Reduced Complexity-and-Latency Variable-to-Check Residual Belief Propagation for LDPC Codes

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- Summary and Conclusions

INTRODUCTION

- **Future system requires higher data throughput**
  - Fast and accurate decoder (fast convergence, high performance)

Standard BP (simultaneous scheduling)

Layered / Shuffled BP (serial scheduling)

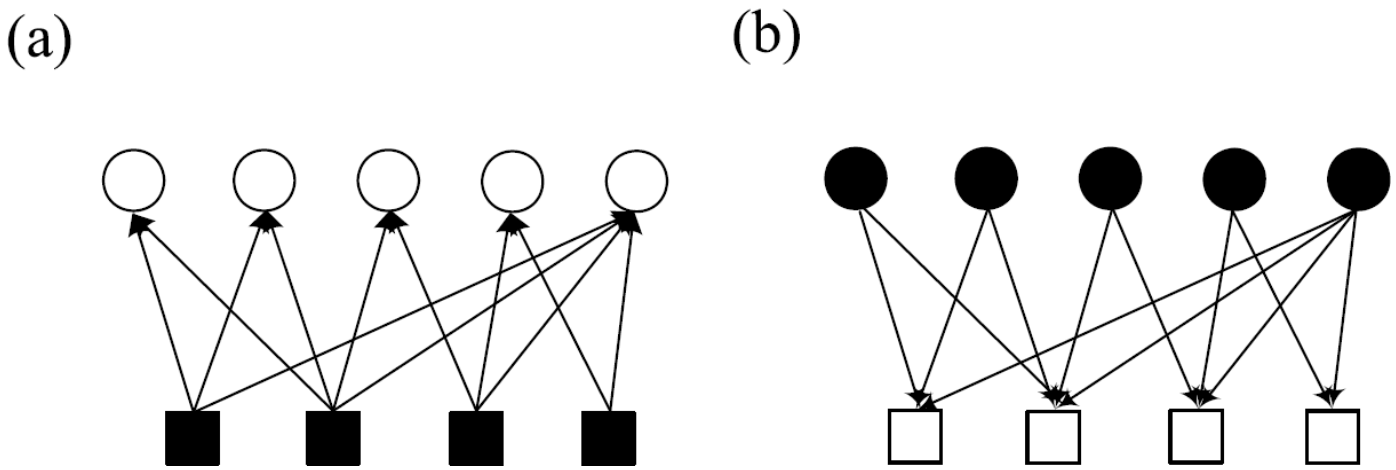
} Non-dynamic scheduling

Residual BP (Dynamic Scheduling)

RBP, Node-wise RBP (NRBP)
Variable-to-Check RBP (VCRBP), Node-wise VCRBP (NVCRBP)
Forced-Convergence NVCRBP (FC-NVCRBP), Sign-based NVCRBP (S-NVCRBP)

INTRODUCTION – standard BP

- **Example Procedure of BP Decoding for LDPC Codes [1]**
  - Simultaneously update all the check nodes and variable nodes

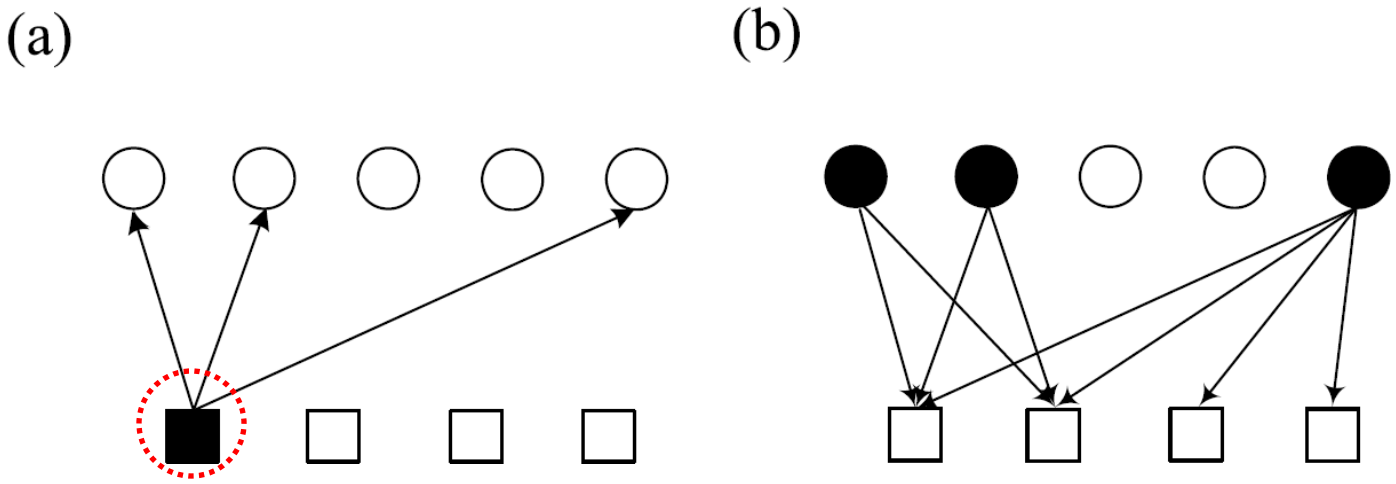


Black circles and squares present updated variable nodes and updated check nodes respectively.

[1] R. G. Gallager, Low-Density Parity-Check Codes. Cambridge, MA: MIT Press, 1963.

INTRODUCTION – layered BP

- **Example Procedure of LBP Decoding for LDPC Codes [2]**
  - Serially update toward check nodes

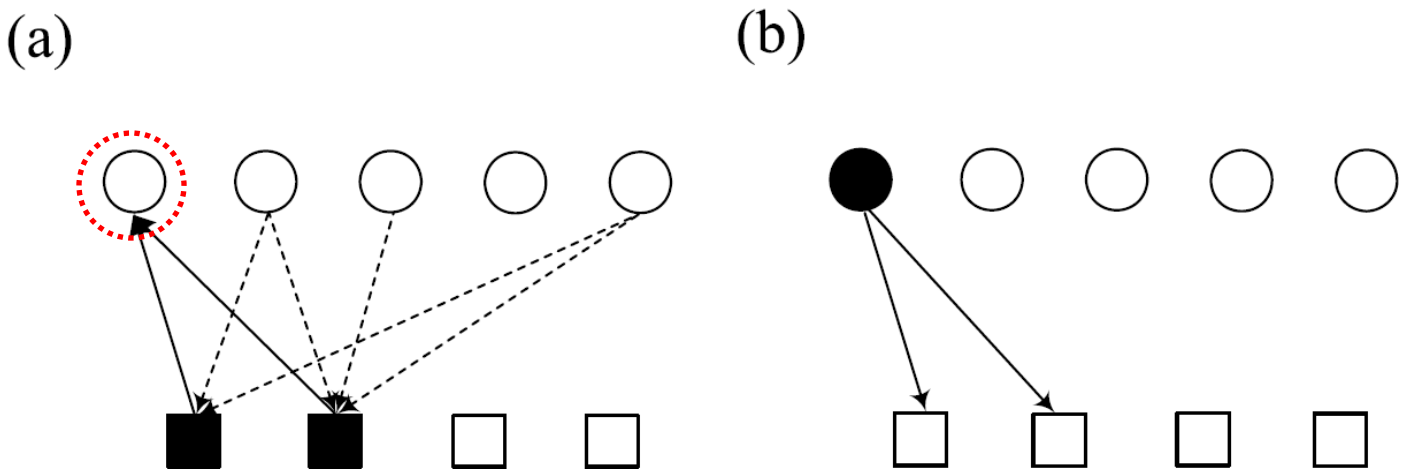


Black circles and squares present updated variable nodes and updated check nodes respectively.

[2] M. Rovini, F. Rossi, P. Ciao, N. LInsalata, and L. Fanucci, ”Layered Decoding of Non-Layered LDPC Codes,” In Proc. 9th EUROMICRO Conference on Digital System Design, pages 537-544, August, 2006.

INTRODUCTION – shuffled BP

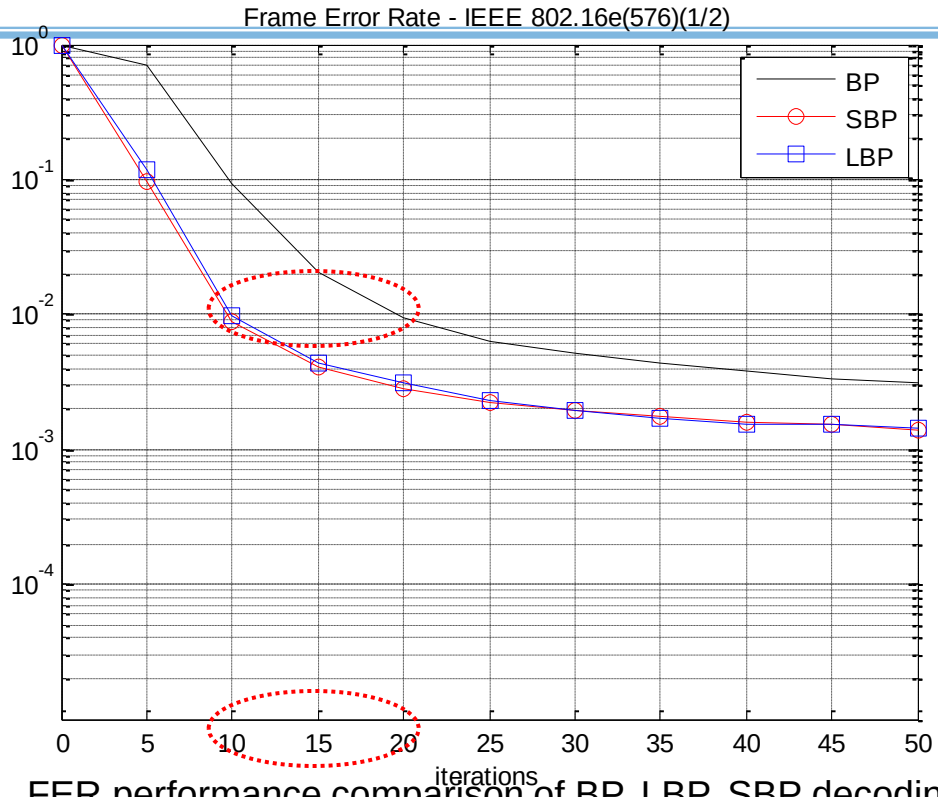
- **Example Procedure of SBP Decoding for LDPC Codes [3]**
  - Serially update toward variable nodes



Black circles and squares present updated variable nodes and updated check nodes respectively.

[3] J. Zhang and M. Fossorier, ”Shuffled belief propagation decoding,” IEEE Trans. on Comm., 53:209-213, February, 2005.

INTRODUCTION - comparison



Convergence speed of the decoding by serial schedule algorithms (LBP [2], SBP [3]) are twice faster in terms of iterations than standard BP [1] algorithm.

FER performance comparison of BP, LBP, SBP decoding using IEEE 802.16e block length-576 rate-1/2 code **up to 50 iterations at 2.5dB.**

[1] R. G. Gallager, Low-Density Parity-Check Codes. Cambridge, MA: MIT Press, 1963.

[2] M. Rovini, F. Rossi, P. Ciao, N. LInsalata, and L. Fanucci, ”Layered Decoding of Non-Layered LDPC Codes,” In Proc. 9th EUROMICRO Conference on Digital System Design, pages 537-544, August, 2006.

[3] J. Zhang and M. Fossorier, ”Shuffled belief propagation decoding,” IEEE Trans. on Comm., 53:209-213, February, 2005.

(CHECK-TO-VARIABLE) RESIDUAL BP =RBP

AND

VARIABLE-TO-CHECK RESIDUAL BP = VCRBP

RBP FOR LDPC CODES

- **Residual Belief Propagation [4]**

$$r(m_k) = |m_k^* - m_k|,$$

where m_k^* is a newly computed m_k by some update function.

RBP for LDPC codes [5]

$$r(m_{c\to v}) = | m^*_{c\to v} - m_{c\to v} |$$

VCRBP for LDPC codes [6]

$$r(m_{v\to c}) = | m^*_{v\to c} - m_{v\to c} |$$

[4] G. Elidan, I. McGraw, and D. Koller, "Residual belief propagation: informed scheduling for asynchronous message passing," *In Proc. 22nd Conference on Uncertainty in Artificial Intelligence, MIT, Cambridge, MA,* July, 2006.

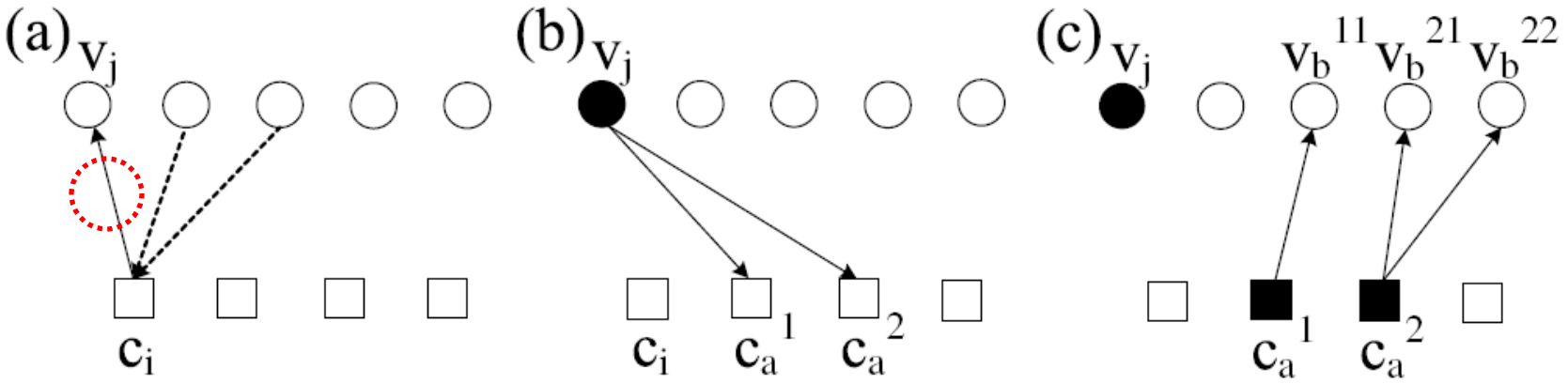
[5] A. I. Vila Casado, M. Griot, and R. D. Wesel, "Informed Dynamic Scheduling for Belief-Propagation Decoding of LDPC Codes," *In Proc. IEEE ICC 2007, Glasgow, Scotland,* June, 2007.

[6] Jung-Hyun Kim, Mi-Young Nam, and Hong-Yeop Song, ”Variable-to-Check Residual Belief Propagation for LDPC Codes,” *IET Electronic Letters, vol.45, no.* 2, pp. 117-118, January, 2009.

RBP FOR LDPC CODES

- **Example Procedure of RBP Decoding for LDPC Codes [5]**

Waste computation

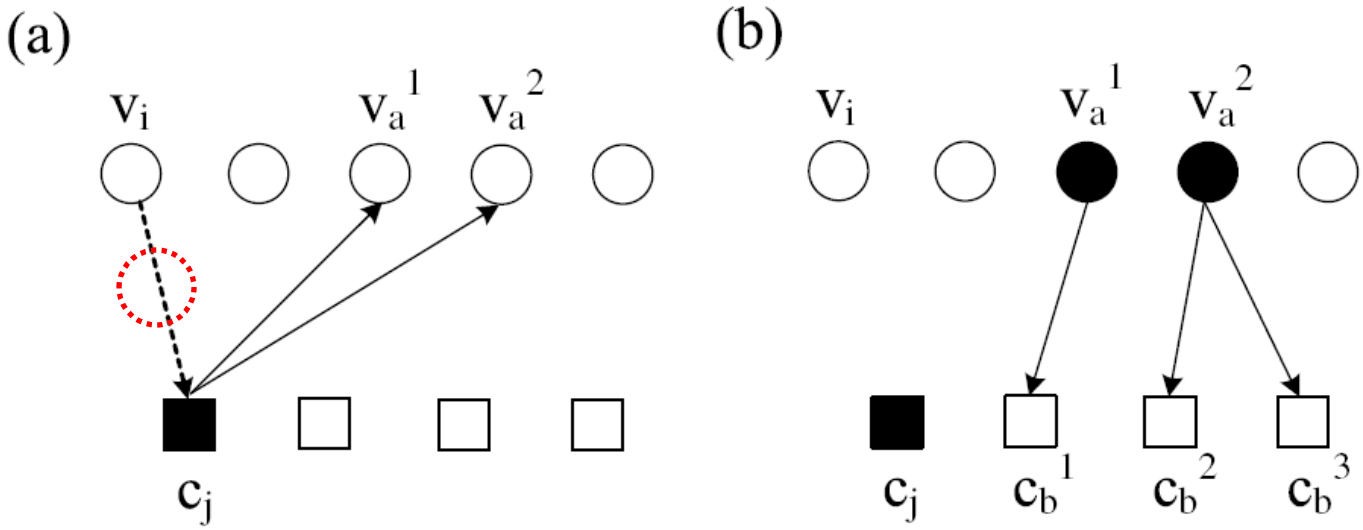


Black circles and squares present updated variable nodes and updated check nodes respectively.

[5] A. I. Vila Casado, M. Griot, and R. D. Wesel, "Informed Dynamic Scheduling for Belief-Propagation Decoding of LDPC Codes," *In Proc. IEEE ICC 2007, Glasgow, Scotland,* June, 2007.

VCRBP FOR LDPC CODES

- **Example Procedure of VCRBP Decoding for LDPC Codes [6]**



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[6] Jung-Hyun Kim, Mi-Young Nam, and Hong-Yeop Song, ”Variable-to-Check Residual Belief Propagation for LDPC Codes,” *IET Electronic Letters, vol.45, no.* 2, pp. 117-118, January, 2009.

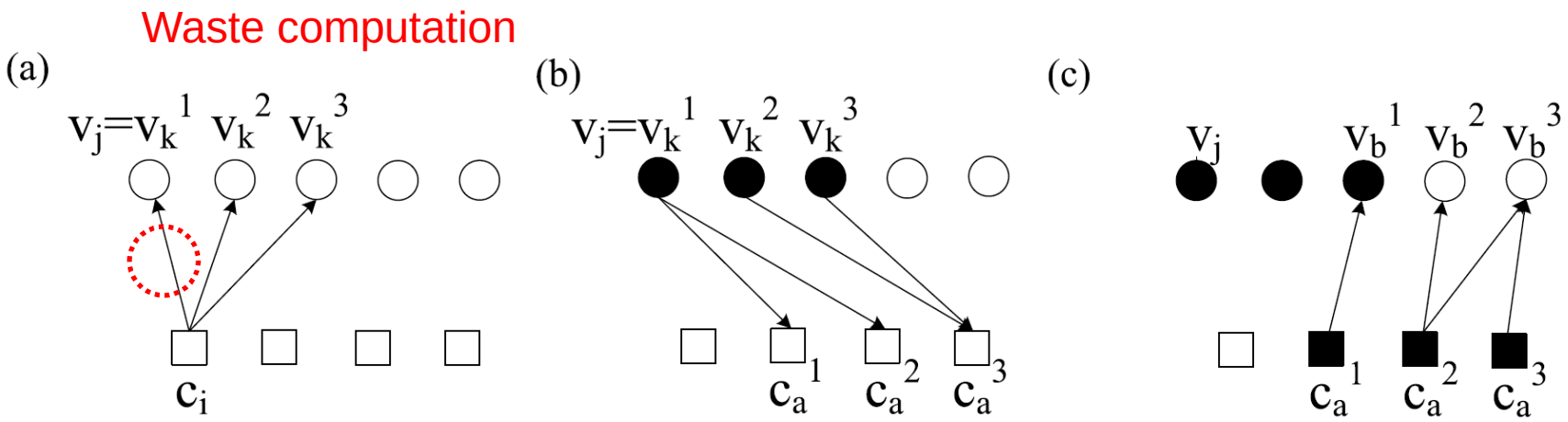
NODE-WISE RBP = NRBP = LAYERED RBP

AND

NODE-WISE VCRBP = NVCRBP = SHUFFLED VCRBP

Node-wise RBP (NRBP) = Layered RBP

- **Example Procedure of NRBP Decoding for LDPC Codes [7]**

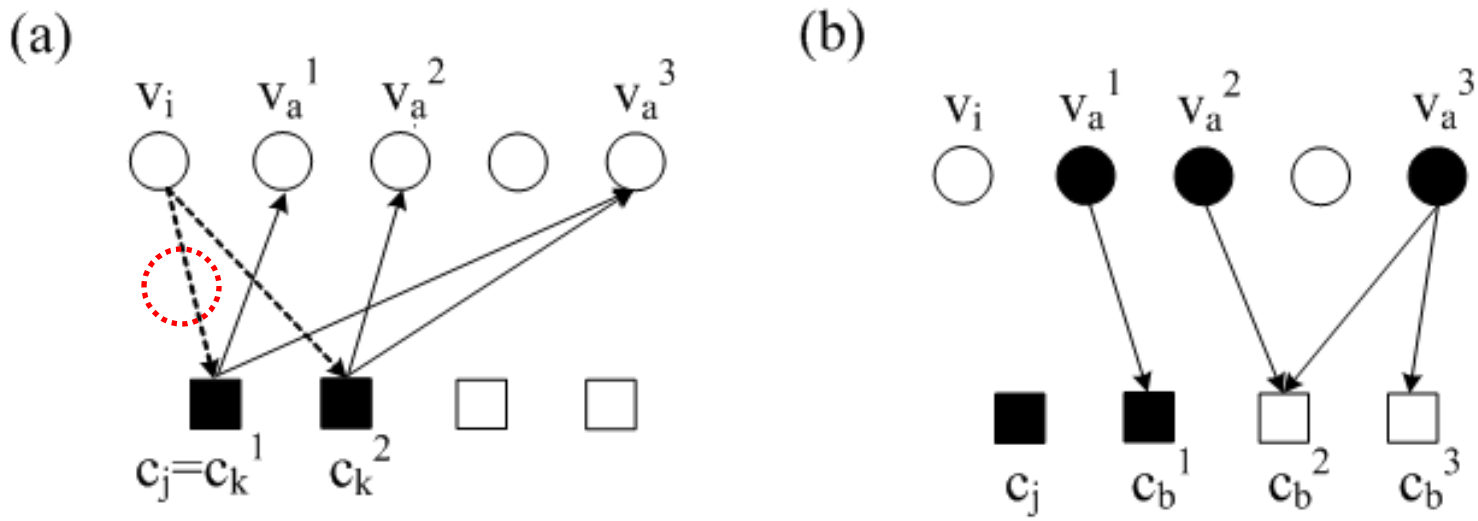


Black circles and squares present updated variable nodes and updated check nodes respectively.

[7] A. I. Vila Casado, M. Griot, and R. Wesel, "Improving LDPC Decoders via Informed Dynamic Scheduling," IEEE Information Theory Workshop 2007, Lake Tahoe, CA, September, 2007.

Node-wise VCRBP (NVCRBP) = Shuffled VCRBP

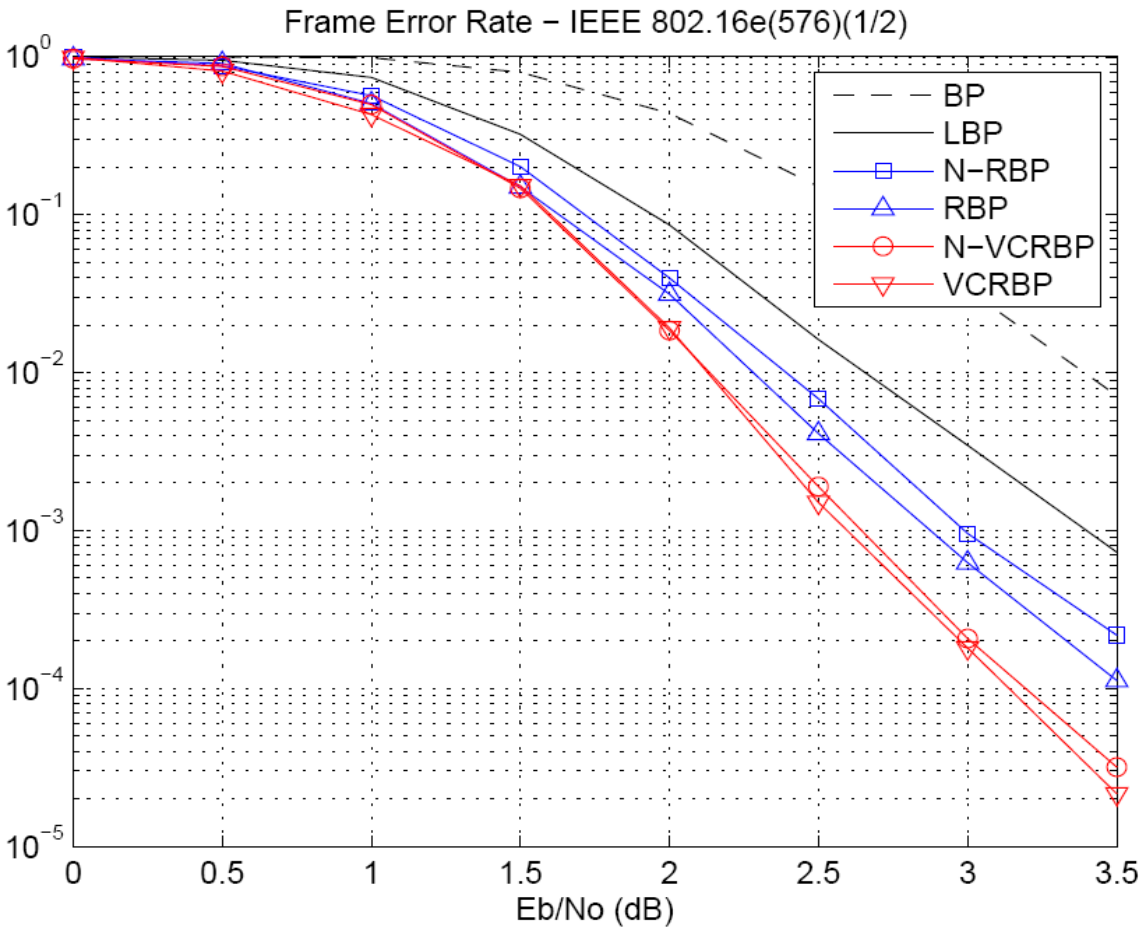
- **Example Procedure of NVCRBP Decoding for LDPC Codes [8]**



Black circles and squares present updated variable nodes and updated check nodes respectively.

[8] Jung-Hyun Kim, Mi-Young Nam and Hong-Yeop Song, "Variable-to-Check Residual Belief Propagation for Informed Dynamic Scheduling of LDPC Codes," *ISITA2008, The Langham Hotel, Auckland, New* Zealand, December 7-10, 2008.

FER Comparison - Simulation

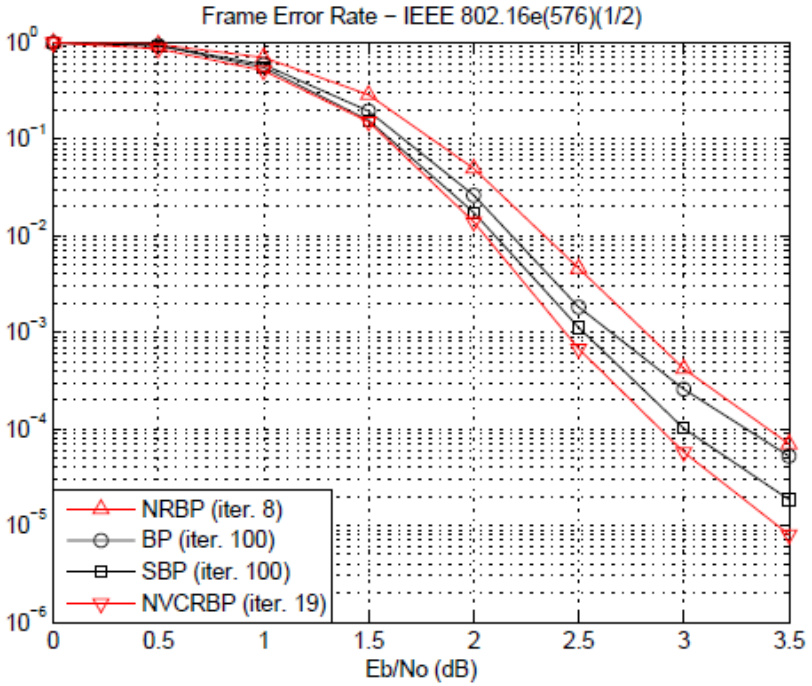


FER performance comparison of BP, LBP, NRBP, RBP, NVCRBP, and VCRBP decoding using IEEE 802.16e block length-576 rate-1/2 code with **at most 8 iterations**

Performance Comparison at Constant Complexity of Computation

APPROXIMATE DECODING COMPLEXITY

	BP / SBP	NRBP	NVCRBP
The number of computations for $m_{c\to v}$ in one iteration	1	$(d_v-1)(d_c-1)+1$	d_c-1
The number of maximum iterations $\times$ The number of computations for $m_{c\to v}$ in one iteration = Approximate decoding complexity (in Fig. 1)	100×1 $=100$	$8\times((3.17-1)(6.33-1)+1)$ $\fallingdotseq 100$	$19\times(6.33-1)$ $\fallingdotseq 100$



NRBP decoding does WORSE than standard BP decoding at the constant complexity of computation!!

FER performance comparison of BP, SBP, NRBP and NVCRBP decoding using IEEE 802.16e block length-576 rate-1/2 code **with maximum 100, 100, 8, and 19 iterations**, separately.

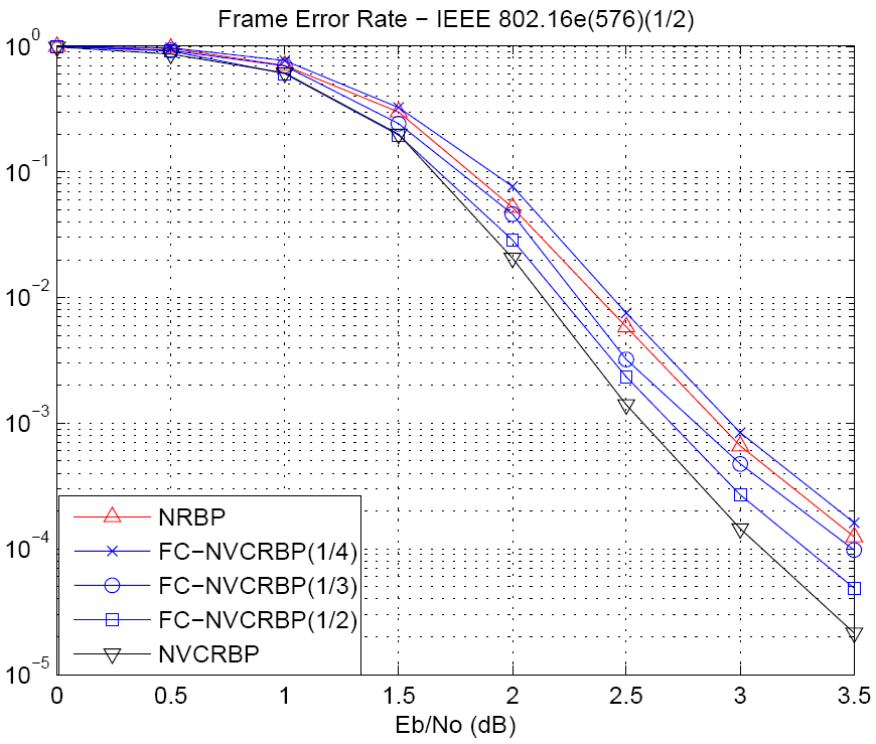
FORCED-CONVERGENCE NVCRBP = FC-NVCRBP

AND

SIGN-BASED NVCRBP = S-NVCRBP

Forced Convergence
FC-NVCRBP FOR LDPC CODES

- **Forced Convergence NVCRBP Decoding for LDPC Codes**



FER performance comparison of NRBP, FCNVCRBP(1/4), FC-NVCRBP(1/3), FC-NVCRBP(1/2), NVCRBP decoding using IEEE 802.16e block length-576 rate-1/2 code with **at most 8 iterations**

Convergence criterion

$$r(m_{v\to c}) = \left| m^{*}_{v\to c} - m_{v\to c} \right| \le r_{th}$$

FC-NVCRBP skips updates of convergent nodes.

Approximate version for r_{th}

Take some appropriate portion of the residuals, say, ½, 1/3, or 1/4

Sign-based
S-NVCRBP FOR LDPC CODES

- **Sign-based NVCRBP Decoding for LDPC Codes**

  New ordering measure s(·):

$$s(m_{v\to c}) = sign(m^{*}_{v\to c}) \times sign(m_{v\to c})$$

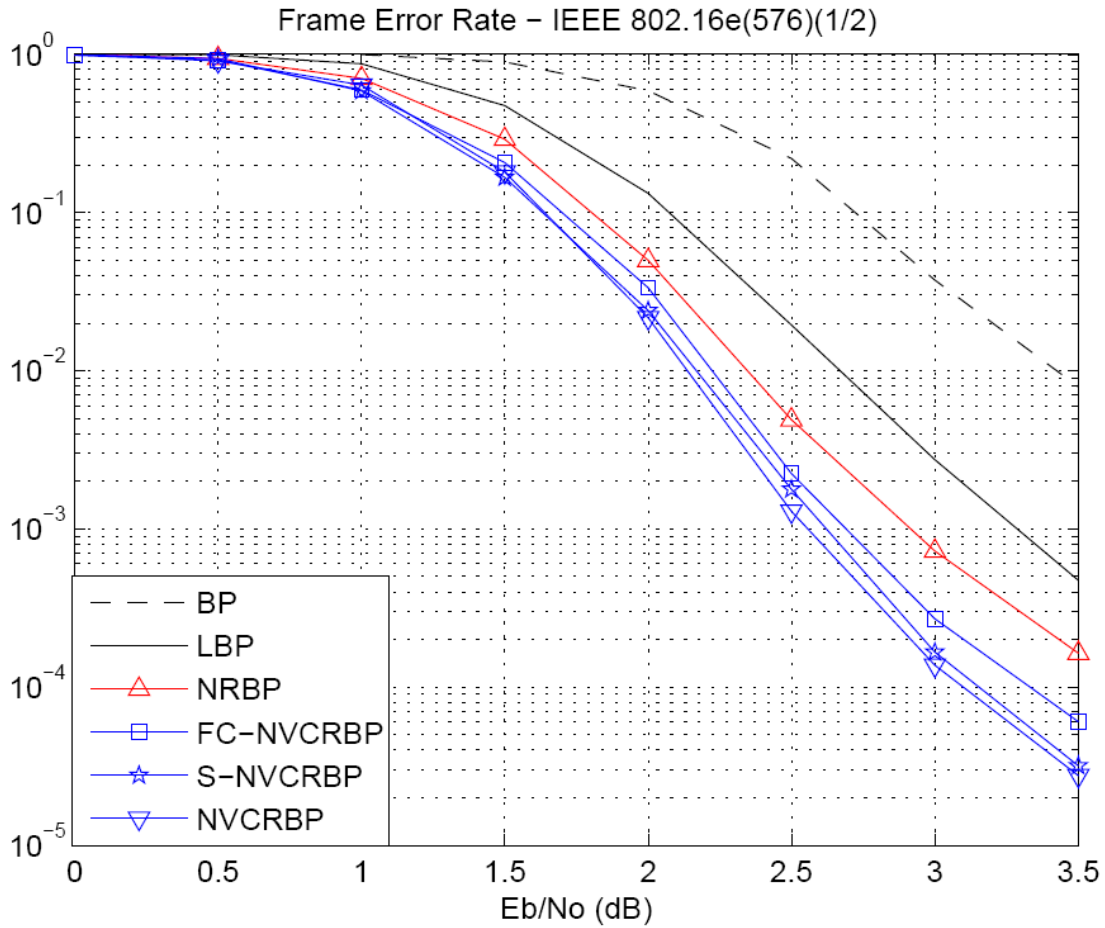
where if $m_{v\to c}$ has a positive value then let $sign(m_{v\to c}) = 1$,

otherwise if $m_{v\to c}$ has a negative value then let $sign(m_{v\to c}) = -1$.

S-NVCRBP does not need to calculate all residuals

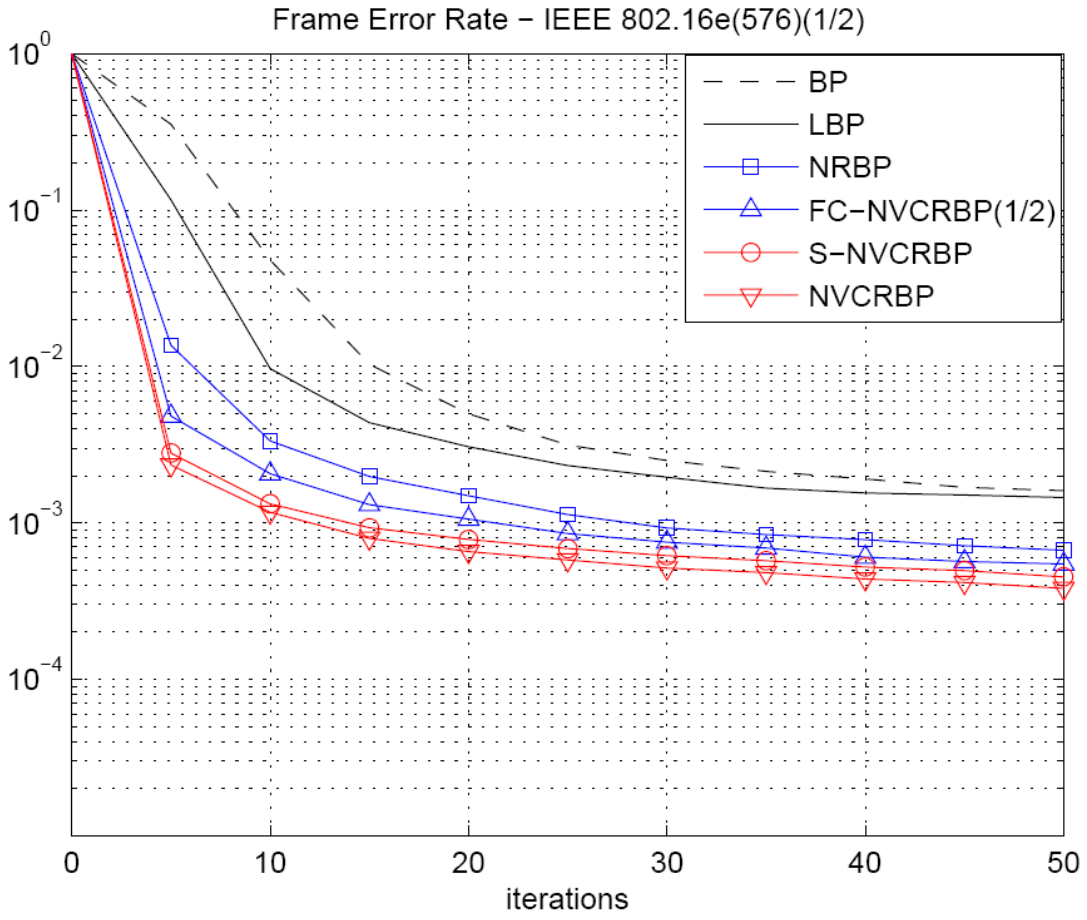
And **neither** to compare all residuals each other.

Performance Comparison



FER performance comparison of BP, LBP, NRBP, FC-NVCRBP(1/2), S-NVCRBP, and NVCRBP decoding using IEEE 802.16e block length-576 rate-1/2 code with **at most 8 iterations.**

Performance as the iteration continues



FER performance comparison of BP, LBP, NRBP, FCNVCRBP(1/2), S-NVCRBP, and NVCRBP decoding using IEEE 802.16e block length-576 rate-1/2 code **up to 50 iterations at 2.5dB.**

FINALLY…

Summary and Conclusions

- **VCRBP**
  - makes LDPC decoding converge much fasts in terms of the number of iterations than RBP (=CVRBP).
  - guarantees better performance with lower decoding complexity than RBP within only 8 iterations.
  - performs similarly better after sufficiently many iterations than RBP.

- **NVCRBP**
  - has very close performance to VCRBP with significantly lower decoding complexity.

- **FC-NVCRBP and S-NVCRBP**
  - very close performance with much lower complexity and latency compared to NVCRBP within only 8 iterations as well as after sufficiently many iterations.

THANK YOU!!