



Application of Stochastic Decoding to 10 Gb Ethernet

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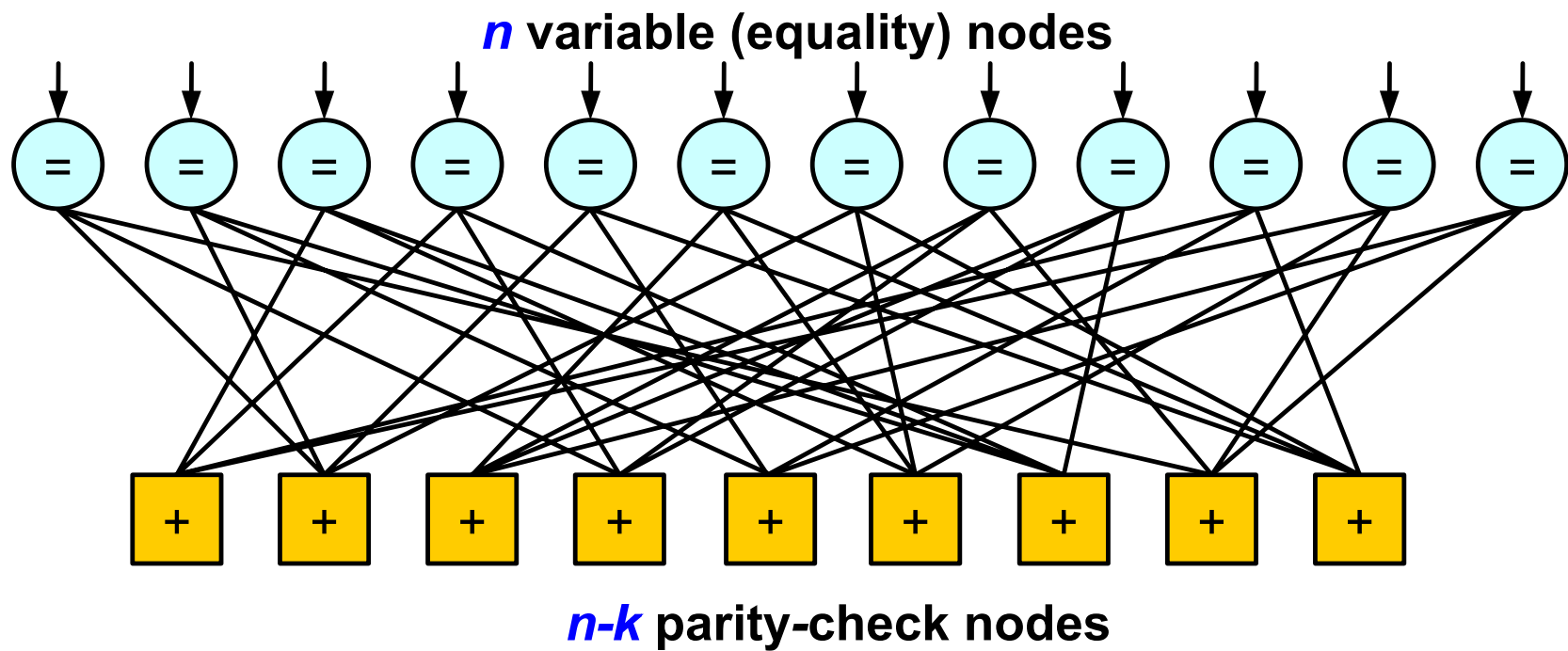
McGill University, Montreal, Quebec, Canada

LDPC Codes are the next wave

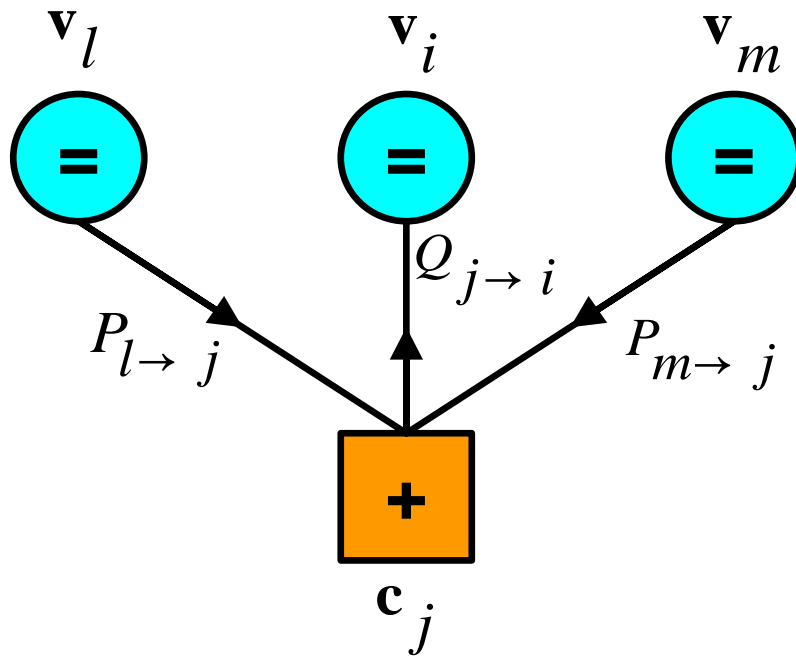
- They provide the best error correction performance of all known codes
- Standards:
 - DVB-S2, CMMB
 - IEEE 802.3an (10GBASE-T)
 - IEEE 802.16e (WiMAX)
 - IEEE 802.11n (WiFi)
 - ITU G.9960 Broadband over Powerline

(n, k) LDPC code

↓ Probabilities from Channel



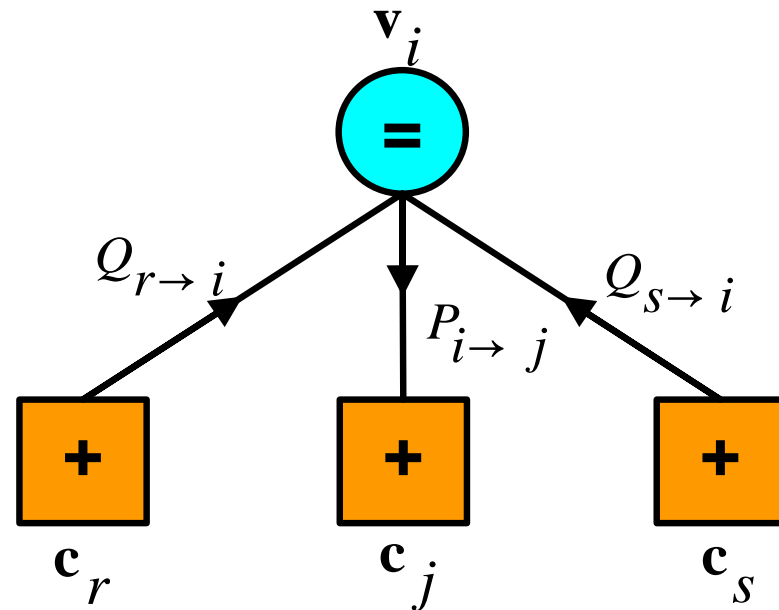
Belief Propagation (Sum-Product Algorithm)



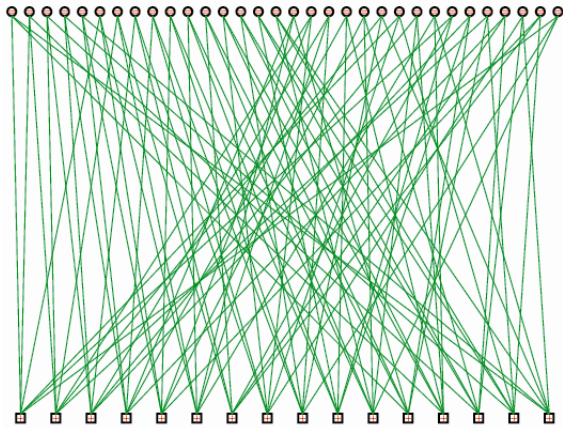
$$Q_{j \rightarrow i} = P_{l \rightarrow j}(1 - P_{m \rightarrow j}) + P_{m \rightarrow j}(1 - P_{l \rightarrow j})$$

Belief Propagation (Sum-Product Algorithm)

$$P_{i \rightarrow j} = \frac{Q_{r \rightarrow i} Q_{s \rightarrow i}}{Q_{r \rightarrow i} Q_{s \rightarrow i} + (1 - Q_{r \rightarrow i})(1 - Q_{s \rightarrow i})}$$

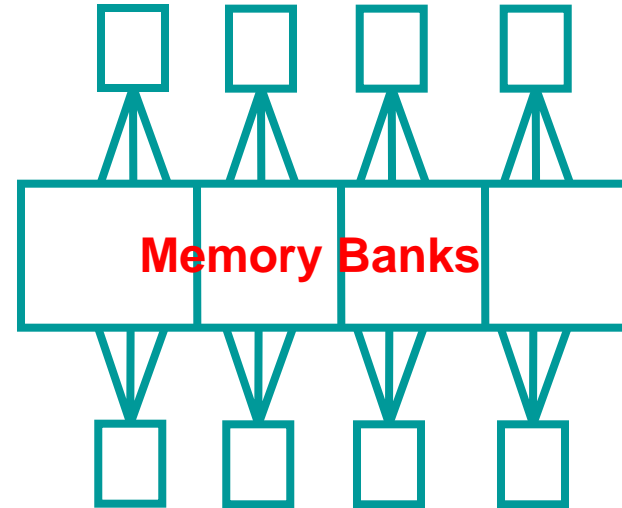


Architectures



Fully parallel

- bit serial,
 - analog
 - stochastic
- (big, fast)



Partially parallel

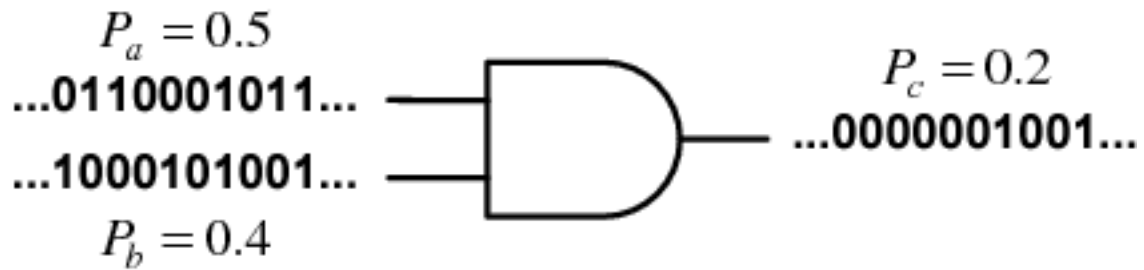
(small, slow, flexible but limited to only certain codes)

Stochastic representation

$$P = 0.76 (= 19/25)$$

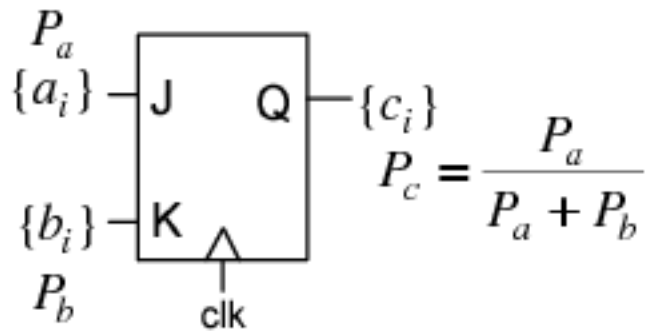
...0111111110011011011111011...

- Probabilities as weighted streams of random bits
- Common fallacy: low precision
 - 0.001 (10 bits vs. 1000 bits)
 - But we care about the **flow of changes of statistics** of bits rather than precise values



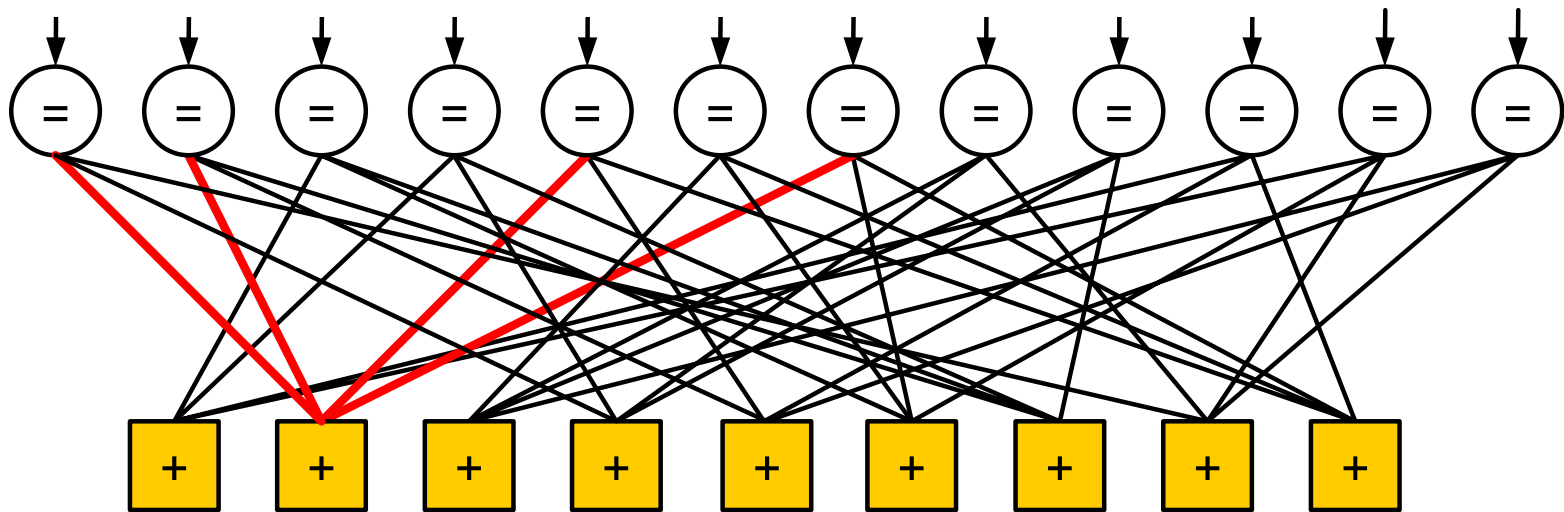
multiplication

Stochastic
Operations



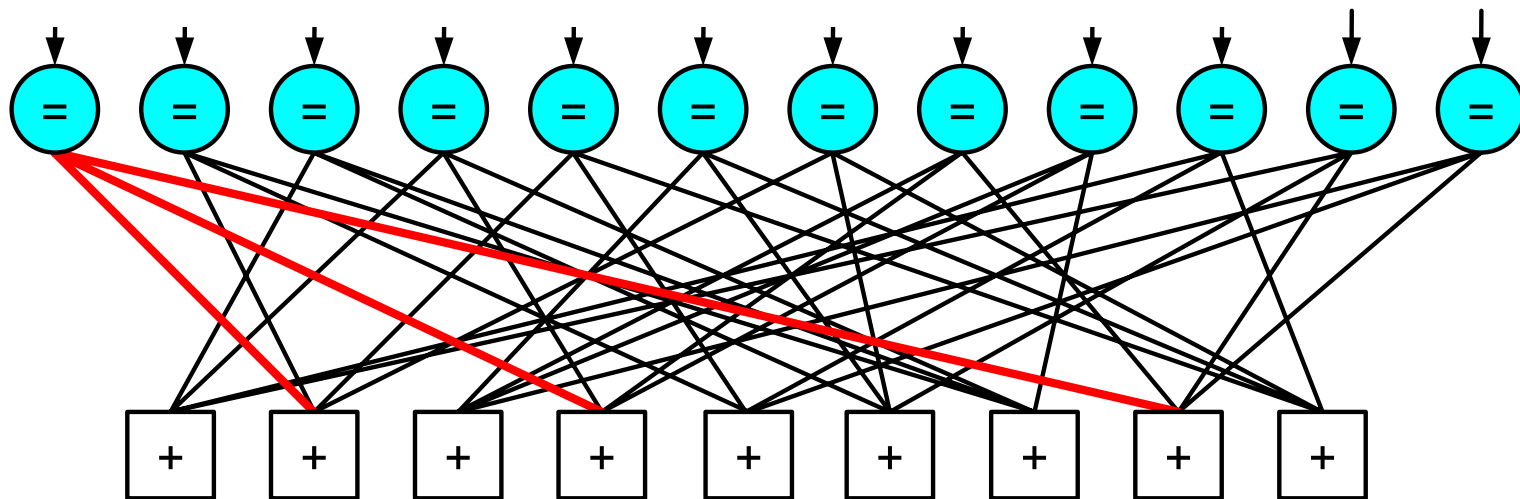
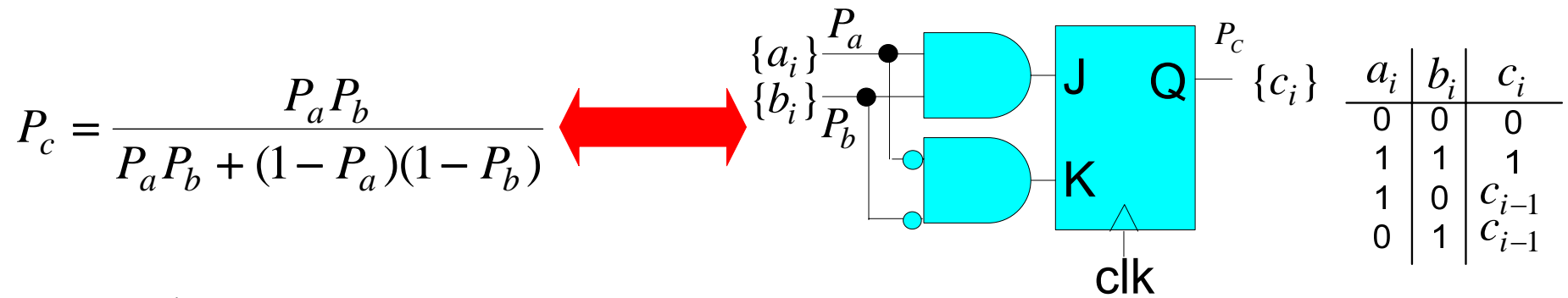
division

Stochastic Parity-Check Node [Gaudet and Rapley, Elec. Letters 2003]

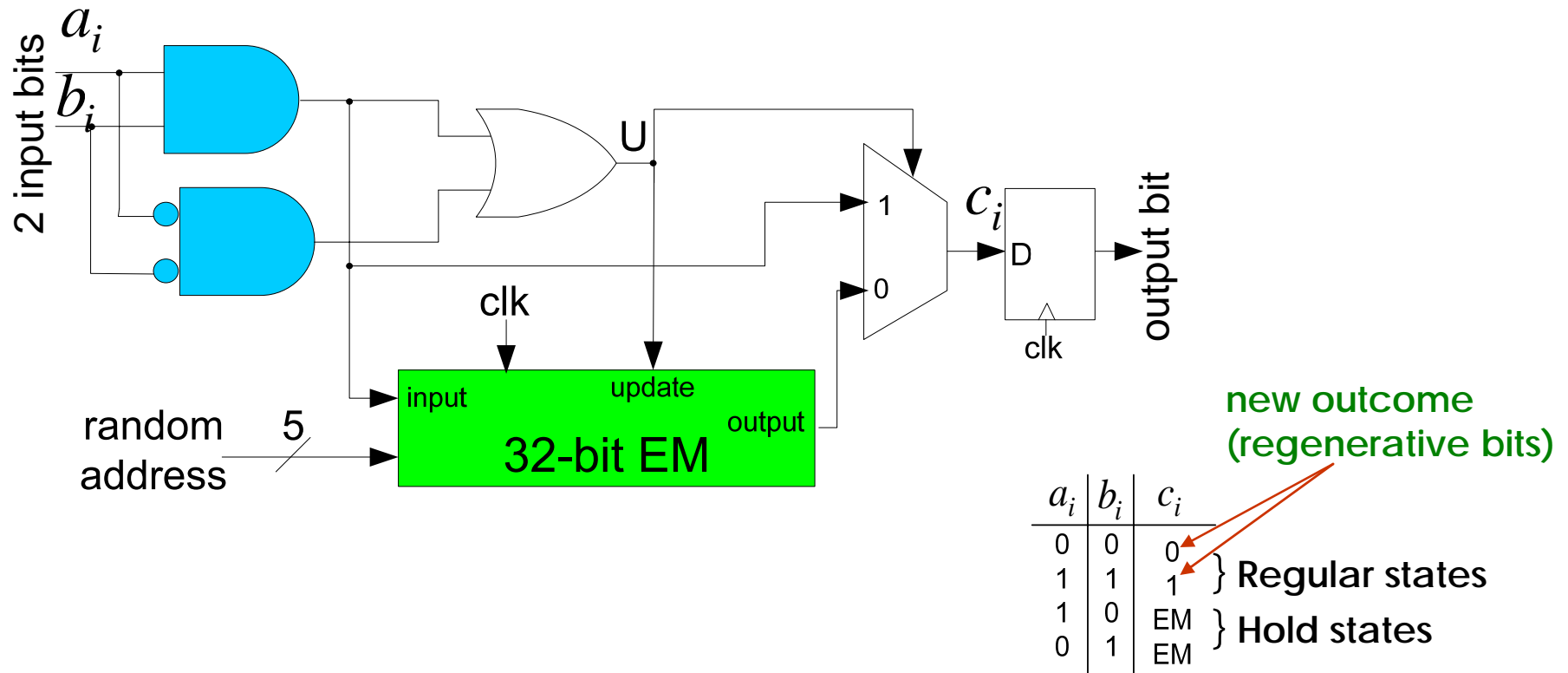


$$P_c = P_a(1 - P_b) + P_b(1 - P_a) \iff \begin{matrix} \{a_i\} \\ \{b_i\} \end{matrix} \begin{matrix} P_a \\ P_b \end{matrix} \text{ Soft XOR } \{c_i\}$$

Stochastic Variable Node [Gaudet and Rapley, Elec. Letters 2003]



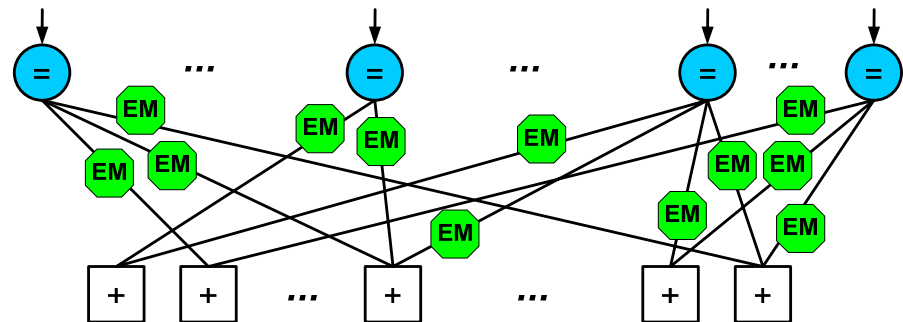
Variable Nodes



- Significant sharing of random numbers
- Share between comparators / EMs

Stochastic Decorrelators

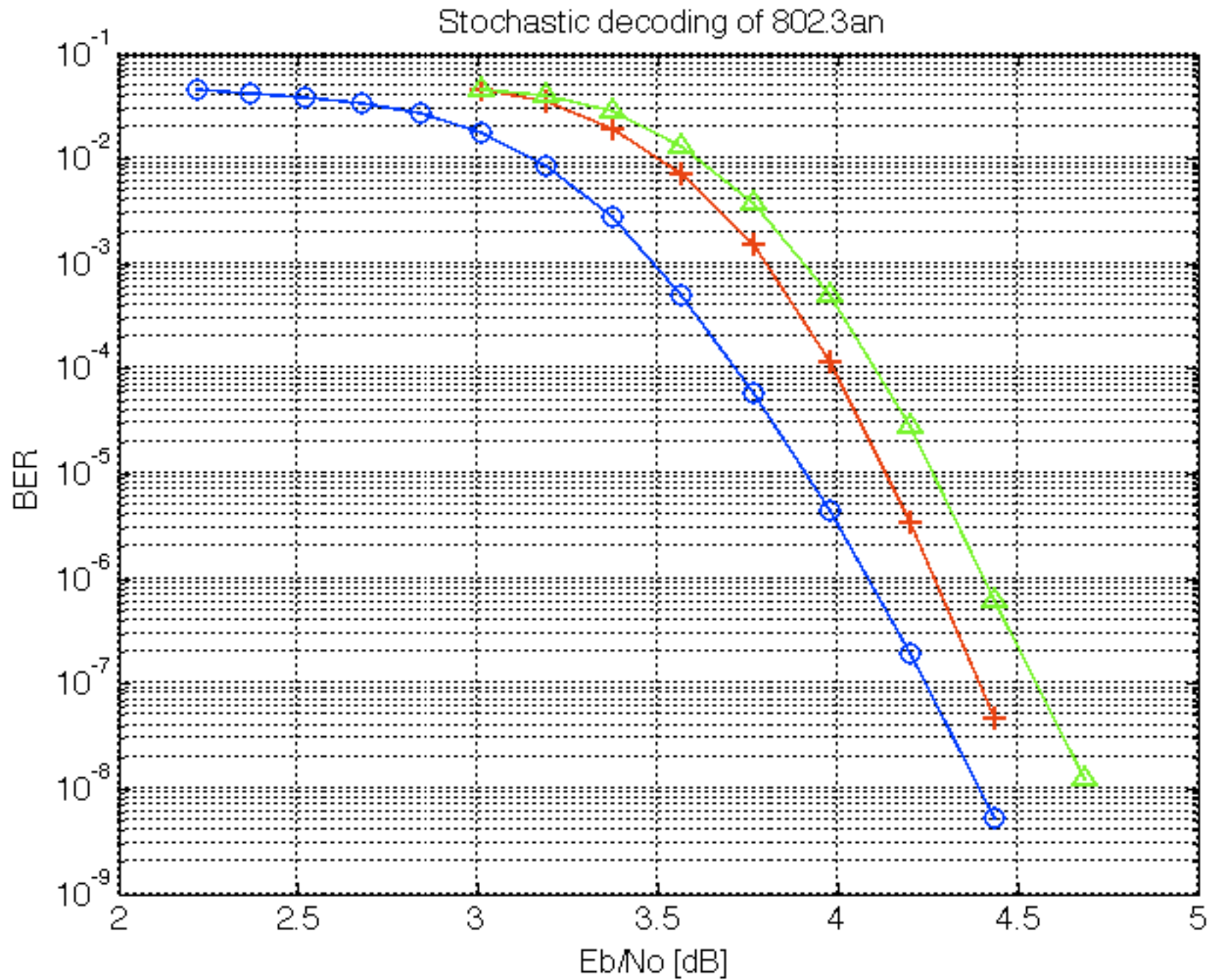
- Decorrelation on the cheap!
 - Break lock-up cycles
 - Output stream has “same” stats
 - Keep a flow of **good** (regenerative) bits
 - Remember/use only the regenerative bits



	a_i	b_i	c_i	
Agreement	0	0	0	}
	1	1	1	
Disagreement	1	0	c_{i-1}	} old outcomes
	0	1	c_{i-1}	

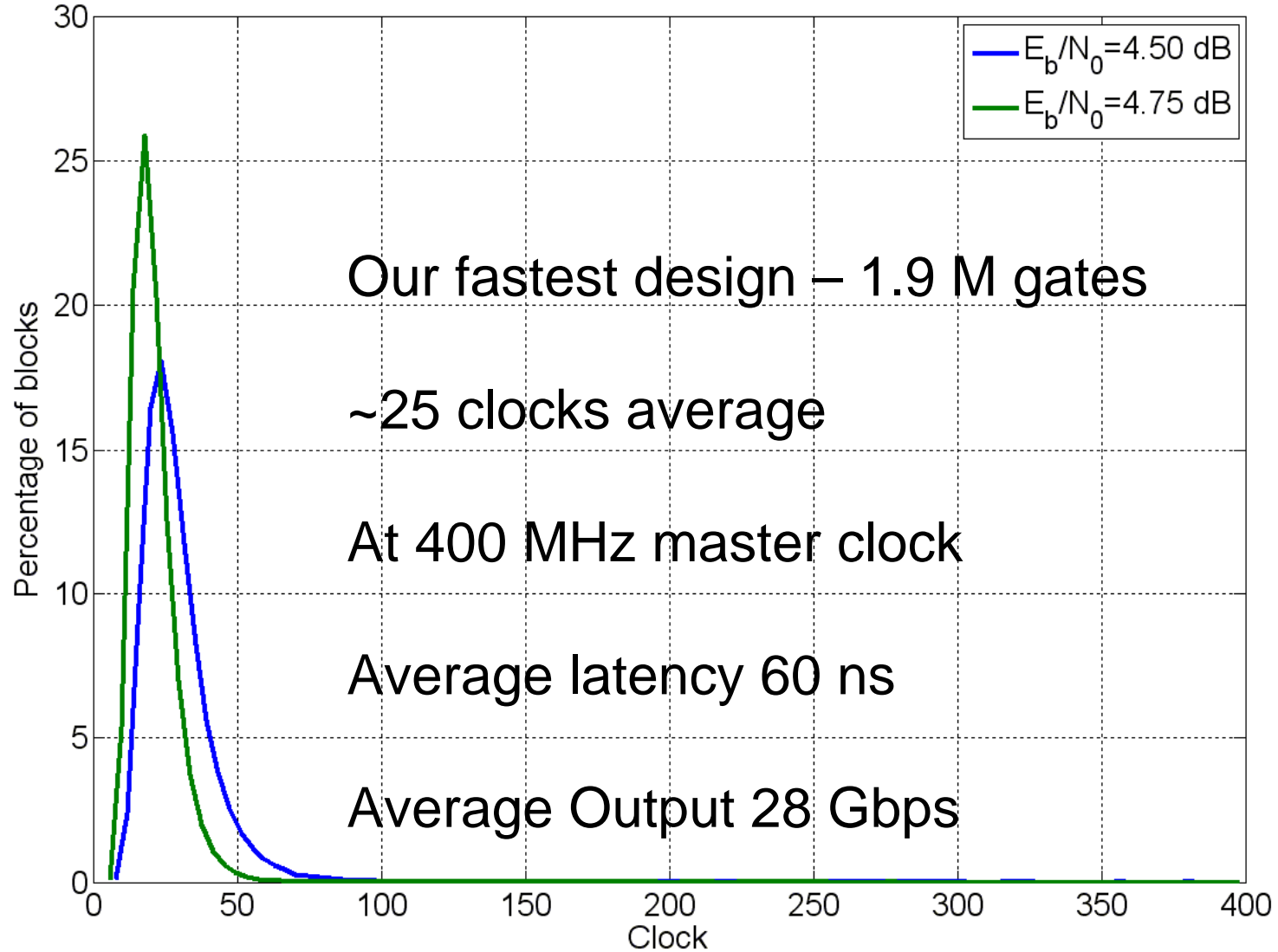
10 Gigabit Ethernet (802.3an)

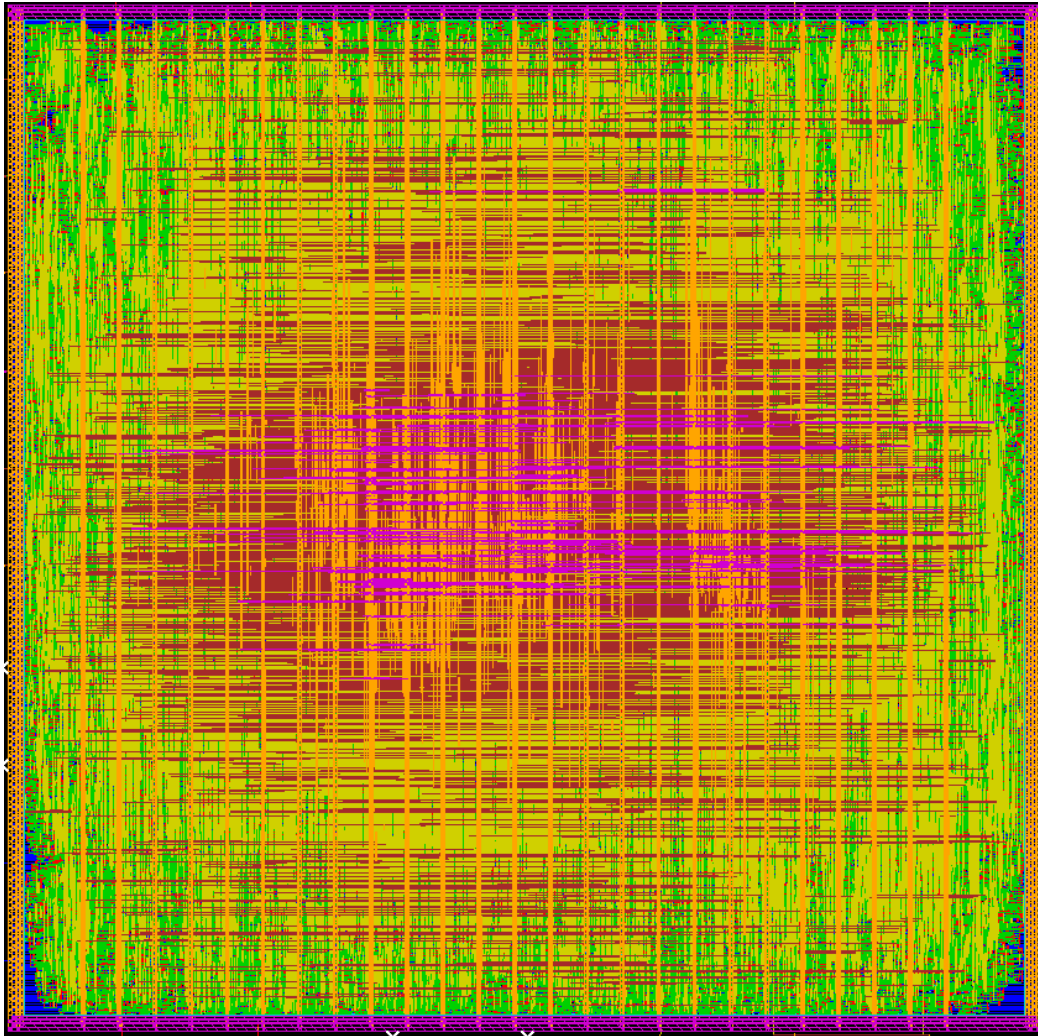
- A single, low-overhead, high-performance LDPC code.
 - IEEE 802.3an (10 GbE)
 - 1723/2048 code
 - No error floor to $1e-12$
 - 4 twisted pairs running at a raw bit rate of 2.5 Gbps (PAM encoded for a symbol rate of 800 Mbaud)



[Francois Leauc-Primeau, Warren Gross, Shie Mannor, 2008]

Stochastic Decoding of 10GBASE-T length-2048 LDPC Code





Our smallest 10 GbE
fully parallel decoder
(2048,1723)

90 nm layout

850 k gates NAND eq

~2.1 mm per side

65% utilization factor

No memory required

14 Gbps avg output

Performance

- Size: 850 kgates
 - Includes all decoder logic plus I/O Buffers and Random Number Generators
 - No memory required
- Estimated Power: 1.2 Watts peak at 400 MHz
 - Excess throughput traded for slower clock or reduced duty cycle
 - For 6 Gbps operation power is < 400 mW
- Decode Performance
 - 0.1 to 0.2 dB loss versus SPA 32b double precision

Other Benefits

- Error Floor
 - At high SNR most packets resolve immediately
 - A stochastic representation builds resolution as more bits are sent, we can reduce error floor by running longer on codes which do not converge
 - Re-run a failed or slow convergence and the stochastic bit stream may result in faster solution on a second try
- Gate Count Reduction
 - Excess throughput is traded by folding the hardware resulting in almost 50% gate count savings

Conclusions

- Stochastic decoding is very attractive for 10 GbE
 - Fully-parallel LDPC decoder
 - Fast and area-efficient
 - Easy, scalable and portable design
 - Potential for very low-power

Acknowledgements

- Saeed Sharifi Tehrani
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