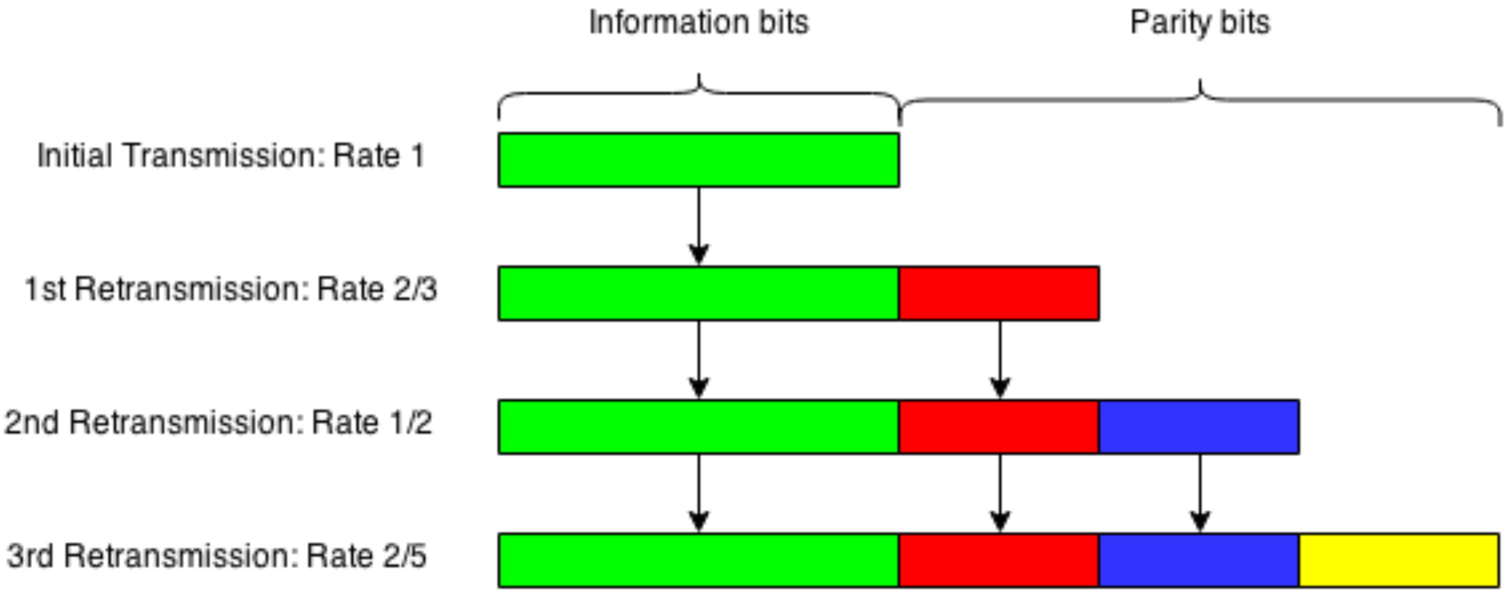
- Code rates for some current deployments:
  - 3GPP LTE: 5 rates (1/3, 1/2, 2/3, 3/4 & 7/8).
  - WiFi 802.11n & WiMAX 802.16e: 4 rates for LDPC option (1/2, 2/3, 3/4, 5/6).
  - DVB (-S2, -T2, -C2): 11 rates.

- For 5G mmWave:
  - Heterogeneity in applications and devices: Frame sizes from a few bits (e.g. weather sensors) to few kbits (e.g. video streaming).
  - It is understood that one channel coding scheme cannot satisfy all rates.
  - **Rate compatible** codes support multiple rates using the same encoding and decoding algorithms (hardware). Crucial to develop efficient hardware.
  - Efficiency of HARQ mechanism depends on the rate support.

Type II Hybrid ARQ

- Automatic repeat request (ARQ):
  - Error detection codes applied to messages
  - If errors are located, the receiver requests a retransmission
- Type II Hybrid ARQ:
  - Combination of error correction and ARQ
  - Uses family of codes of different rates
  - Parity bits of higher-rate codes embed into lower-rate codes (rate compatibility)
  - If a transmission fails, a retransmission can be made using a lower-rate code

Type II Hybrid ARQ: Rate Compatibility

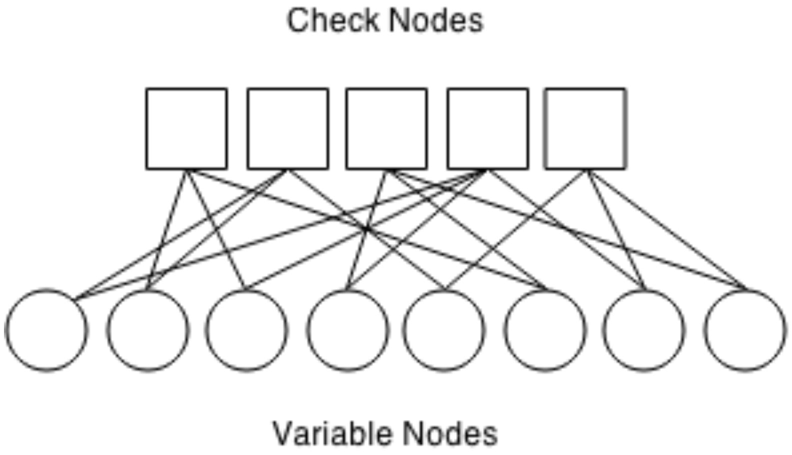


Each retransmission sends only bits which have not been sent

Goals in Rate Compatibility

- Fine rate adaptation
- Performance granularity
- Ideal – linear relationship between parity bits added and performance gained
- Simple extending/puncturing algorithms

Low-Density Parity-Check (LDPC) Codes



Tanner Graph

Variables

Checks

$$\begin{bmatrix} 0 & 1 & 1 & 0 & 0 & 1 & 0 & 1 \\ 1 & 1 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix}$$

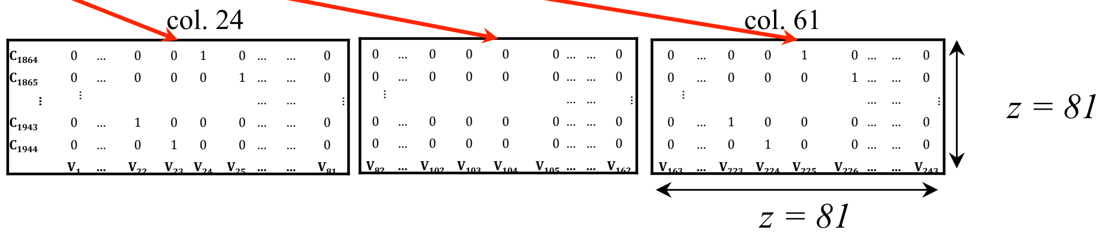
Adjacency/Parity Check Matrix

All variables connected to a given check node sum to 0 (mod 2)

Quasi-Cyclic (QC) LDPC Codes

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	B17	B18	B19	B20	B21	B22	B23	B24
L1	57	-1	-1	-1	50	-1	11	-1	50	-1	79	-1	1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
L2	3	-1	28	-1	0	-1	-1	-1	55	7	-1	-1	-1	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1
L3	30	-1	-1	-1	24	37	-1	-1	56	14	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1	-1	-1	-1
L4	62	53	-1	-1	53	-1	-1	3	35	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1	-1	-1
L5	40	-1	-1	20	66	-1	-1	22	28	-1	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1	-1
L6	0	-1	-1	-1	8	-1	42	-1	50	-1	-1	8	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1	-1
L7	69	79	79	-1	-1	-1	56	-1	52	-1	-1	-1	0	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1
L8	65	-1	-1	-1	38	57	-1	-1	72	-1	27	-1	-1	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1
L9	64	-1	-1	-1	14	52	-1	-1	30	-1	-1	32	-1	-1	-1	-1	-1	-1	-1	-1	0	0	-1	-1
L10	-1	45	-1	70	0	-1	-1	-1	77	9	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	-1
L11	2	56	-1	57	35	-1	-1	-1	-1	-1	12	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0
L12	24	-1	61	-1	60	-1	-1	27	51	-1	-1	16	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0

IEEE 802.11n (2012) Base matrix (shift values)



Ref: IEEE 802.11 std. Part-11, Wireless LAN MAC & PHY specifications, P802.11-REVmb/D12, Nov. 2011.

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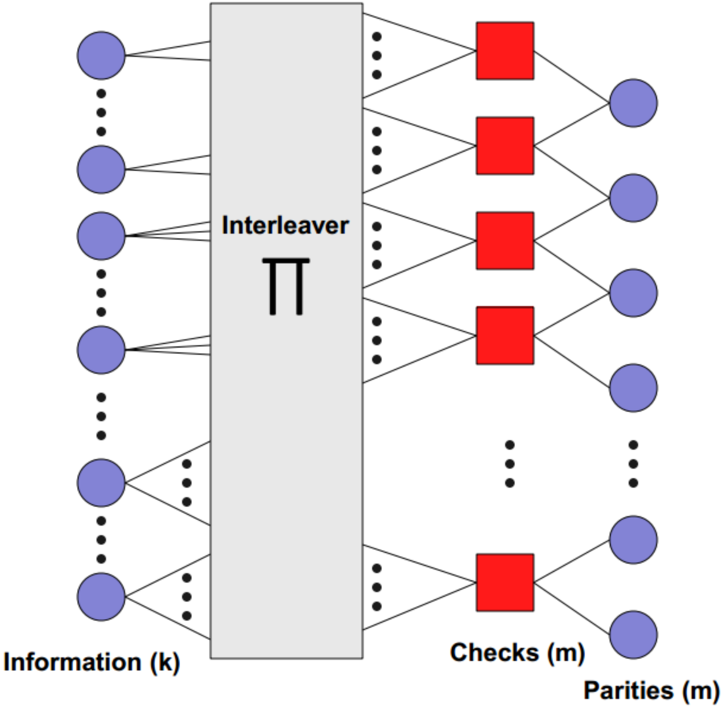
Irregular Repeat-Accumulate Codes



- LDPC codes with an "zig-zag" parity structure
- Variable nodes easily partitioned into systematic information and parity check bits
- Quasi-cyclic/structured IRA (S-IRA), generalized IRA (G-IRA), quasi-cyclic generalized IRA (QCGIRA) forms

QC-LDPC and IRA Codes

- Why QC-LDPC?
  - Hardware-implementations needed for low-latency
  - Avoid routing congestion
  - Parallel processing
  - Rate adaptation
- Why IRA?
  - Linear-time encoding algorithms
  - No generator matrix required (encode with shift registers)
  - Intuitive rate adaptation
- IRA-inspired QC-LDPC used in: 802.11n, 802.16e/m

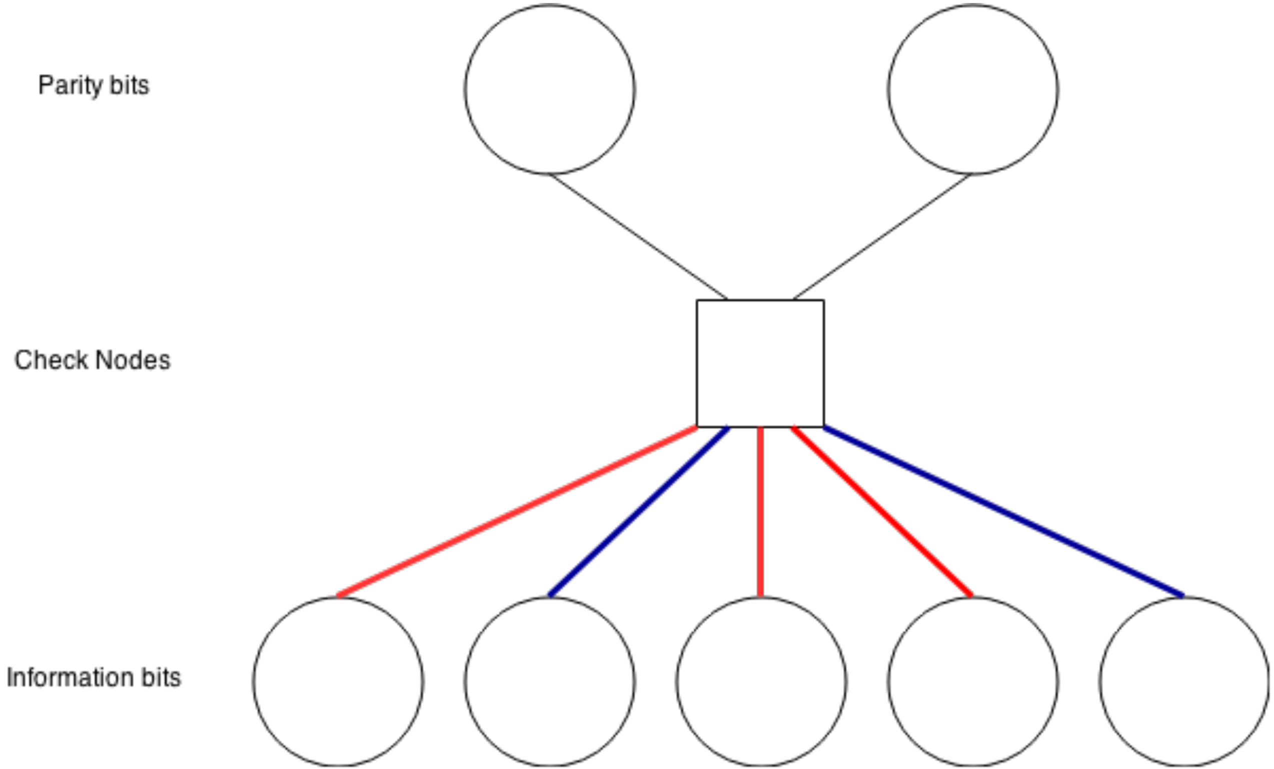
Rate Compatibility with IRA Codes

- Puncturing or extending should preserve structure (IRA becomes IRA, S-IRA becomes S-IRA, etc.)

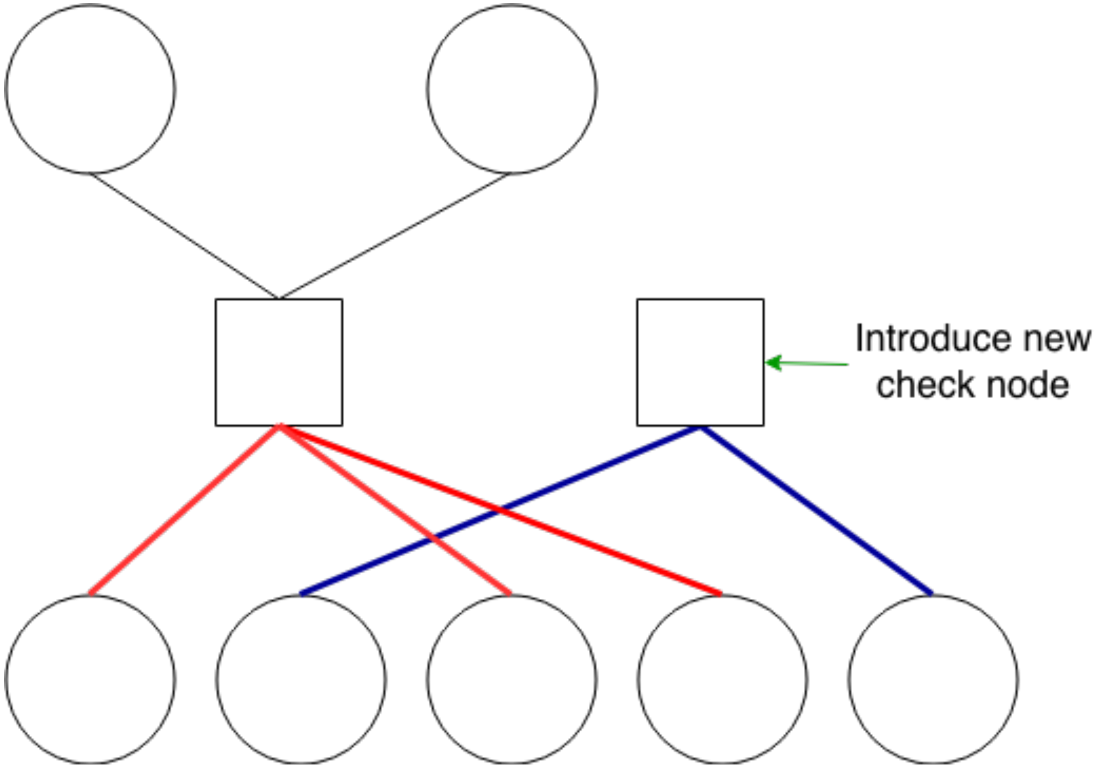
- Our focus is extending:

  - We must introduce new parity bits
  - How do these parity bits relate to the information?
  - How do these parity bits relate to each other?

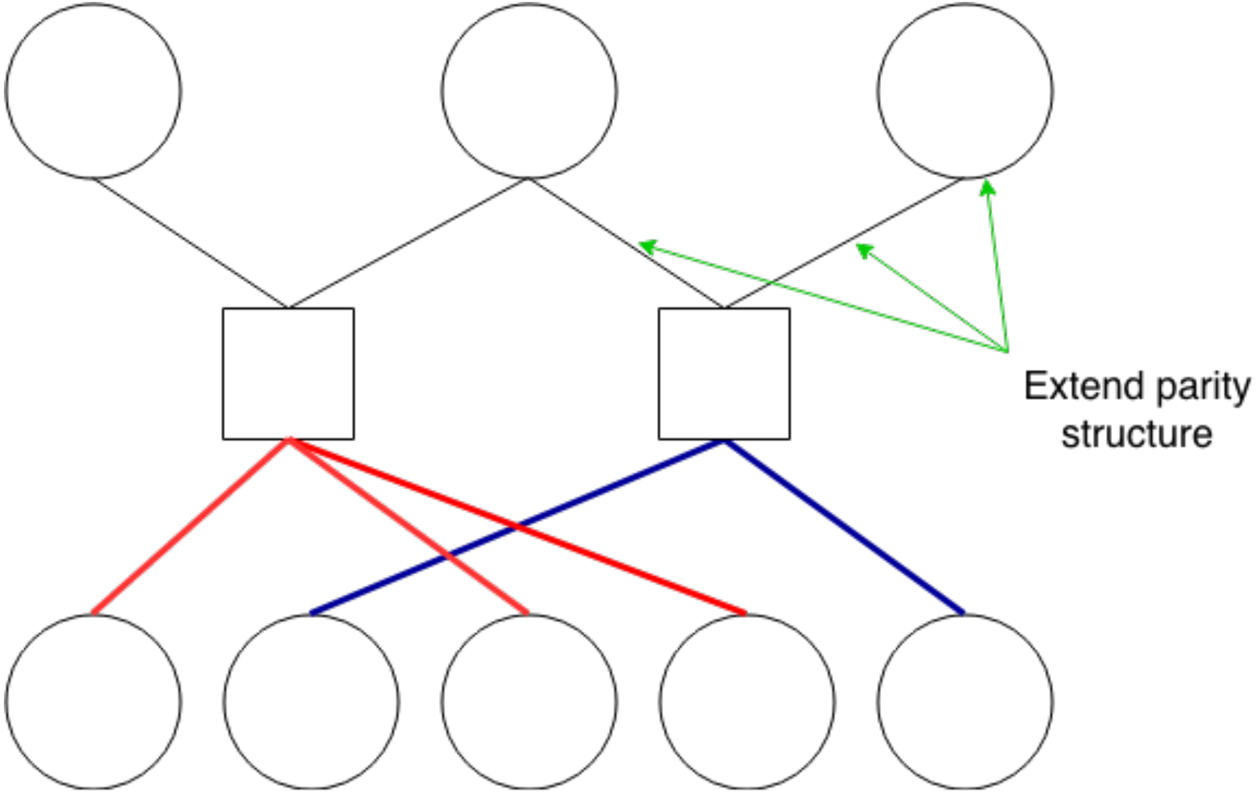
Row Splitting



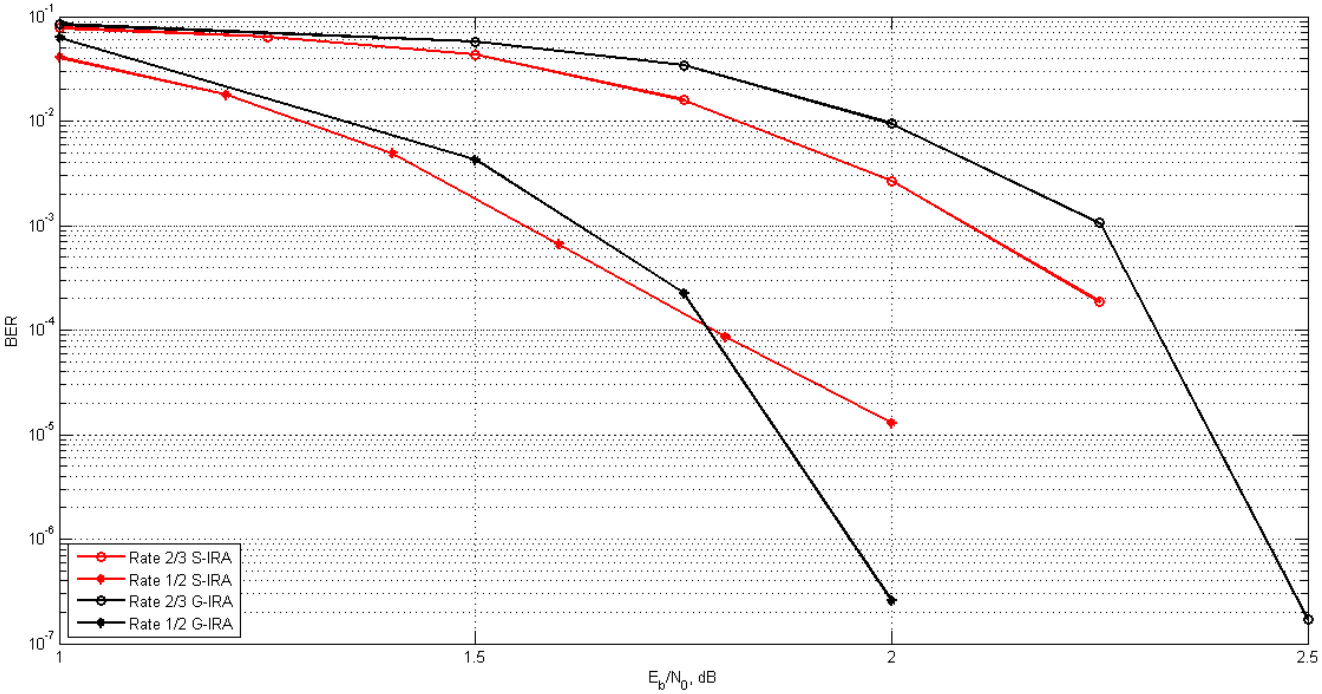
Row Splitting



Row Splitting



Some Results



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Current Work in Row Splitting

- Development of good splitting algorithms
- Application to broader classes (G-IRA)
- Granularity in splitting

Thank you!