Signal Detection Based on Belief Propagation in a Massive MIMO System

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Background (1)

- Massive MIMO
  - An order of 100 antenna elements
    - channel capacity issue
  - Fading reduction effect

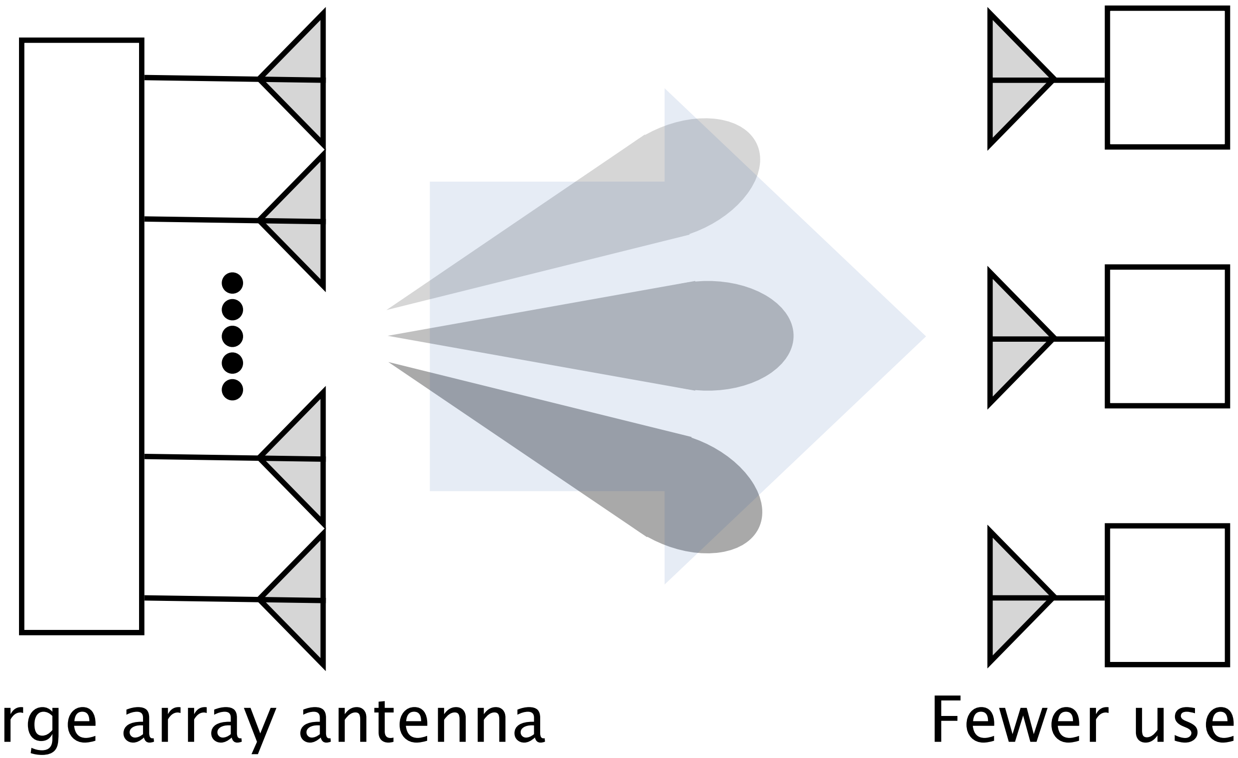
$\boldsymbol{H}$: N x N channel matrix
(i.i.d. complex Gaussian random variables)

$$\boldsymbol{H}^H \boldsymbol{H} \simeq N \boldsymbol{I}$$

$$\log\det\left(\boldsymbol{I} + \frac{\gamma}{N}\boldsymbol{H}^H\boldsymbol{H}\right) \simeq \log\det\left(\boldsymbol{I} + \gamma\boldsymbol{I}\right)$$
$$= N\log(1+\gamma)$$

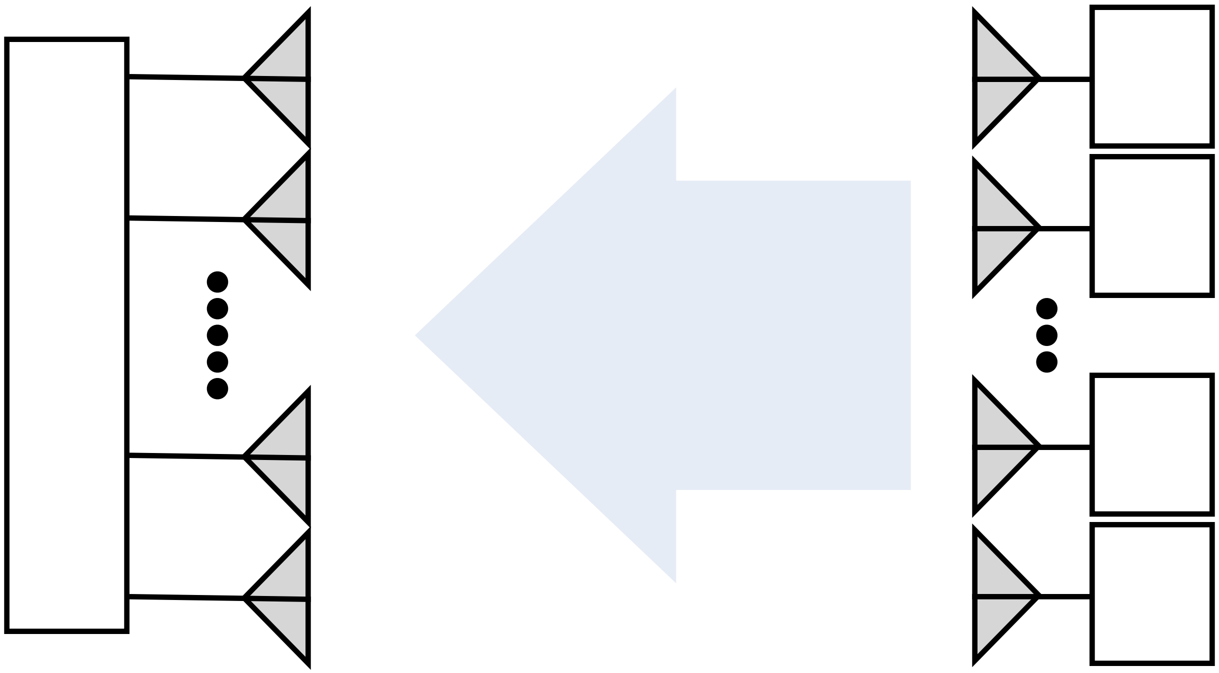
Background (2)

- Promising application
  - Multiuser MIMO



Problem

- If the number of users increase.....



Detection of a large number of streams is required.

Objective

- Spatial demultiplexing
  - MAP detection: $O(L^N)$
  - Spatial filtering (MMSE, ZF): $O(N^3)$
  - QR decomposition based algorithms: $O(N^3)$

- Less complex method
  - Detection based on belief propagation (BP): $O(N^2)$

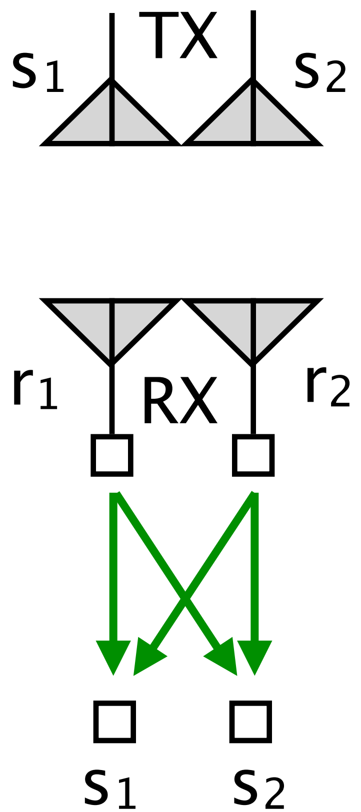
N. Srinidhi, S. K. Mohammed, A. Chockalingam, and B. S. Rajan, “Low-Complexity Near-ML Decoding of Large Non-Orthogonal STBCs using Reactive Tabu Search,” Proc. IEEE ISIT, pp. 1993-1997, June/July 2009.
C. Knievel, M. Noemm, and P. A. Hoeher, “Low-Complexity Receiver for Large-MIMO Space-Time Coded Systems,” Proc. IEEE VTC-Fall, Sept. 2011.

  - Capability of pure BP-based algorithm

Contents

- Factor graph expression
- BP-based detection algorithm
- EXIT analysis
- Performance evaluation
- Conclusions

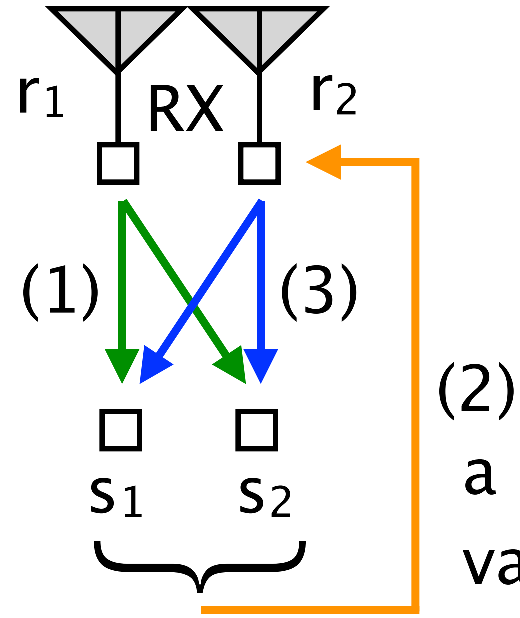
Factor graph expression (1)



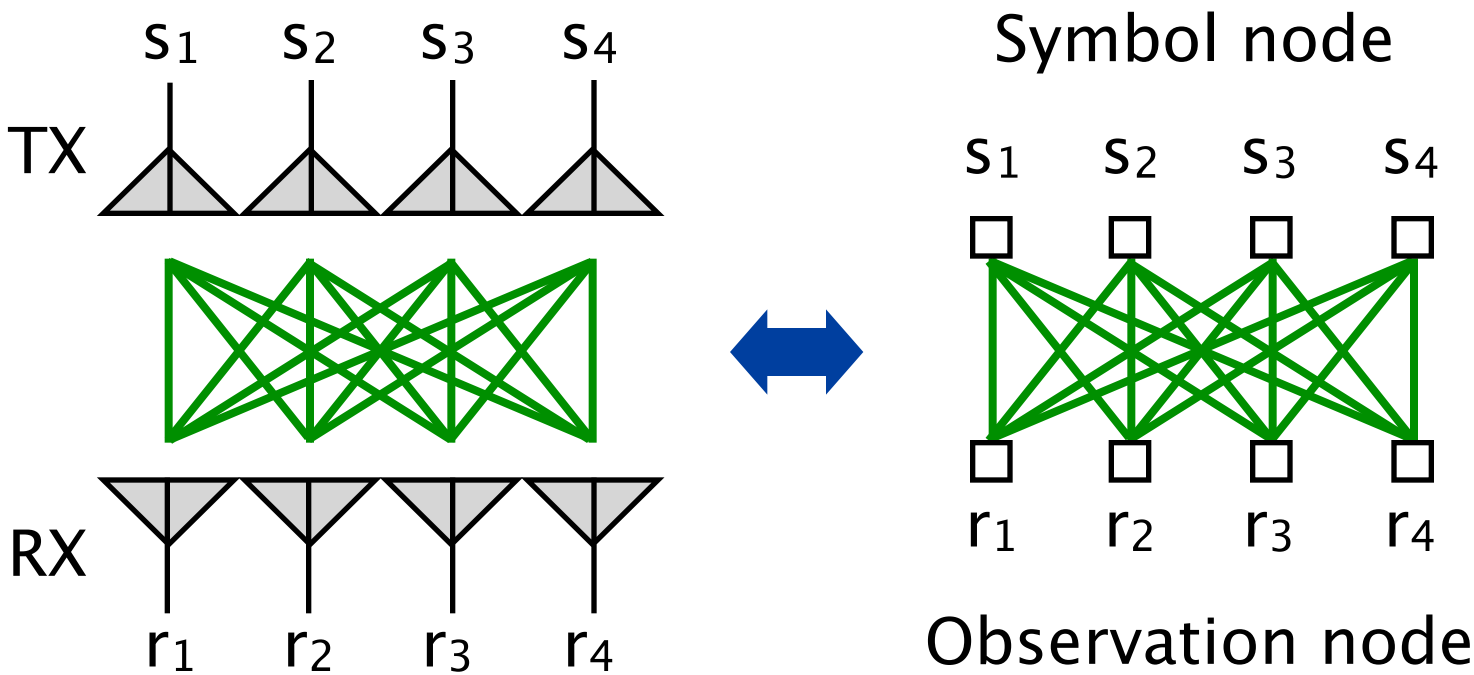
Problem is to estimate s_1 and s_2 from r_1 and r_2.

Estimated symbols and received signals are mutually related.

ex)



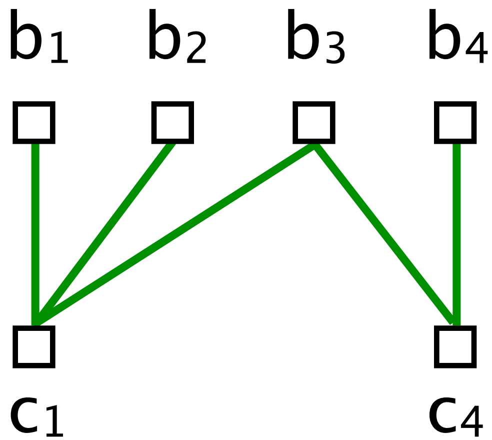
Factor graph expression (2)



Factor graph expression (3)

- MIMO detection vs LDPC decoding

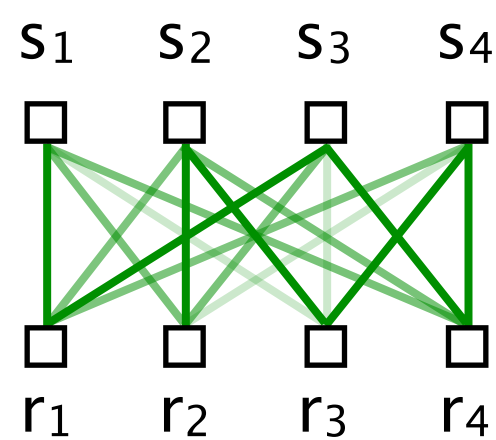
Message node



Check node

$b_1+b_2+b_3=0$ $b_3+b_4=0$

Symbol node

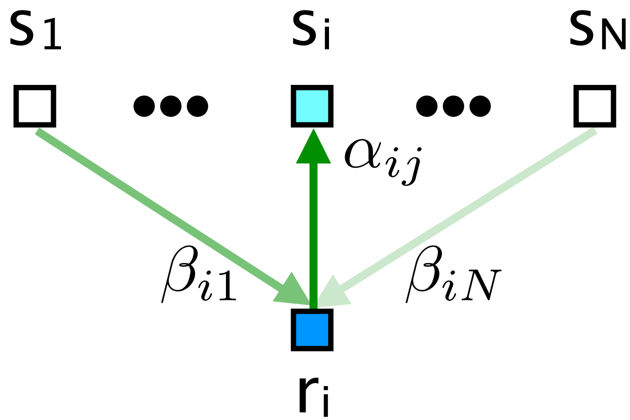


Observation node

$r_i=h_{i1}s_1+h_{i2}s_2+h_{i3}s_3+h_{i4}s_4$

BP-based detection (1)

- Message update at observation node



α_{pq} β_{pq} : LLR

(1) soft replica generation

$$\underline{\beta_{ik}} \Rightarrow \hat{s}_k$$

extrinsic value

(2) parallel interference cancellation (PIC)

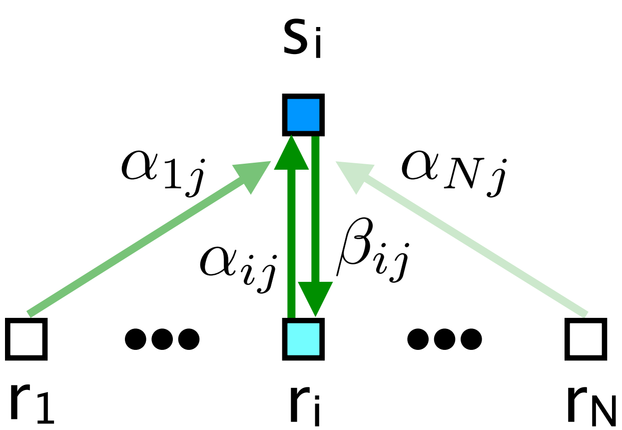
$$\hat{r}_i^{(j)} = r_i - \sum_{k=1,k\neq j}^{N} h_{ik}\hat{s}_k \quad \text{O}(\text{N}^2)$$

(3) detection

$$\log \frac{P(\hat{r}_i^{(j)} | s_j = 1)}{P(\hat{r}_i^{(j)} | s_j = 0)} = \alpha_{ij}$$

BP-based detection (2)

- Message update at symbol node



(1) a posteriori LLR calculation

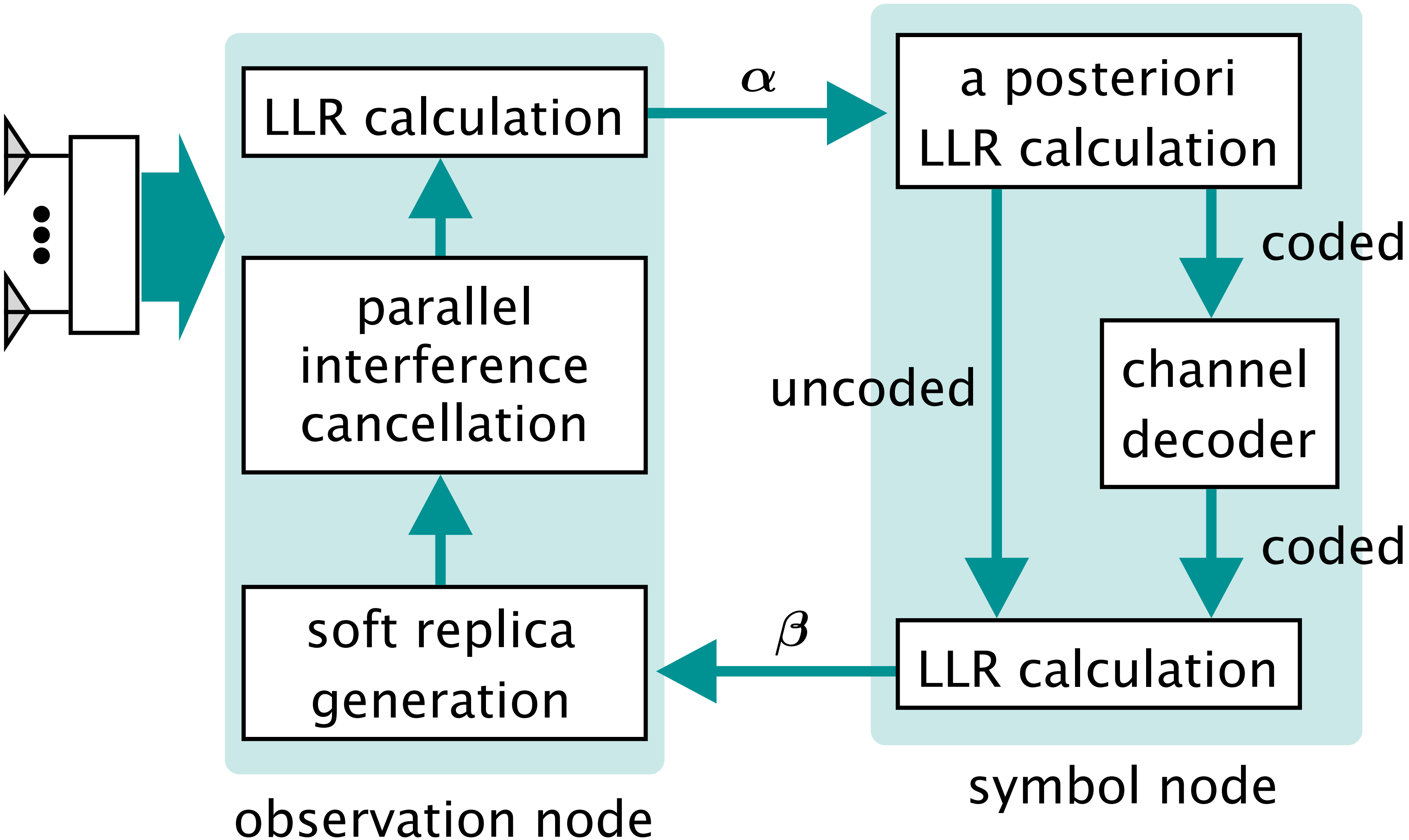
$$\gamma_j = \sum_{k=1}^{N} \alpha_{kj}$$

γ_j ➡ final decision

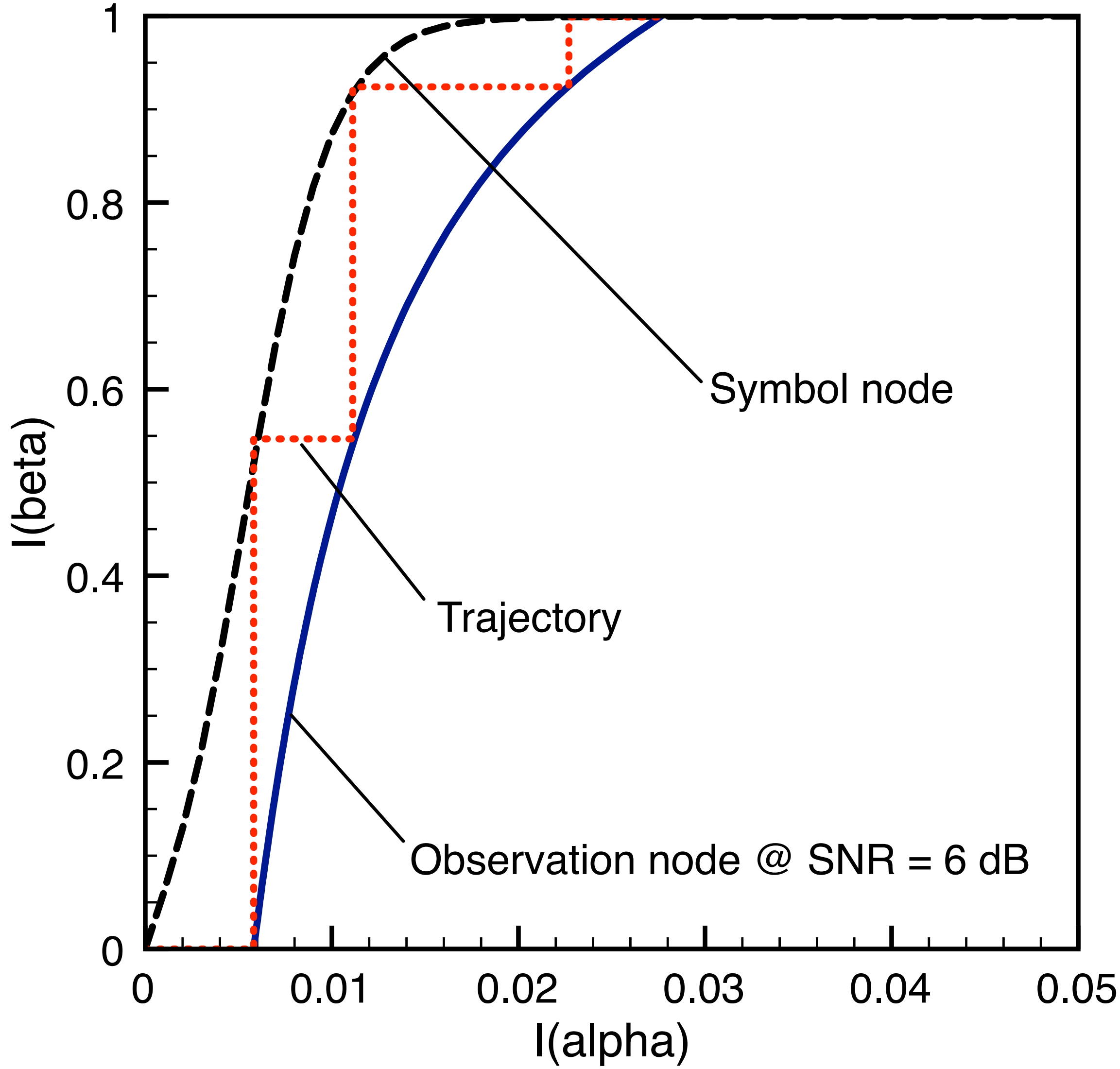
(2) message calculation

$$\underbrace{\beta_{ij}}_{\text{extrinsic value}} = \gamma_j - \alpha_{ij}$$

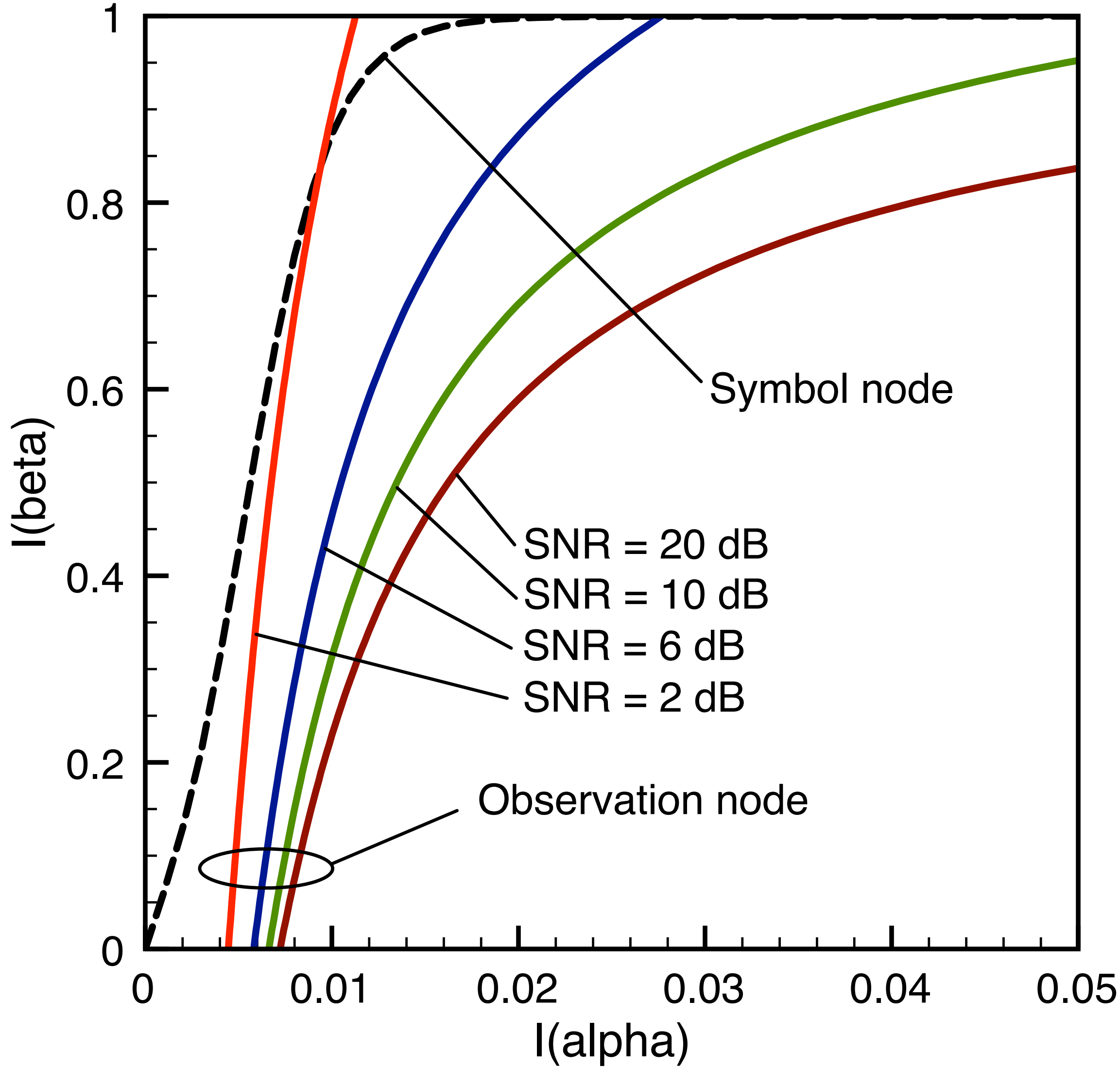
Block diagram of BP-based detection



An example of reliability improvement



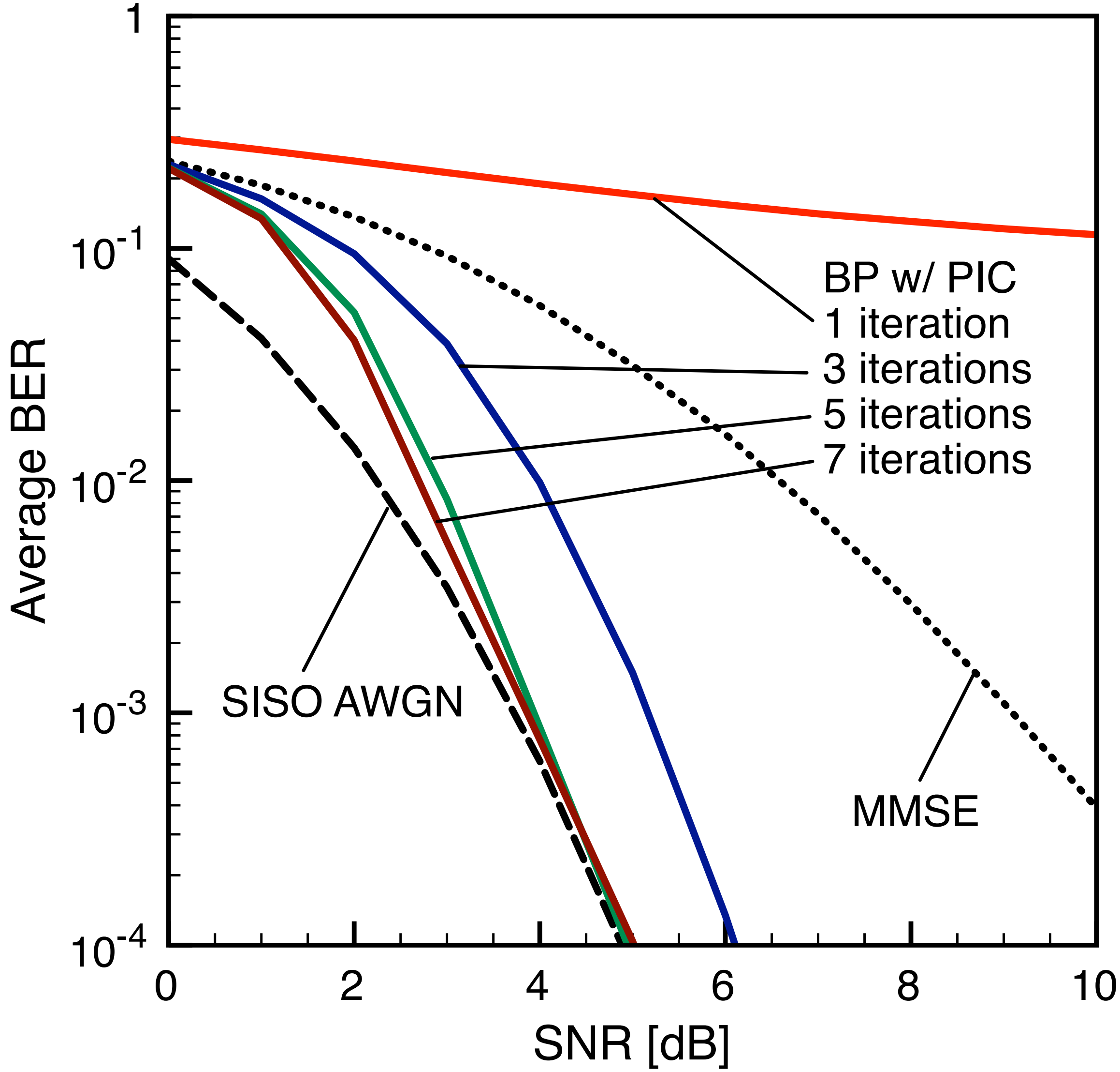
EXIT analysis



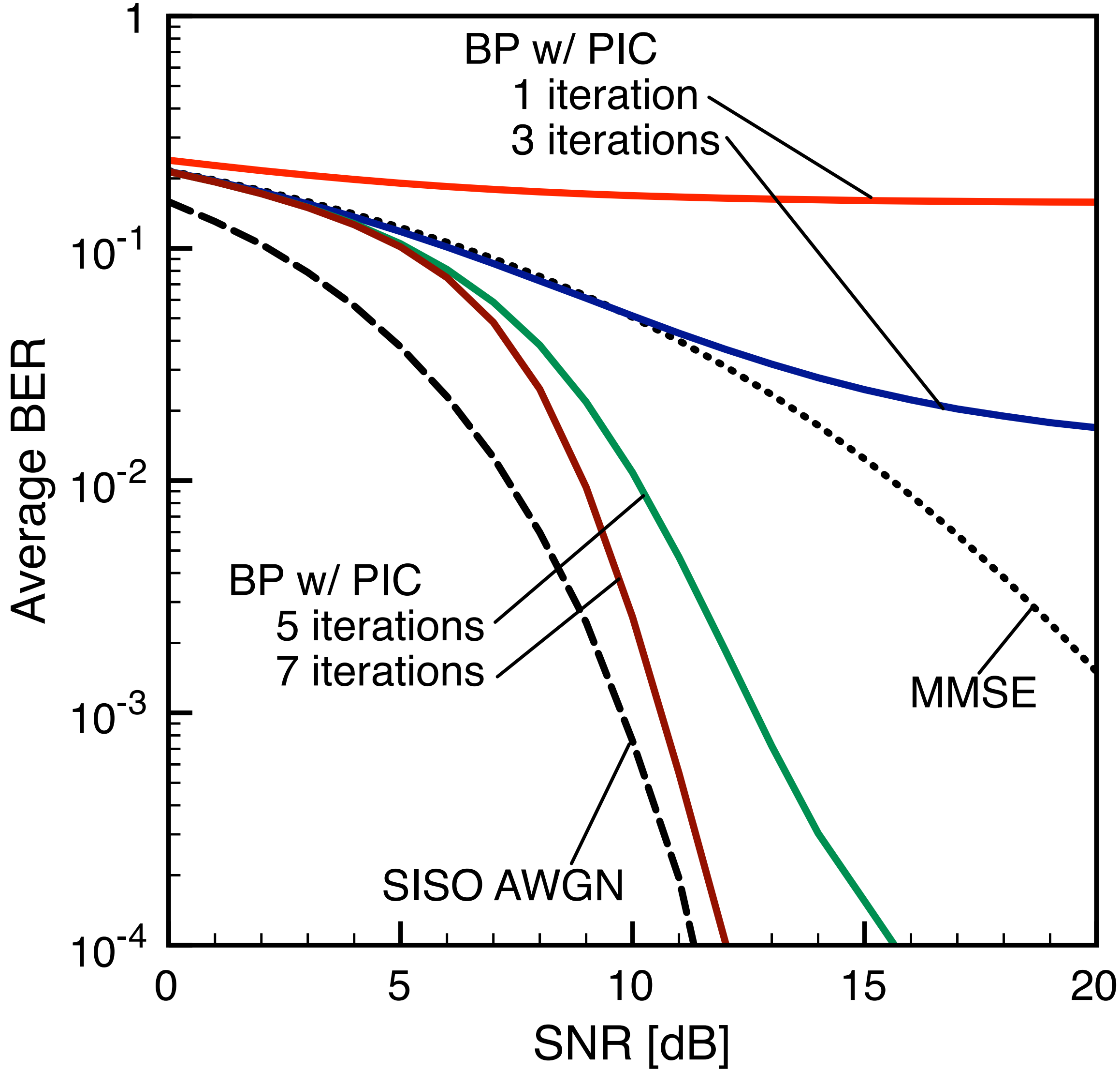
Simulation parameters

	BP with PIC	MMSE
Number of antennas	10 x 10, 30 x 30, 50 x 50, 100 x 100, 200 x 200	
Modulation	QPSK	
Channel statistics	quasi-static Rayleigh fading	
Noise	AWGN	
Frame length	10-100 symbols	
Number of frames	10,000	
Channel encoding	Convolutional code (constraint length 3, coding rate 1/2)	
Channel decoding	Max-Log MAP decoder	

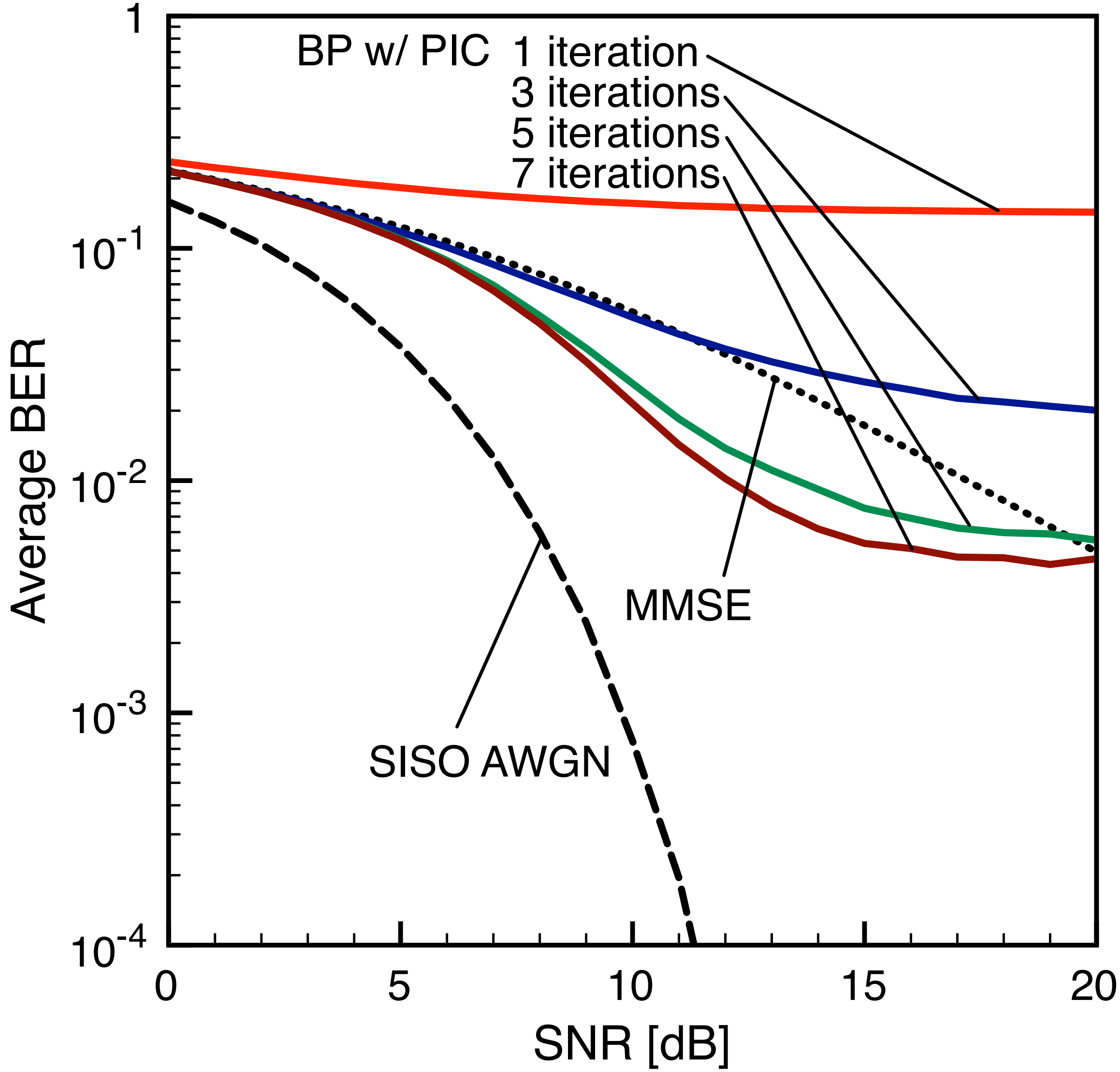
BER performance (100 x 100, coded case)



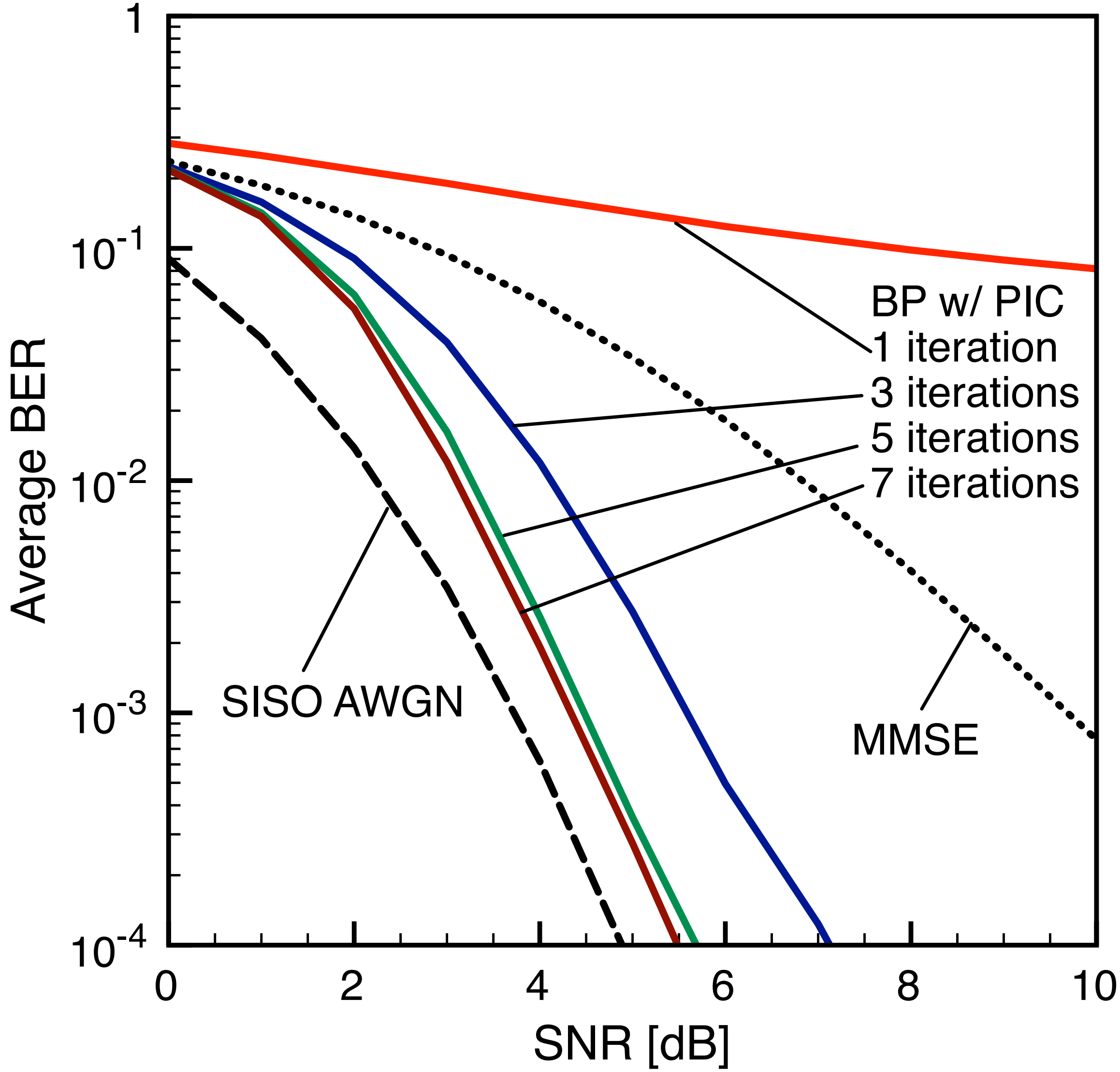
BER performance (100 x 100, uncoded case)



BER performance (10 x 10, uncoded case)



BER performance (10 x 10, coded case)



Conclusions

- We have clarified the capability of pure BP-based detection for spatially multiplexed streams.
- BP-based detection
    - is implementable in $O(N^2)$
    - achieves better performance than spatial filtering with MMSE
    - works only when size of array is large
    - converges more quickly with channel encoding
- Future works
    - effects of channel correlation
    - higher level modulation