MIMO-OFDM移動通信用MAP受信機における
ファクターグラフに基づく逐次伝送路推定

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Outline

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- Iterative MAP Receiver
- Message-Passing Algorithm
- Factor Graph of One Packet
- Smoothing and Removing
- Derivation of Recursive Formula
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Background (1/2)

Conventional Technology

- **An iterative MAP receiver** for LDPC-coded MIMO-OFDM mobile communications is considered.
- **The EM algorithm is applied to the MAP symbol detection** to reduce the complexity
  - MAP demodulation and channel estimation is performed iteratively

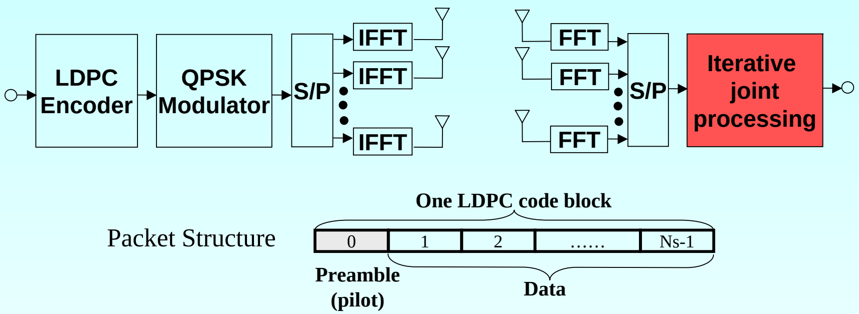
Background (2/2)

Problem

- MMSE CHE cannot sufficiently track the fast fading
- RLS CHE in the iterative MAP symbol detection has a noise amplification problem

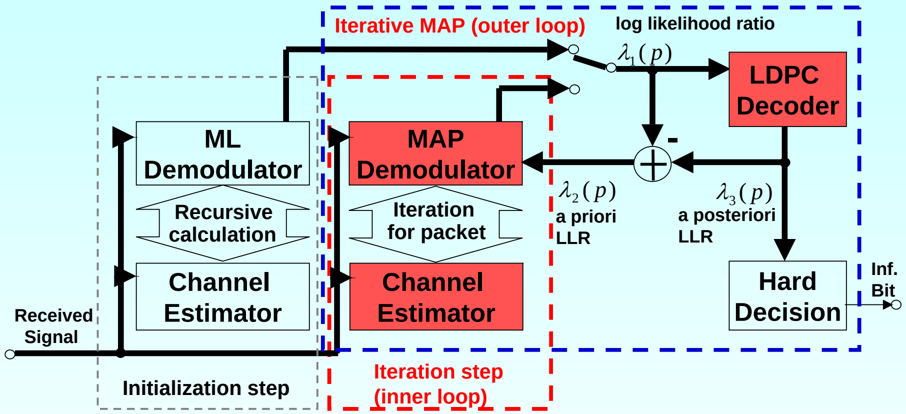
Reconsideration of the iterative MAP symbol detection via **the Message-Passing Algorithm**

System Model



- LDPC-coded MIMO-OFDM
- Rayleigh fading channel: both multi-path and MIMO spatial paths are uncorrelated.
- The first symbol a preamble for channel estimation

Iterative MAP Receiver (1/2)



- Outer loop: Update P(X|Y)
  - Inner loop updates P(Y|X) via MAP symbol detection
  - Channel decoding updates P(X)

Iterative MAP Receiver (2/2)

- MAP detection requires a prohibitive complexity

$$\hat{X} = \arg\max_{X} \log P(X \mid Y)$$

X: transmitted signal
Y: received signal
H: channel response

- EM algorithm is applied to reduce complexity

$$\text{E step} : Q(X \mid X^{(r)}) = E_H\left\{\log P(Y \mid H, X) \mid Y, X^{(r)}\right\}$$

$$\text{M step} : X^{(r+1)} = \arg\max_{X} \left[Q(X \mid X^{(r)}) + \log P(X)\right]$$

Consider the optimal channel estimation algorithm for the inner loop

Message Passing Algorithm

- Calculation of marginal conditional probability functions, such as $P(X_i|Y)$. (e.g. LDPC decoding is a message passing over Tanner graph)

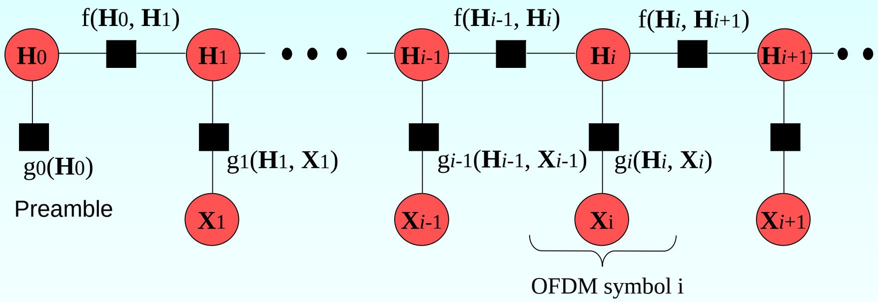
Suitable for the MAP symbol detection

- Iteration for achieving the convergence of a calculation.

The iterative MAP detection can be reconsidered in this context

Factor Graph of One Packet

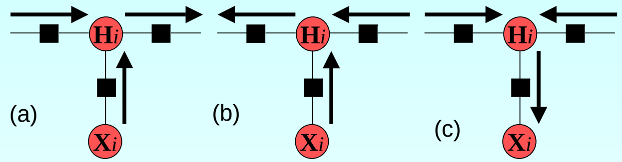
- The message passing is performed on a factor graph representing the system model.
- The fast fading is modeled as a random walk



$g_i(\mathbf{H}_i, \mathbf{X}_i)$: $\mathbf{Y}_i = \mathbf{H}_i\mathbf{X}_i + \mathbf{n}_i$ $\quad$ $f(\mathbf{H}_{i-1}, \mathbf{H}_i)$: $\mathbf{H}_i = \mathbf{H}_{i-1} + \mathbf{q}_i$

Smoothing and Removing

Three types of message passing at each symbol



- (a)+(b): forward and backward RLS CHE

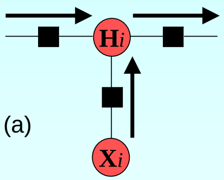
  ➡ **Smoothing is necessary**

- (c): CHE for the detection of X_i does not include the direct contribution from X_i

  ➡ **Removing is necessary**

Derivation of RLS

(a) corresponds to the RLS channel estimation.



Normal Equation

$$\hat{\mathbf{h}}(m) = \mathbf{R}(m)^{-1}\mathbf{V}(m), \quad \mathbf{P}(m) = \mathbf{R}(m)^{-1}$$

$$\mathbf{R}(m) = \sum_{m'=0}^{m} \lambda^{m-m'}\mathbf{x}(m')\mathbf{x}^{H}(m'),$$

$$\mathbf{V}(m) = \sum_{m'=0}^{m} \lambda^{m-m'}\mathbf{x}(m')y^{*}(m')$$

λ is the forgetting factor

m is the index of OFDM sampling interval

RLS

$$\mathbf{K}(m) = \mathbf{P}(m-1)\mathbf{x}(m)\left[\mathbf{x}^{H}(m)\mathbf{P}(m-1)\mathbf{x}(m) + \lambda\right]^{-1}$$

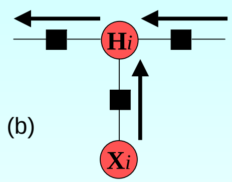
$$\hat{\mathbf{h}}(m) = \hat{\mathbf{h}}(m-1) + \mathbf{K}(m)\left[\mathbf{y}^{*}(m) - \mathbf{x}^{H}(m)\hat{\mathbf{h}}(m-1)\right]$$

$$\mathbf{P}(m) = \lambda^{-1}\left[\mathbf{P}(m-1) - \mathbf{K}(m)\mathbf{x}^{H}(m)\mathbf{P}(m-1)\right]$$

RLS is performed forward from the preamble

Derivation of S-RLS

(a)+(b) means that **all symbols are used for CHE**



Normal Equation

$$\hat{\mathbf{h}}_s(m) = \mathbf{R}_s(m)^{-1}\mathbf{V}_s(m), \quad \mathbf{P}_s(m) = \mathbf{R}_s(m)^{-1}$$

$$\mathbf{R}_s(m) = \sum_{m'=0}^{N_m-1} \lambda^{|m-m'|}\mathbf{x}(m')\mathbf{x}^{H}(m')$$

$$\mathbf{V}_s(m) = \sum_{m'=0}^{N_m-1} \lambda^{|m-m'|}\mathbf{x}(m')y^{*}(m')$$

S-RLS performs *Smoothing* after RLS

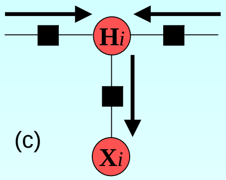
$$\mathbf{P}_s(m) = \mathbf{P}(m) + \lambda^{2}\left[\mathbf{P}_s(m+1) - \lambda^{-1}\mathbf{P}(m)\right]$$

$$\hat{\mathbf{h}}_s(m) = \hat{\mathbf{h}}(m) + \lambda\left[\hat{\mathbf{h}}_s(m+1) - \hat{\mathbf{h}}(m)\right]$$

Smoothing is performed backward

Derivation of SR-RLS

(c) means that CHE of Hi does not include for Xi



Normal Equation (index *i* is omitted)

$$\hat{\mathbf{h}}_{\mathrm{r}}(m_a)=\mathbf{R}_{\mathrm{r}}(m_a)^{-1}\mathbf{V}_{\mathrm{r}}(m_a),\qquad \mathbf{P}_{\mathrm{r}}(m_a)=\mathbf{R}_{\mathrm{r}}(m_a)^{-1}$$

$$\mathbf{R}_{\mathrm{r}}(m_a)=\mathbf{R}_{\mathrm{s}}(m_a)-\sum_{m'=m_h}^{m_t}\lambda^{|m_a-m'|}\mathbf{x}(m')\mathbf{x}^{\mathrm{H}}(m')$$

$$\mathbf{V}_{\mathrm{r}}(m_a)=\mathbf{V}_{\mathrm{s}}(m_a)-\sum_{m'=m_h}^{m_t}\lambda^{|m_a-m'|}\mathbf{x}(m')y^{*}(m')$$

$m_h(i)$, $m_t(i)$, and $m_a(i)$ are the head, tail and avarage sampling point

SR-RLS performs *Removing* after S-RLS

$$\hat{\mathbf{h}}_{\mathrm{r}}(m_a;m_h,m)=\hat{\mathbf{h}}_{\mathrm{r}}(m_a;m_h,m-1)+A^{-1}\mathbf{P}_{\mathrm{r}}(m_a;m_h,m-1)\mathbf{x}(m)\left\{y^{*}(m)-\mathbf{x}^{\mathrm{H}}(m)\hat{\mathbf{h}}_{\mathrm{r}}(m_a;m_h,m-1)\right\}$$

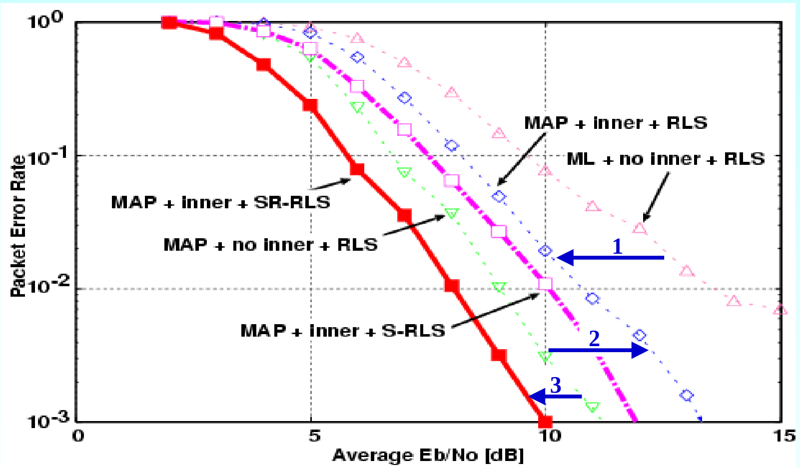
$$\mathbf{P}_{\mathrm{r}}(m_a;m_h,m)=\mathbf{P}_{\mathrm{r}}(m_a;m_h,m-1)+A^{-1}\mathbf{P}_{\mathrm{r}}(m_a;m_h,m-1)\mathbf{x}(m)\mathbf{x}^{\mathrm{H}}(m)\mathbf{P}_{\mathrm{r}}(m_a;m_h,m-1)$$

$$A=-\lambda^{|m^a-m|}+\mathbf{x}^{\mathrm{H}}(m)\mathbf{P}_{\mathrm{r}}(m_a;m_h,m-1)\mathbf{x}(m)$$

Simulation condition

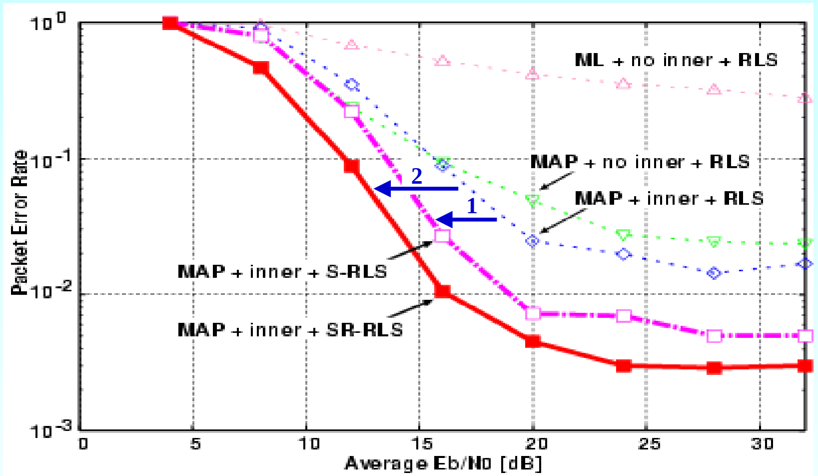
MIMO antennas	2 × 2
Modulation	QPSK, 64 subcarriers OFDM
Guard Interval/OFDM duration	16/80
Packet format	1 Preamble OFDM symbol + 16 Data OFDM symbols
RLS forgetting factor	0.99
Channel model	9-path Rayleigh with 0.8-decay
Number of inner (EM) iterations	4
Max number of outer (Turbo) iterations	10
Channel coding	Half-rate LDPC (2048 info. Bits)

Simulation result ($f_D T_S = 0.02$)



1. MAP demodulation achieves better PER than ML demodulation
2. Inner loop with RLS degrades the PER performance (noise amplified)
3. Inner loop with SR-RLS improves the PER performance in all Eb/No

Simulation result ($f_D T_S = 0.03$)



1. Inner loop with S-RLS improves the PER. No PER degradation.
2. Inner loop with SR-RLS improves the PER performance in all Eb/No

Conclusion

- New recursive channel estimation algorithm (**SR-RLS**) has been proposed via **the message-passing algorithm**.
  - **Capable to track the fast fading**
  - **Optimal for the iterative MAP receiver**

- ***Smoothing*** uses all symbols for the channel estimation.

- ***Removing*** modifies S-RLS to remove the direct contribution of the targeted OFDM symbol

- ***Removing* is the most effective** for the performance improvement.