NJIT New Jersey's Science & Technology University

Coding for Leveraging Network Gains in 5G

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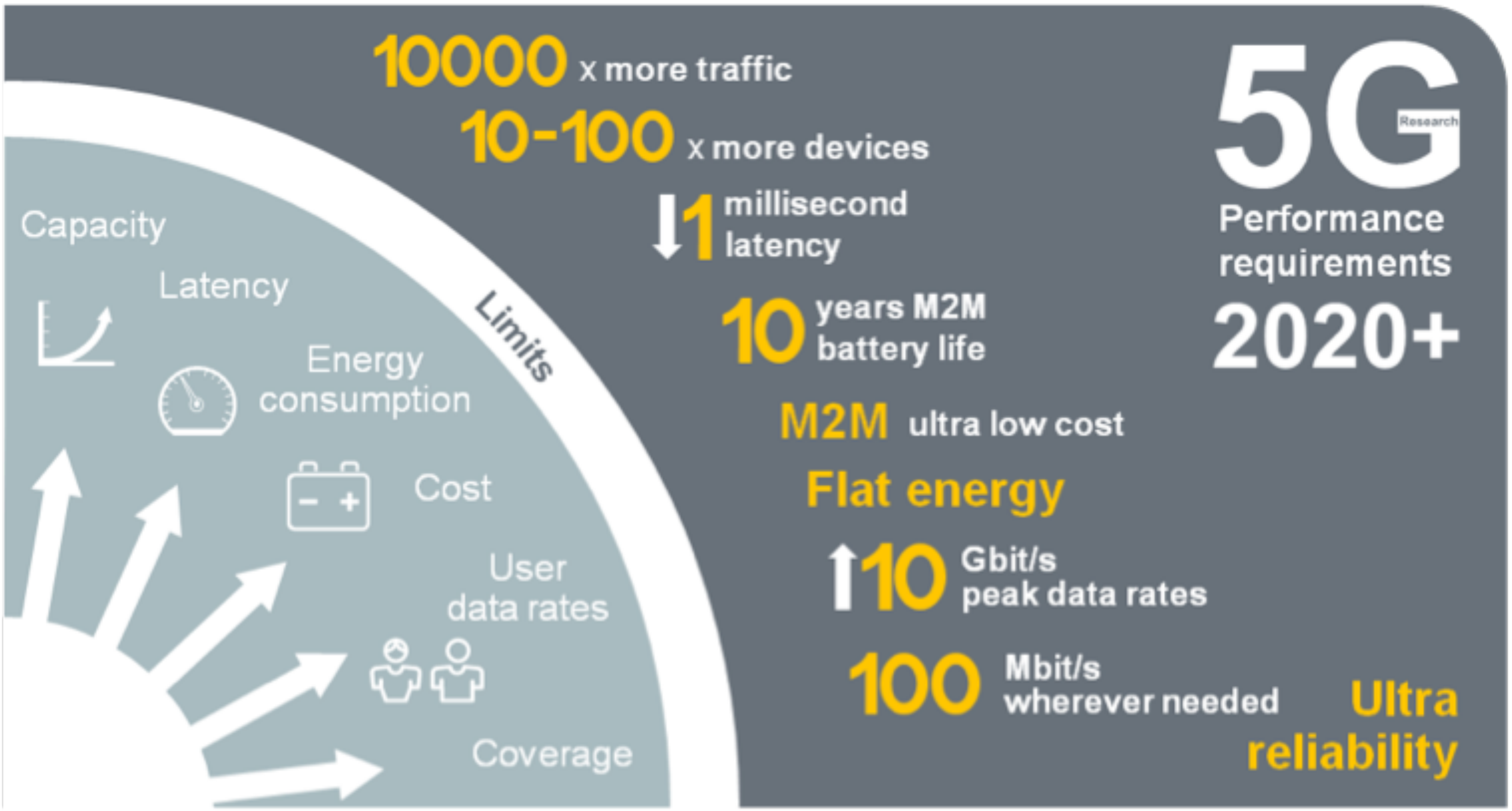
Communications And Signal Processing Research

The Zettabyte Area

[Cisco Systems Inc.: The zettabyte area. White paper, 2015]

How Can Cellular Systems Keep Up?



[Nokia Networks: Looking ahead to 5G. White paper, April 2014]

Leveraging Network Gains

- Recent advantages in communication and information theory constitute promising approaches to leverage network gains
  - network capacity
  - cooperative and opportunistic communication
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In this talk: How to leverage network gains for both error correction and compression with modern graph based codes?

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  - Low-density parity check codes
  - Spatially coupled codes
  - Polar codes

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    - **Multi-terminal coding and decoding** (i.e., for relaying, cooperation, broadcast)

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Solution:
Nested Codes

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- Partitioning into subcodes $\mathcal{C}_\ell, \ \ell = 1, 2, \ldots, M$
- Can be seen as structured linear binning schemes
- Finite-field version of physical layer superposition codes

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- Many more: relay channels, cooperative diversity, wiretap channels, …

Nested Codes

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- M information words $\mathbf{i}_k$
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$$\mathbf{c} = [\mathbf{i}_1, \mathbf{i}_2, \ldots, \mathbf{i}_M]\,\mathbf{G} = [\mathbf{i}_1, \mathbf{i}_2, \ldots, \mathbf{i}_M] \begin{bmatrix} \mathbf{G}_1 \\ \mathbf{G}_2 \\ \vdots \\ \mathbf{G}_M \end{bmatrix}$$

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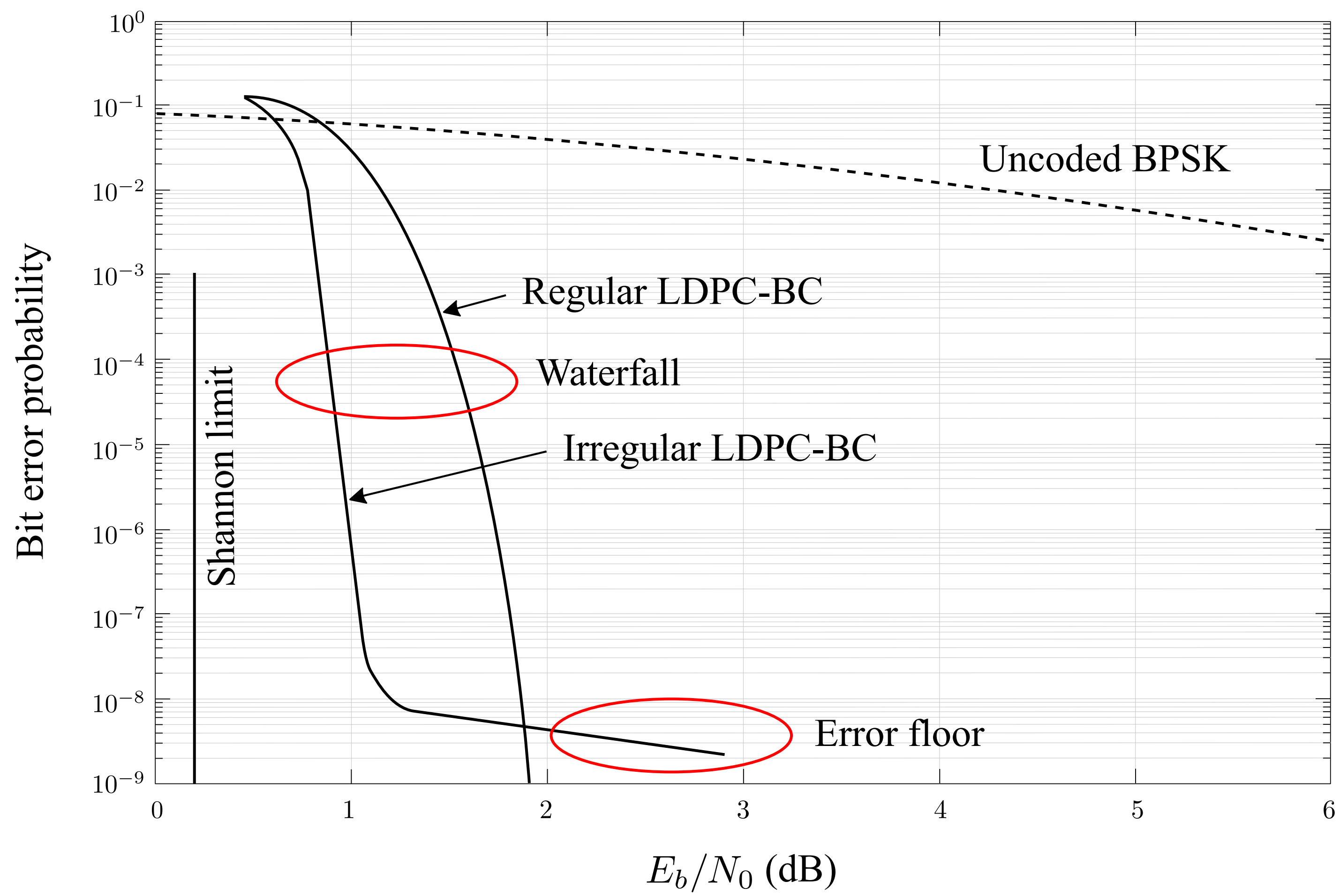
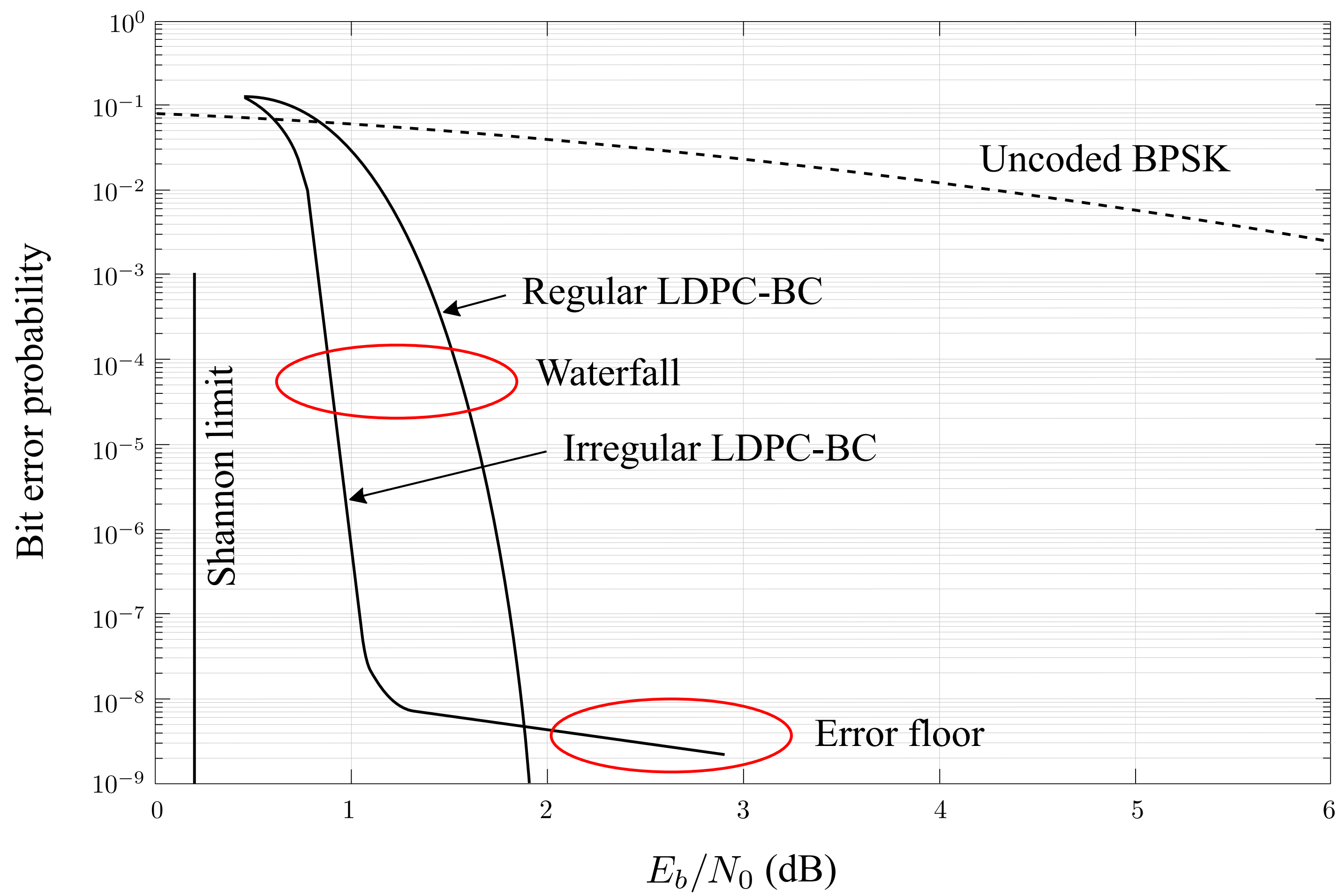
- **Type-2** codes: Partitioning of parity check matrix **H** into subcodes $\mathcal{C}_\ell$ with parity check matrix $\mathbf{H}_\ell$

$$\underbrace{\begin{bmatrix}\mathbf{H}_1 \\ \mathbf{H}_2 \\ \vdots \\ \mathbf{H}_M\end{bmatrix}}_{=\mathbf{H}}$$

LDPC Block Codes

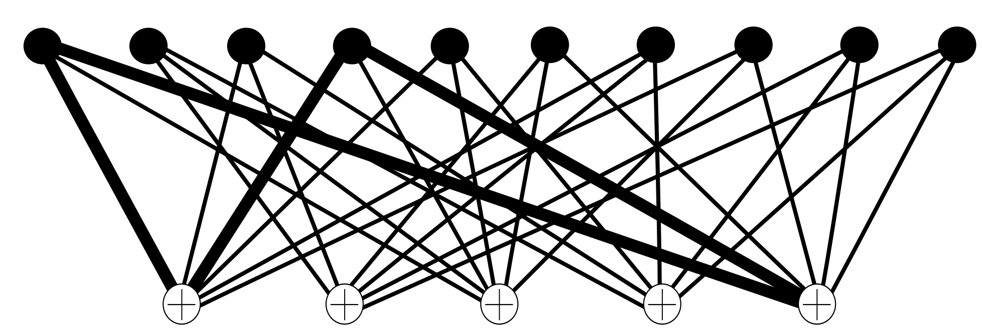


LDPC Block Codes



Tanner graph (3,6) regular LDPC code:

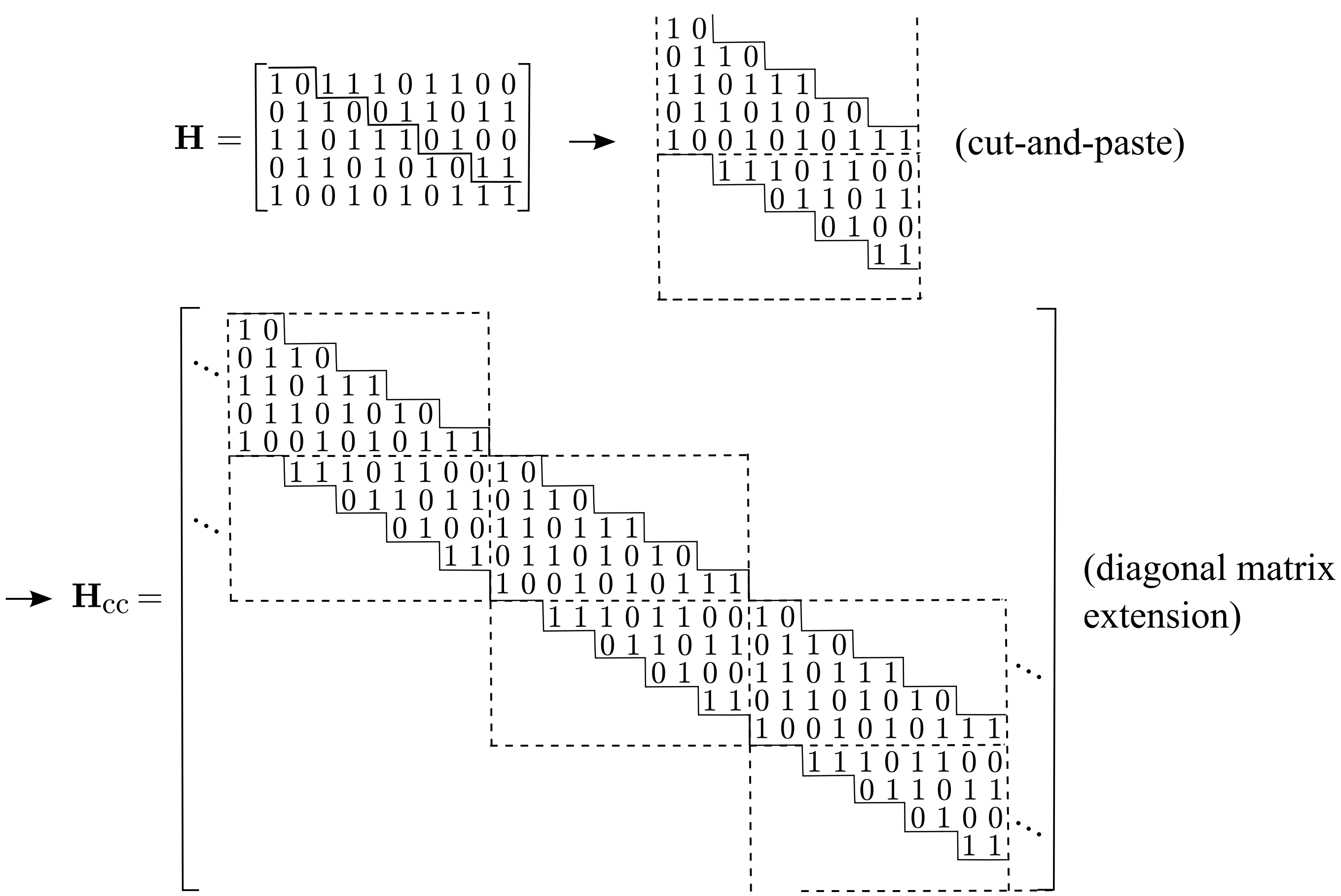
$$\mathbf{H} = \begin{bmatrix} 1&0&1&1&1&0&1&1&0&0 \\ 0&1&1&0&0&1&1&0&1&1 \\ 1&1&0&1&1&1&0&1&0&0 \\ 0&1&1&0&1&0&1&0&1&1 \\ 1&0&0&1&0&1&0&1&1&1 \end{bmatrix}$$



Graph sparsely connected

Spatially Coupled LDPC Codes

Coupling construction via unwrapping:



Convolutional code structure

[Costello, Dolecek, Fuja, Kliewer, Mitchell, Smarandache, 2014]

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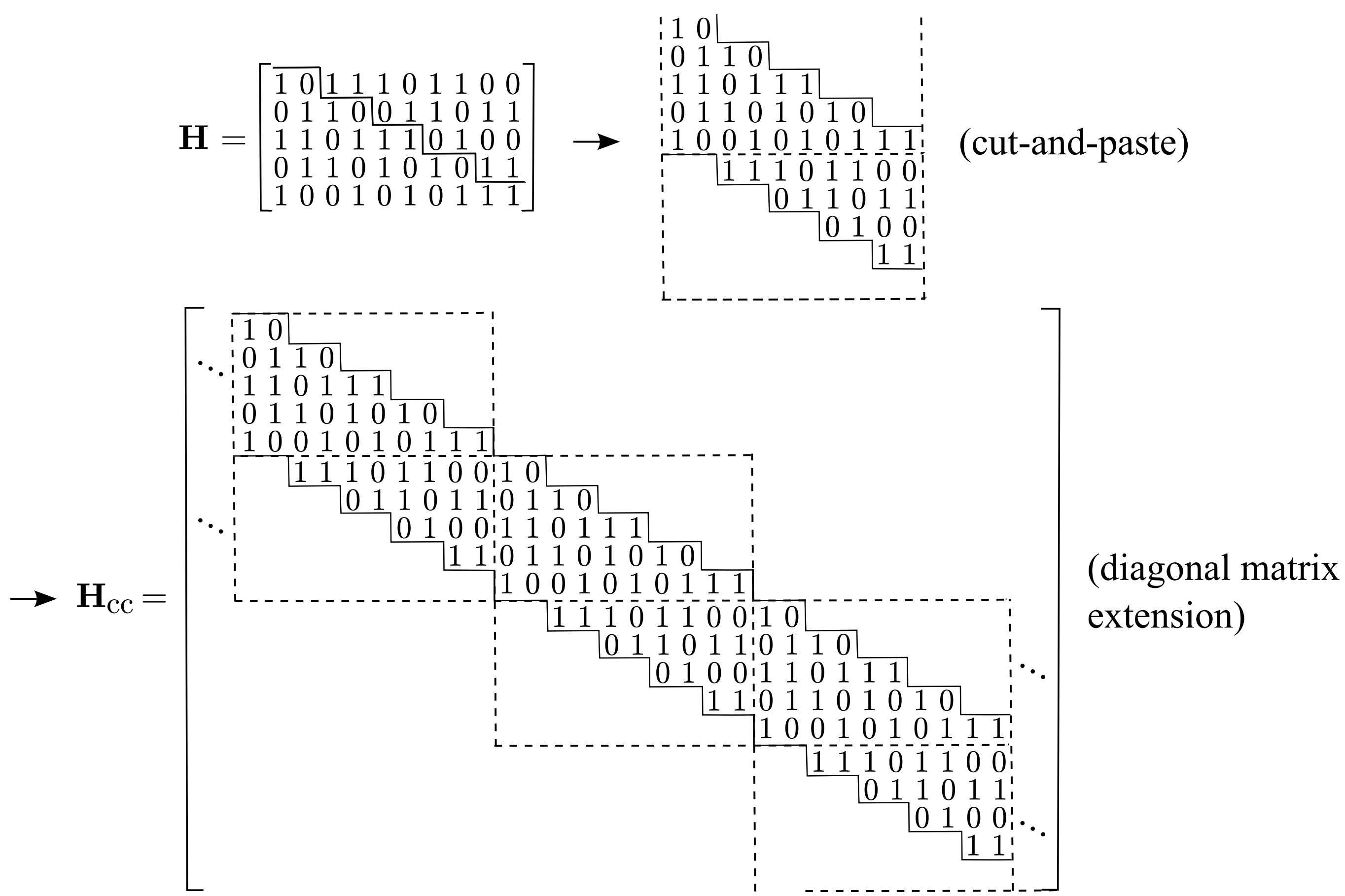
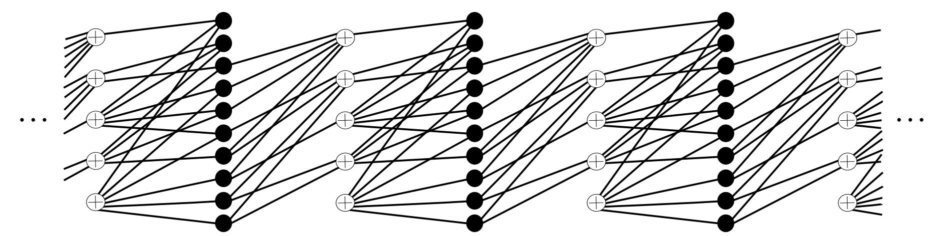


Resulting Tanner graph:



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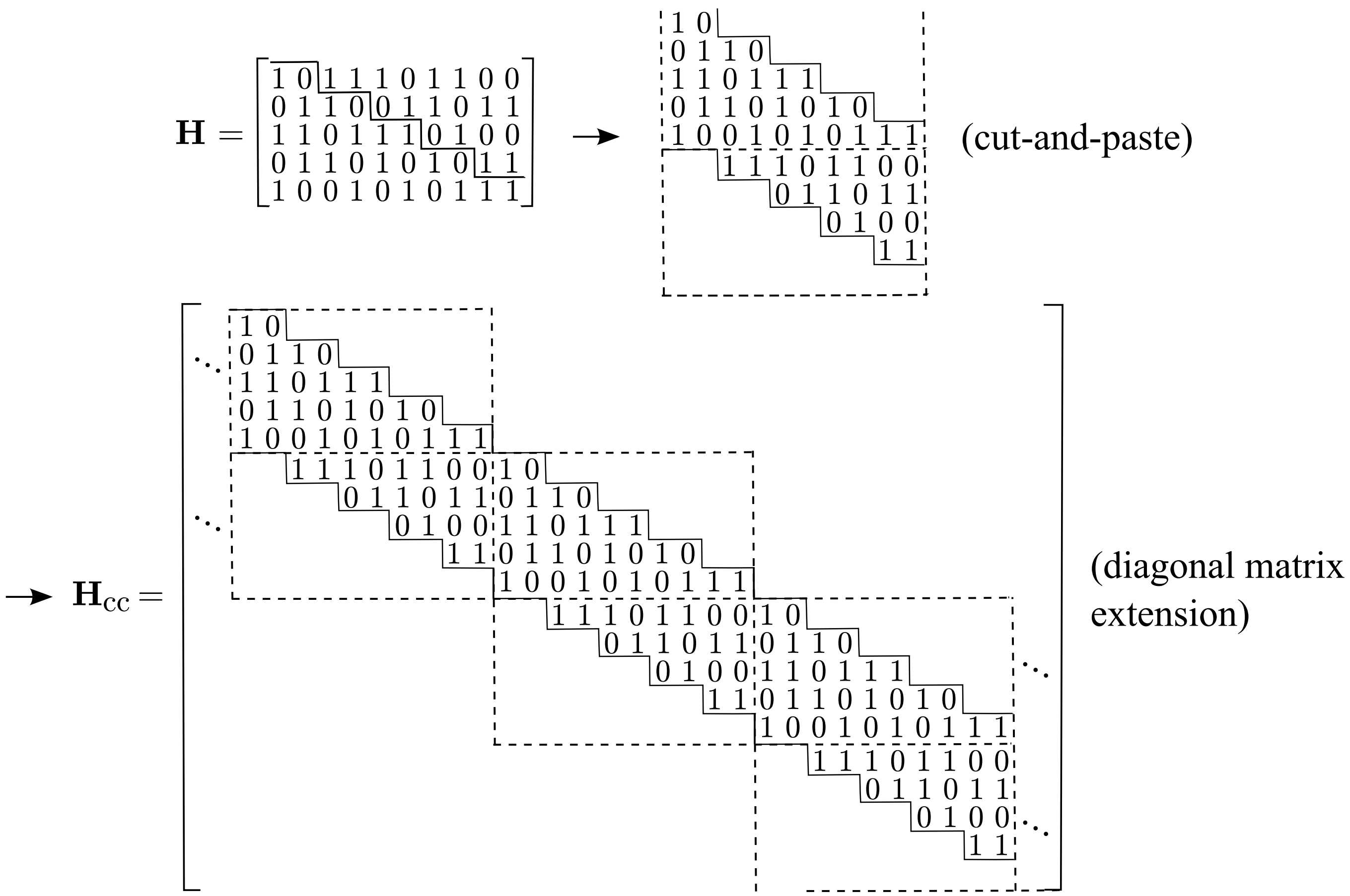

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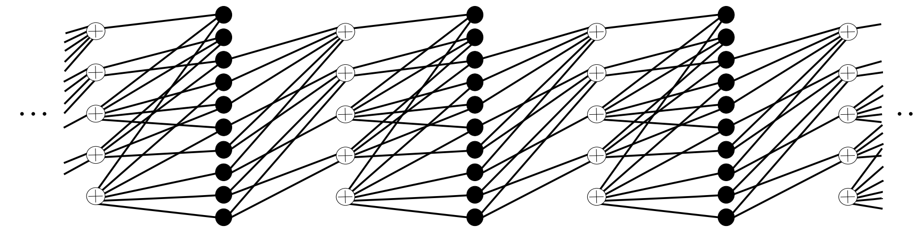
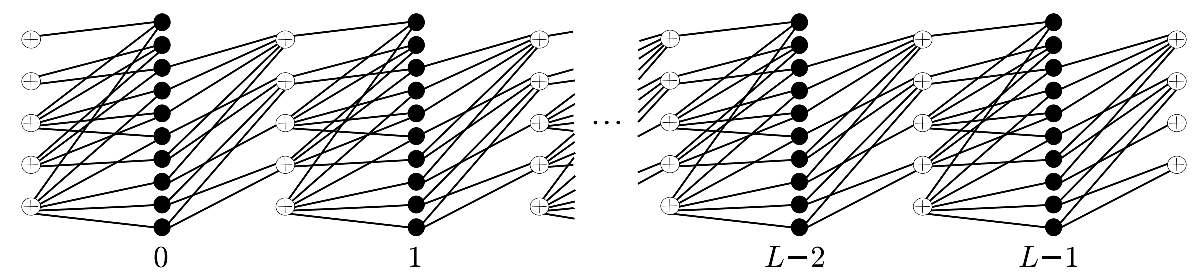


Terminated Tanner graph:



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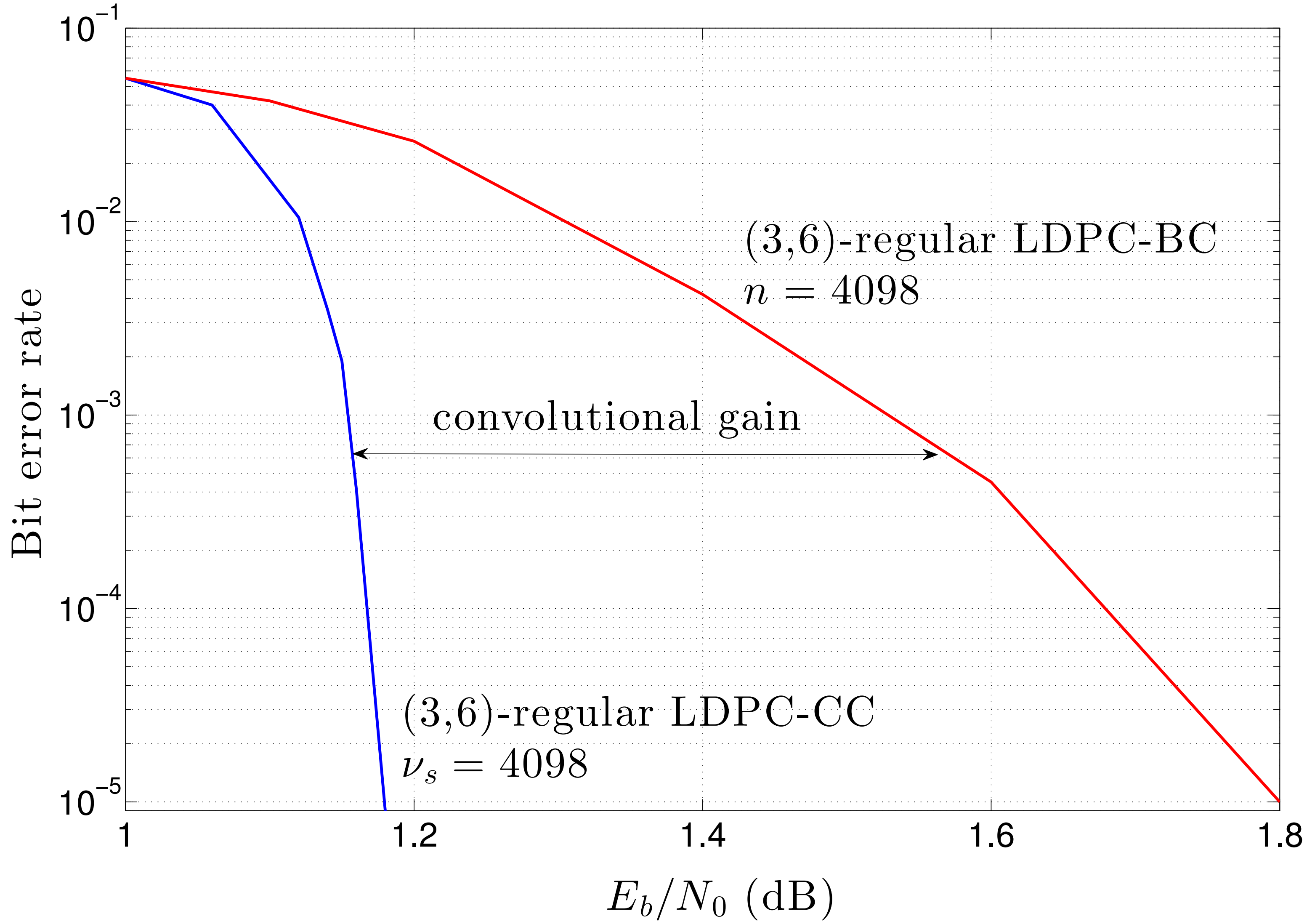
Spatially Coupled LDPC Codes: Performance



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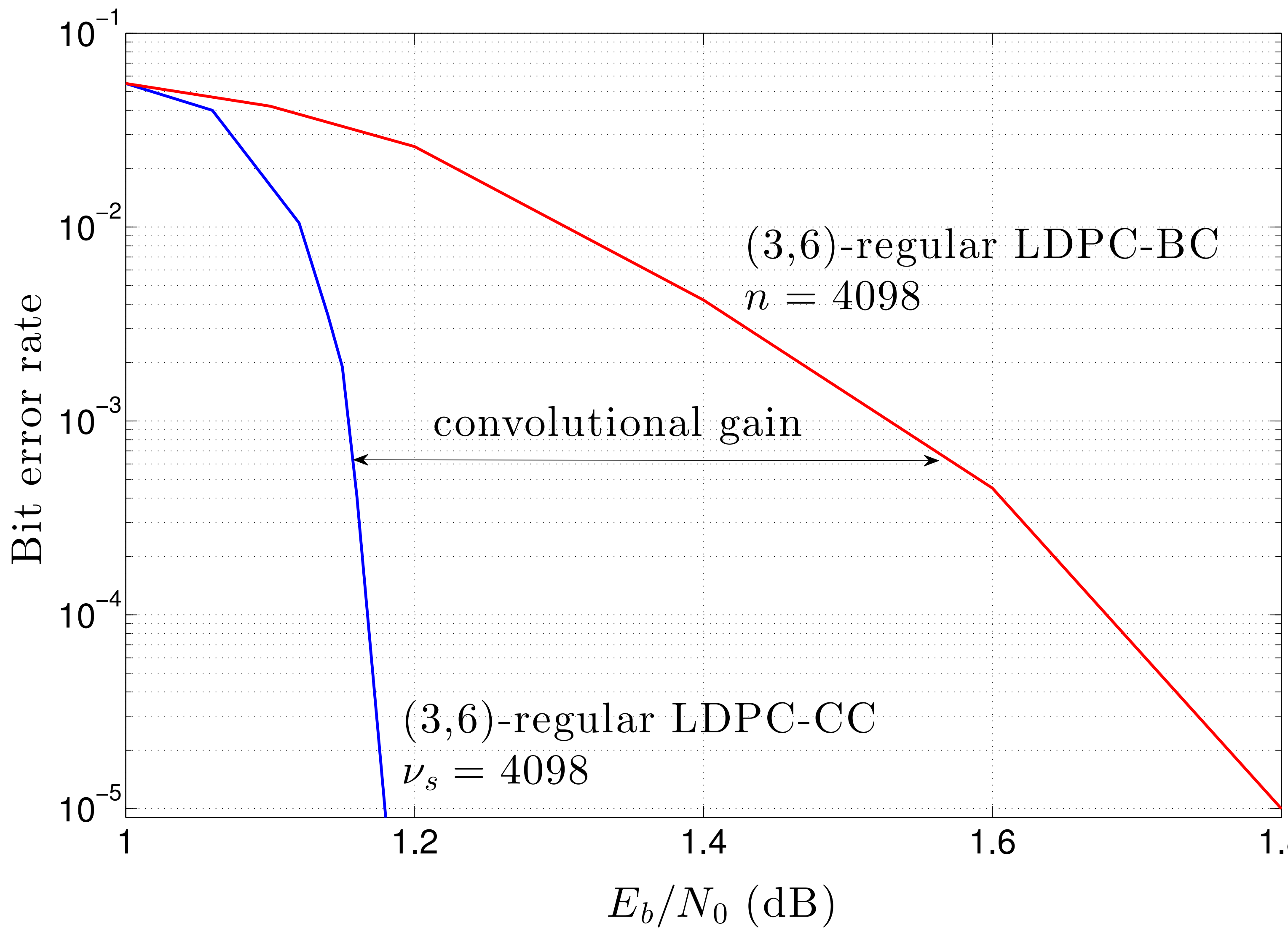
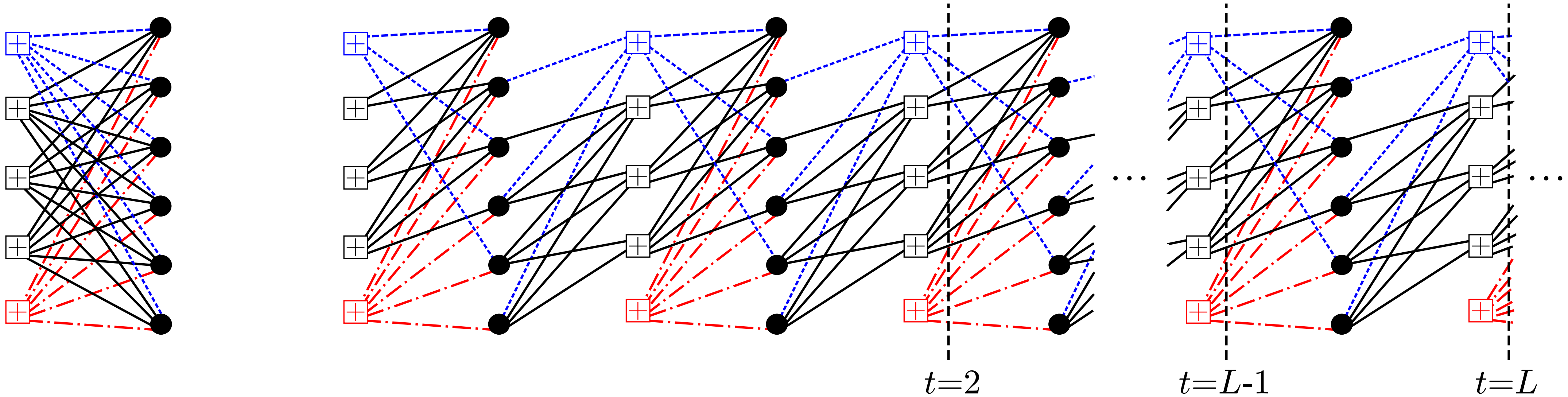


How can we build good nested codes with spatially coupled LDPC codes?

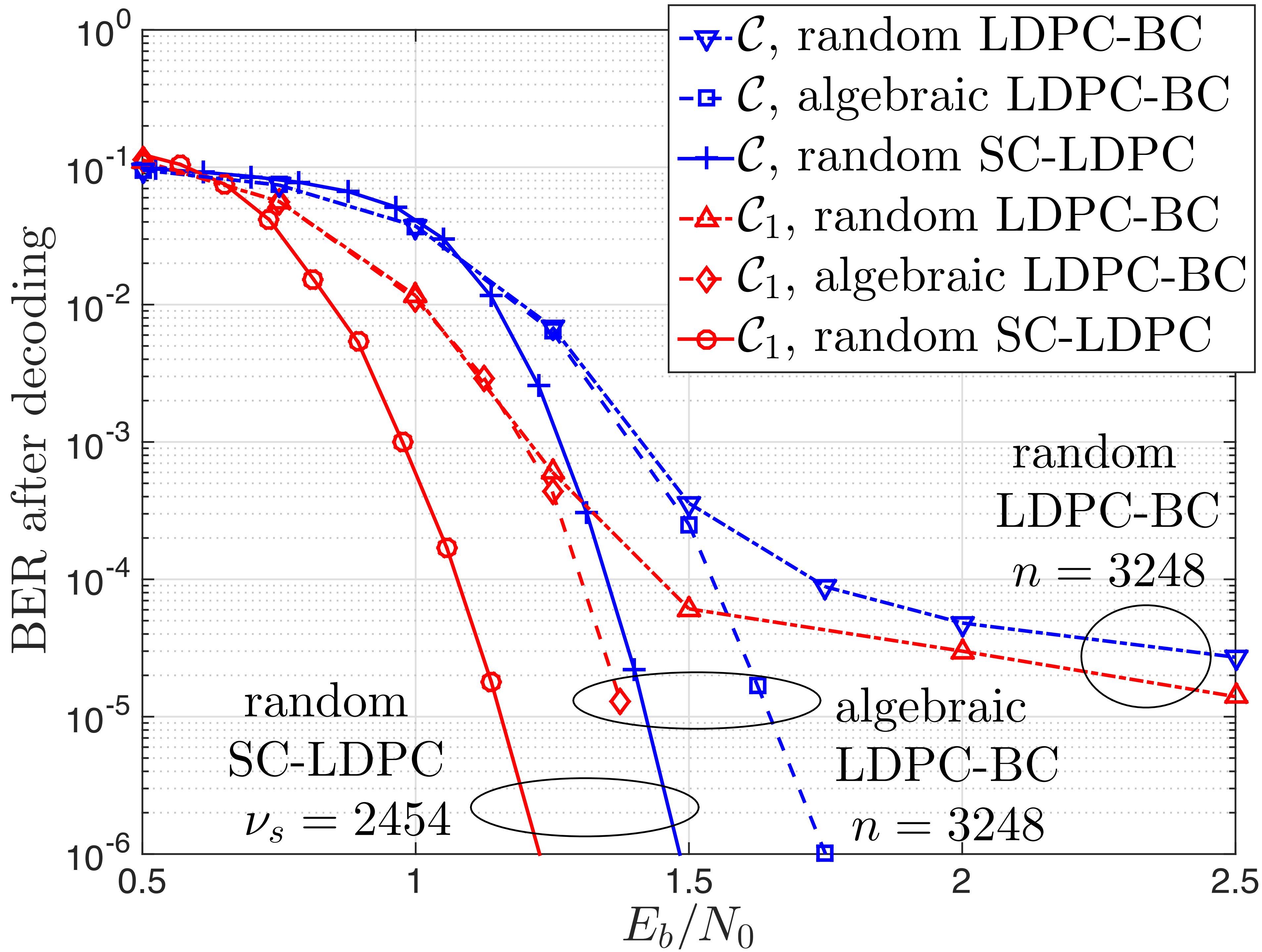
Nested Spatially Coupled LDPC Codes

Protograph representation of a type-1 nested spatially coupled LDPC code ensemble for *M*=2



(a) (b)

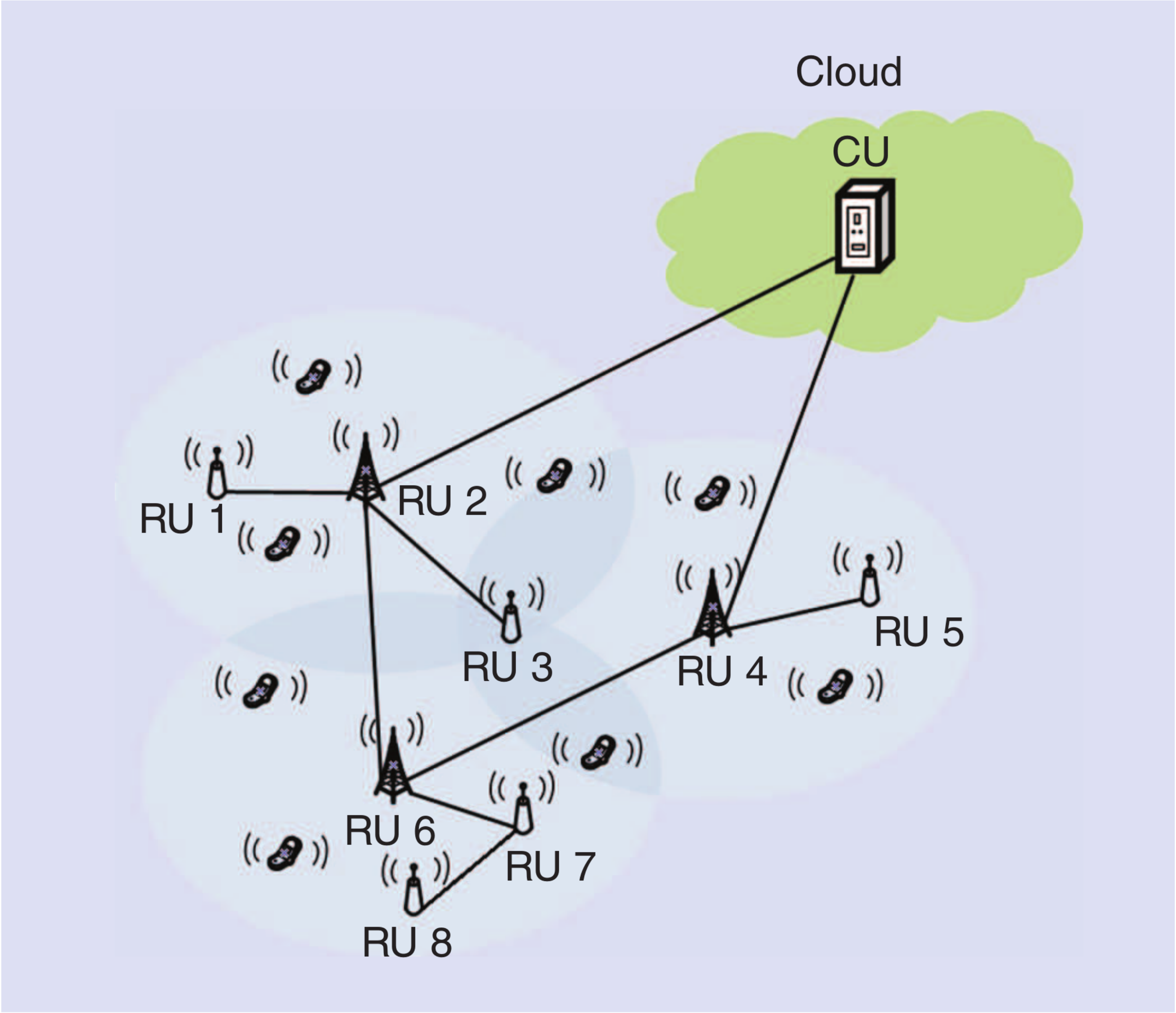
Results



$\mathcal{C}$, random LDPC-BC
$\mathcal{C}$, algebraic LDPC-BC
$\mathcal{C}$, random SC-LDPC
$\mathcal{C}_1$, random LDPC-BC
$\mathcal{C}_1$, algebraic LDPC-BC
$\mathcal{C}_1$, random SC-LDPC
BER after decoding
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0.5
1
1.5
2
2.5
E_b/N_0
random LDPC-BC $n = 3248$
random SC-LDPC $\nu_s = 2454$
algebraic LDPC-BC $n = 3248$

Network Gains From Data Compression

Example: Distributed fronthaul compression for cloud radio access networks (CRANs) in 5G



[Park, Simeone, Sahin, Shamai, 2014]

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Network Gains From Data Compression

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- Practical network based compression approaches virtually unknown
- **In the following:** Lossy compression based on spatially coupled low-density generator matrix (LDGM) codes
  - Low encoding and decoding complexity (linear in time)
  - Performance very close to the rate-distortion limit

Source Compression with Channel Codes

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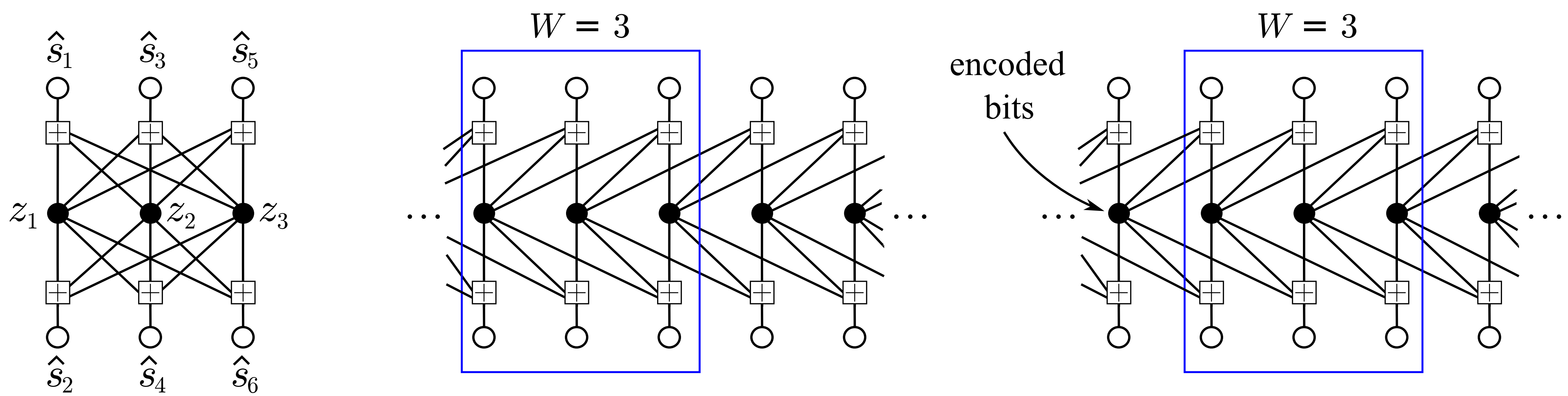
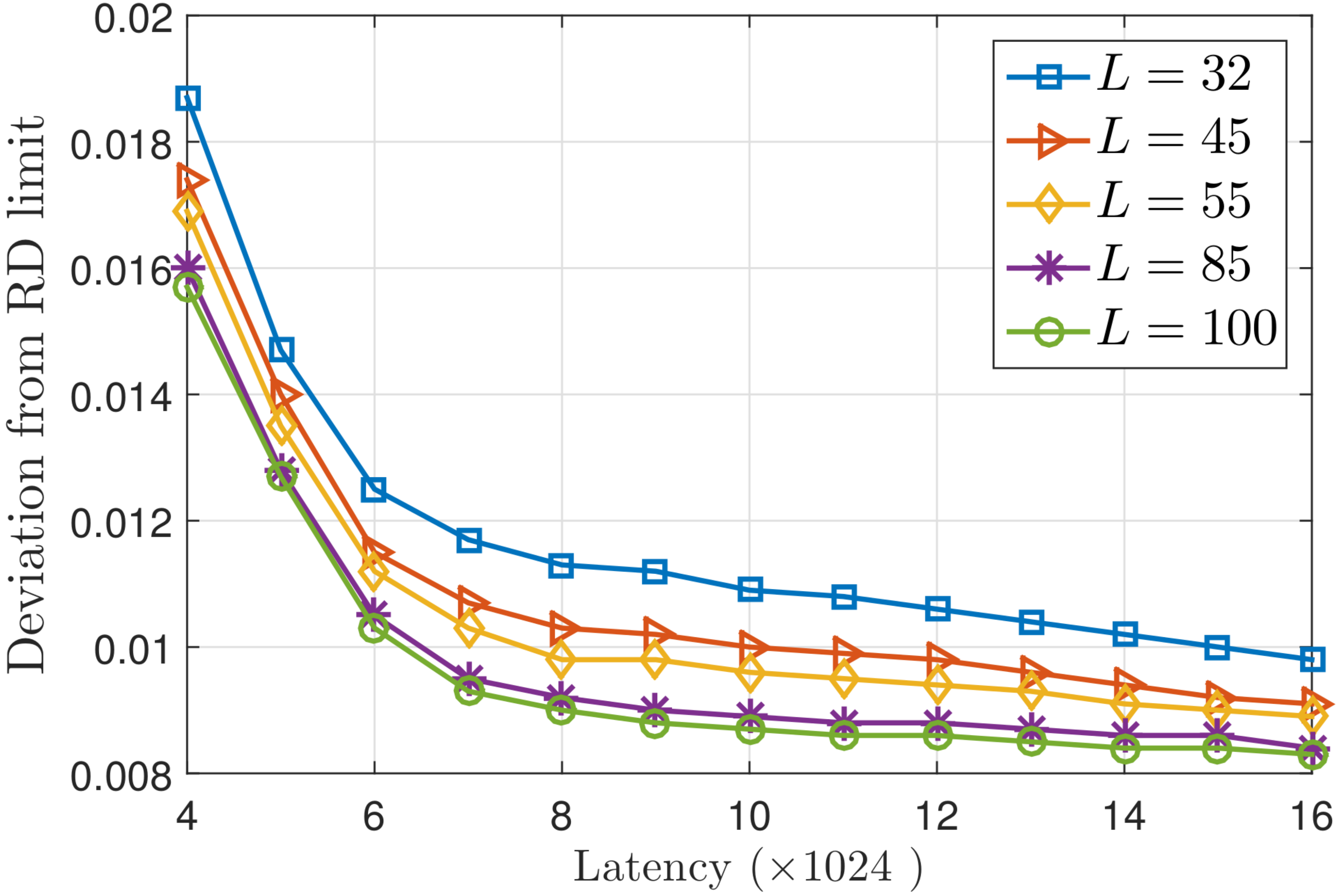
- Source decoding via channel encoding

Coupling of Low-Density Generator Matrix Codes



(a) LDGM-BC (b) SC-LDGM code: time t (c) SC-LDGM code: time $t+1$

Results: Symmetric Bernoulli Source



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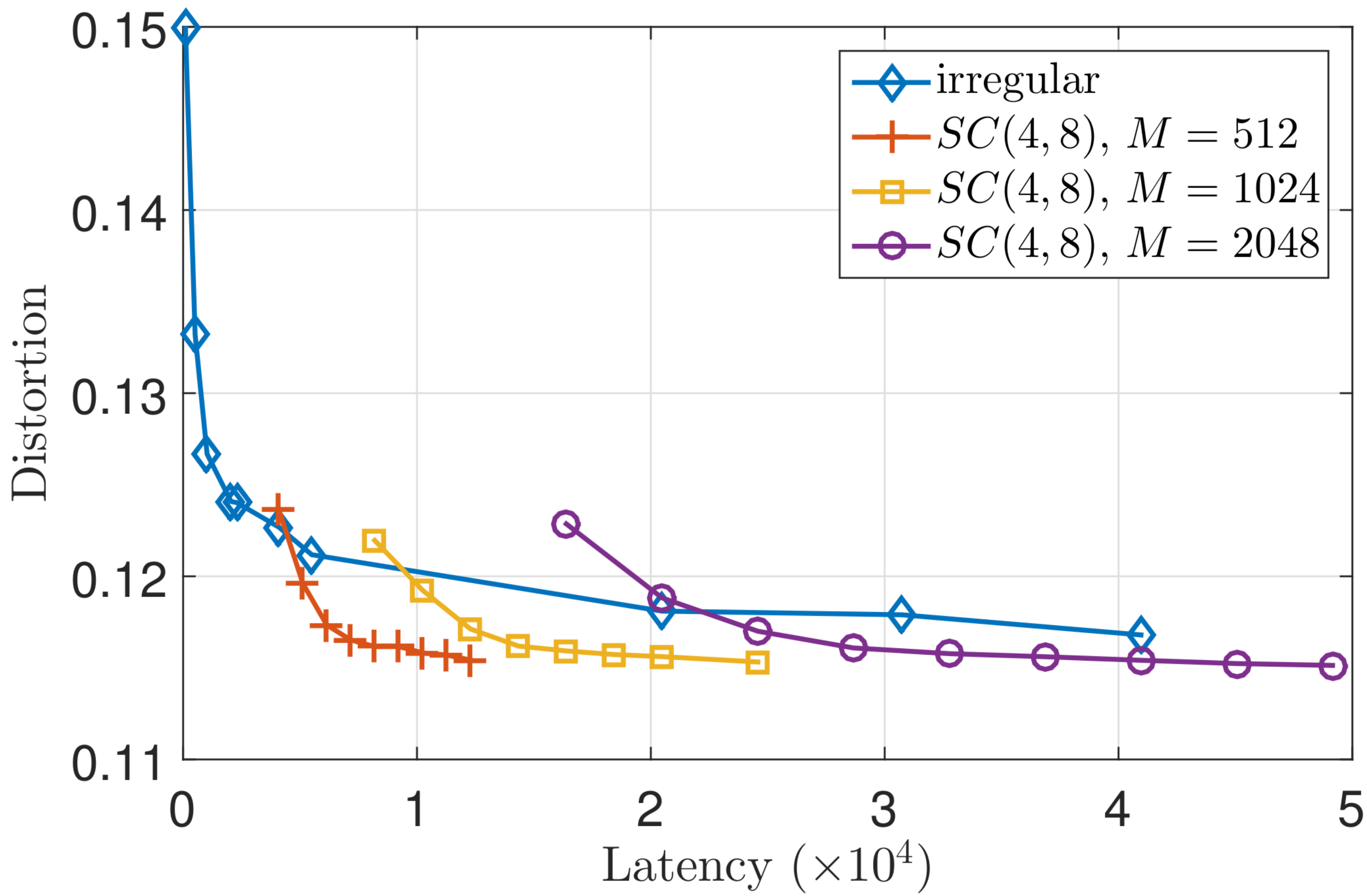

Take Aways

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  - relaying, broadcast, and cooperative diversity scenarios
- Low-complexity lossy and lossless compression with SC-LDGM codes

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- Leveraging network gains in canonical multi terminal problems by nested SC-LDPC codes
  - relaying, broadcast, and cooperative diversity scenarios
- Low-complexity lossy and lossless compression with SC-LDGM codes
- Example applications which can benefit from network compression gains:
  - Distributed compression for CRANs in 5G
  - Distributed compression of phasor measurement units in wide area measurement systems
- **Open:**
  - Communication problem: Design of nested codes for $M>2$
  - Compression problem: Design of nested codes and universal codes

Follow Up...

- A. Golmohammadi, D. Mitchell, J. Kliewer, D. J. Costello: Windowed encoding of spatially coupled LDGM codes for lossy source compression, Submitted to *ISIT 2016*.
- Y.-C. Liang, S. Rini, J. Kliewer: On the design of LDPC codes for joint decoding over the multiple access channel, Submitted to *ITW 2016*.
- E. En Gad, Y. Li, J. Kliewer, M. Langberg, A. Jiang, J. Bruck, Asymmetric error correction and flash-memory rewriting using polar codes, *IEEE Trans. Information Theory*, 2016, to be published.
- D. J. Costello, L. Dolecek, T. E. Fuja, J. Kliewer, D. G. M. Mitchell, R. Smarandache: Spatially coupled codes on graphs: Theory and practice, *IEEE Communications Magazine*, July 2014.
- B. Amiri, J. Kliewer, L. Dolecek: Analysis and enumeration of absorbing sets for non-binary graph-based codes. *IEEE Trans. Commun.*, February 2014.
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- C. A. Kelley, J. Kliewer: Algebraic constructions of graph-based nested codes from protographs. Proc. IEEE Int. Symp. on Information Theory, June 2010
- L. Xiao, T. E. Fuja, J. Kliewer, D. J. Costello, Jr.: A network coding approach to cooperative diversity. *IEEE Trans. Inf. Theory*, October 2007.