

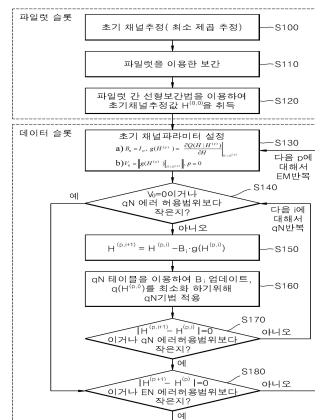
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(22)	2008 10 15	464-8	4 107-60 202	320-303
: 4	(74)	98	(72)	464-8

(54)

(57)

OFDM

- 3a



1

$$Y = XH + N$$
 (, H , N)
 , H
 $H^{(\theta, \theta)}$
 ,
 ,
 $o(M^3)$ $o(M^2)$
 3 2
 , OFDM

2

1 ,
 ,
 ,
 0 qN
 1 , 2
 $H^{(p, i)}$
 ($H^{(p, i)}$ p (EM) , i)
 $H^{(p, i)}$, $Y(=XH+N)$ H X ,
 OFDM

3

2 ,

$$\mathbf{B}_0 = I_N, \mathcal{G}(H^{(p)}(\mathbf{m})) = \left. \frac{\partial Q(H(\mathbf{m}) | H^{(p)}(\mathbf{m}))}{\partial H(\mathbf{m})} \right|_{H=H^{(p)}}$$

$$V_0 = \left\| \mathcal{G}(H^{(p)}(\mathbf{m})) \right\|_{H=H^{(p)}}, p = 0$$

 , OFDM

4

3 ,
 1 , $\mathbf{B}_i$ $g(\cdot)$ $H^{(p+1)} = H^{(p)} - \mathbf{B}_i \cdot g(H^{(p)})$,
 $H^{(p+1)}$ $H^{(p)}$ '0' EM ,
 2 , $H^{(p+1)} = H^{(p)} - \mathbf{B}_i \cdot g(H^{(p)})$ i $H^{(p, i+1)} = H^{(p, i)} - \mathbf{B}_i \cdot$
 $g(H^{(p, i)})$ $H^{(p, i+1)}$ $H^{(p, i)}$ '0' qN()
 , OFDM

[0001] (Orthogonal Frequency Division Multiplexing: OFDM)

OFDM
, (EM(expectation maximization))
.

[0002] . (preamble)
.

, . ,
.

[0003] ,
.

[0004] , N) , Y X $Y = XH + N$, H
.

[0005] OFDM
 $H^{(\theta, \theta)}$,
.

, $o(M^3)$
2 $o(M^2)$.

[0006] , ,

[0007] ,

[0008] 1 0 qN ,
2
 $H^{(p, i)}$ ($H^{(p, i)}$ p
(EM) , i

[0009] $H^{(p, i)}$, $Y(=XH+N)$ H X .

[0010]
$$\mathbf{B}_0 = I_M, \mathcal{G}(H^{(p)}(\mathbf{m})) = \frac{\partial \mathcal{Q}(H(\mathbf{m}) | H^{(p)}(\mathbf{m}))}{\partial H(\mathbf{m})} \Big|_{H=H^{(p)}}$$

$$V_0 = \left\| \mathcal{G}(H^{(p)}(\mathbf{m})) \Big|_{H=H^{(p)}} \right\|, p = 0$$

 ,

- [0011] 1, $\mathbf{B}_i$ $g(\cdot)$ $H^{(p+1)} = H^{(p)} - \mathbf{B}_i \cdot g(H^{(p)})$,
 $H^{(p+1)}$ $H^{(p)}$ '0' EM ,
- [0012] 2, $H^{(p+1)} = H^{(p)} - \mathbf{B}_i \cdot g(H^{(p)})$ i $H^{(p,i+1)} = H^{(p,i)} - \mathbf{B}_i \cdot$
 $g(H^{(p,i)})$ $H^{(p,i+1)}$ $H^{(p,i)}$ '0' qN()
.
- [0013] OFDM
.
- [0014] ,
(maximum
likelihood) , , ,
, .
- [0015] , ,
.
- [0016] ' ' X () Y, H
.
- 1**
- [0017] $Y = XH + N$
- [0018] , X , Y , H , N . X Y
, (least square)
.
- 2**
- [0019] $H = (X^*) \cdot (|X|^2)^{-1} \cdot Y$
- [0020] , $|X|^2$ $X \cdot X^*$. OFDM
. Y X
.
- [0021] Y $Z = (X, Y)$ θ
. θ Y . E- $Q(\theta | \theta^{(p)})$ θ
, , $\log f(Z | \theta)$. X θ $\theta^{(p)}$ Y .
3 .
- 3**
- [0022] $Q(\theta, \theta(p)) = E[\log f(Z | \theta) | X, \theta(p)]$

$$[0023] \quad \theta^{(p+1)} \quad \theta \quad Q(\theta, \theta^{(p)}) \quad \theta$$

4

$$[0024] \quad \theta^{(p+1)} = \arg \max_{\theta} Q(\theta | \theta^{(p)})$$

$$[0025] \quad \theta^{(1)}, \theta^{(2)}, \theta^{(3)} \quad .$$

5

$$[0026] \quad f(Y(m) | X_i(m), H(m)) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{1}{\sigma^2} |Y(m) - H(m)X_i(m)|^2\right)$$

$$[0027] \quad m \quad , \quad i \quad .$$

6

$$[0028] \quad f(Y(m) | H(m)) = \sum_{i=1}^C \frac{1}{\sqrt{2\pi\sigma^2}C} \exp\left(-\frac{1}{\sigma^2} |Y(m) - H(m)X_i(m)|^2\right)$$

$$[0029] \quad , \quad Y \quad , \quad (Y, X) \quad . \quad f(Y|H)$$

7

$$[0030] \quad :$$

$$[0031] \quad Q(H(m) | H^{(p)}(m)) = E_x\{\log f(Y(m), X(m) | H(m)) | Y(m), H^{(p)}(m)\}$$

8

$$[0032] \quad :$$

$$[0033] \quad H^{(p+1)}(m) = \arg \max_H Q(H(m) | H^{(p)}(m))$$

$$[0034] \quad ,$$

9

$$[0035] \quad \begin{aligned} & \arg \max_H Q(H(m) | H^{(p)}(m)) \\ &= \arg \max_H \sum_{i=1}^C \log \left\{ \frac{1}{C} f(Y(m) | H(m), X_i(m)) \right\} f(X_i(m) | Y(m), H^{(p)}(m)) \\ &= \arg \max_H \sum_{i=1}^C \log \left\{ \frac{1}{C} f(Y(m) | H(m), X_i(m)) \right\} \frac{f(Y(m) | H^{(p)}(m), X_i(m))}{C f(Y(m) | H^{(p)}(m))} \\ &= \arg \min_H \sum_{i=1}^C \log \left\{ |Y(m) - H(m)X_i(m)|^2 \right\} \frac{f(Y(m) | H^{(p)}(m), X_i(m))}{C f(Y(m) | H^{(p)}(m))} \end{aligned}$$

[0036]

$$\mathbf{H}^{(p+1)} = \mathbf{H}^{(p)} + \frac{1}{\mathbf{H}^{(p)} \mathbf{H}^{(p)}} \mathbf{H}^{(p)} \mathbf{H}^{(p)}$$

[0037]

10

$$H^{(p+1)} = \left[\sum_{i=1}^C X(m) \cdot X(m)^* \frac{f(Y(m) | H^{(p)}(m), X_i(m))}{Cf(Y(m) | H^{(p)}(m))} \right]^{-1} \\ \times \left[\sum_{i=1}^C Y(m) \cdot X(m)^* \frac{f(Y(m) | H^{(p)}(m), X_i(m))}{Cf(Y(m) | H^{(p)}(m))} \right]$$

[0038]

$$\mathbf{H}^{(p+1)} = \mathbf{H}^{(p)} + \frac{\mathbf{H}^{(p)} \mathbf{H}^{(p)}}{\mathbf{H}^{(p)} \mathbf{H}^{(p)}} \mathbf{H}^{(p)} \mathbf{H}^{(p)}$$

[0039]

11

$$\hat{X}(m) = \arg \min_{X \in C} |Y(m) - \hat{H}(m)X(m)|^2, \quad 0 \leq m \leq M-1$$

[0040]

$$\mathbf{M} = \mathbf{M} + \mathbf{M} \mathbf{M}^T$$

[0041]

12

$$\hat{X}(m) = Quantization \left(\frac{Y(m)}{\hat{H}(m)} \right), \quad 0 \leq m \leq M-1$$

[0042]

$$\mathbf{H}^{(p+1)} = \mathbf{H}^{(p)} + \frac{1}{\mathbf{H}^{(p)} \mathbf{H}^{(p)}} \mathbf{H}^{(p)} \mathbf{H}^{(p)}$$

(Newton-Raphson, Isaac Newton and Joseph Raphson)

[0043]

13

$$H^{(p,i+1)}(m) = H^{(p,i)}(m) - \mathbf{B}_i \cdot \frac{\partial Q(H(m) | H^{(p,i)}(m))}{\partial H(m)}$$

[0044]

$$\mathbf{B}_i = \mathbf{B}_i + \mathbf{B}_i \mathbf{B}_i^T$$

[0045]

$$\mathbf{B}_i = \mathbf{B}_i + \mathbf{B}_i \mathbf{B}_i^T$$

. $\mathbf{B}_i$, 2 .

$O(N^3)$

14

[0046]

:

[0047]

$$H^{(p+1)}(m) = \left[\sum_{i=1}^C |X_i(m)|^2 \frac{f(Y(m) | H(m), X_i(m))}{Cf(Y(m) | H^{(p)}(m))} \right]^{-1} \left[\sum_{i=1}^C YX_i^* \frac{f(Y(m) | H(m), X_i(m))}{Cf(Y(m) | H^{(p)}(m))} \right]$$

[0048]

, 1 3 (3rd order) $O(M^3)$ 2
(2nd order) $O(M^2)$

15

[0049]

$$H^{(p,i+1)}(m) = H^{(p,i)}(m) - \mathbf{B}_i \cdot \frac{\partial Q(H(m) | H^{(p,i)}(m))}{\partial H(m)}$$

[0050]

p , i
 $O(N^3)$. $H^{(p,0)}(m)$ $H^{(p,i)}(m)$ i
 $H^{(0)}(m)$ $H^{(p)}(m)$ $p \cdot O(N^3)$
(i · p · $O(M^2)$)
(3a).

[0051]

$H^{(0,0)}(m)$

3

2

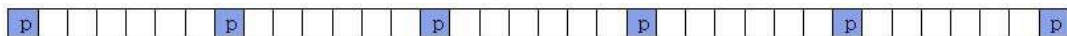
[0052]

, (pilot slot) .

[0053]

S100: , (p)

[0054]



[0055]

S110: (interpolation) p () .

[0056]

S120: (linear interpolation) $H^{(0,0)}$ () .

[0057]



[0058]

(iteration) , $H^{(p,i)}$
p (EM) , i

[0059]

S130: $\mathbf{B}_0 = I_N, \mathcal{E}(H^{(p)}(m)) = \frac{\partial Q(H(m) | H^{(p)}(m))}{\partial H(m)} \Big|_{H=H^{(0)}}$,
 $V_0 = \left\| \mathcal{E}(H^{(p)}(m)) \Big|_{H=H^{(0)}} \right\|, p=0$ $H^{(0,0)}$

$H^{(p,0)}$

$\mathbf{B} \quad \mathbf{V}$

[0060] S140: $V_0=0$ qN $(qN($) $H^{(p,i)}$ $H^{(p,i-1)}$
) (S140), S140 ' '

S105

[0061] S150: $\mathbf{B}_i$ $g(\cdot)$ $H^{(p,i+1)} = H^{(p,i)} - \mathbf{B}_i \cdot g(H^{(p,i)})$

[0062] S160: $g(H^{(p,i)})$ 2 qN $\mathbf{B}_i$ ()
' ,
EM(expectation maximization) 3b N^3
EM (inverse matrix term) EM
, 3c EM

[0063] S170: p i $H^{(p,i+1)}$ $H^{(p,i)}$
'0' qN (S170)
S140 i

[0064] S180: EM EM S180
 $H^{(p,i)}$ $Y(=XH+N)$ H X

[0065] DVB-H 2K
(interleaving) Rician cost 207-RA4
(4) , Rayleigh cost 207-TU6 (5) cost 207-HT6 (6)
(i.i.d) QPSK
, ε

16

[0066] $\sum_{m=0}^{K-1} \|H(m)^{(p)} - H(m)^{(p-1)}\| < \varepsilon$

[0067] $\varepsilon \quad 10^{-5}$
, 0
7 0dB
2048 $O(M^2)$ $O(M^3)$
, 20dB
M
8K 2K 20dB
BFGS(Broyden, Fletcher, Goldfarb, and Shanno) (, ε)

[0068] DFP(Davidon-Fletcher-Powell) 0dB
8 9 SNR BER
BER

. 10 11 . cost 207 RA4
 , 128 16 . 10
 . 11

3 2

[0069]

[0070]

1

[0071]

2

(quasi-Newton)

[0072]

3a

[0073]

3b

3c

[0074]

4

2K / cost 207 RA4

[0075]

5

Rural Area

[0076]

6

Typical Urban

[0077]

7

Bad Urban

[0078]

8

Typical Urban 70km/h

[0079]

9

Hilly Terrain 70km/h

[0080]

10

[0081]

11

1

$$\begin{aligned}
 H^{(p+1)} &= \arg \max_H (Q(H | H^{(p)})) \\
 &= \arg \min_H \sum_{i=1}^C \log \{ |Y - HX_i|^2 \} \frac{f(Y | H, X_i)}{Cf(Y | H^{(p)})}
 \end{aligned}$$

$$\begin{aligned}
 \frac{\partial Q(H | H^{(p)})}{\partial H} \Big|_{H=H^{(p)}} &= \sum_{i=1}^C YX_i^* \frac{f(Y | H, X_i)}{Cf(Y | H^{(p)})} - \sum_{i=1}^C H^{(p)} |X_i|^2 \frac{f(Y | H, X_i)}{Cf(Y | H^{(p)})} = 0 \\
 \tilde{H}^{(p+1)} &= \left[\sum_{i=1}^C |X_i|^2 \frac{f(Y | H, X_i)}{Cf(Y | H^{(p)})} \right]^{-1} \left[\sum_{i=1}^C YX_i^* \frac{f(Y | H, X_i)}{Cf(Y | H^{(p)})} \right]
 \end{aligned}$$

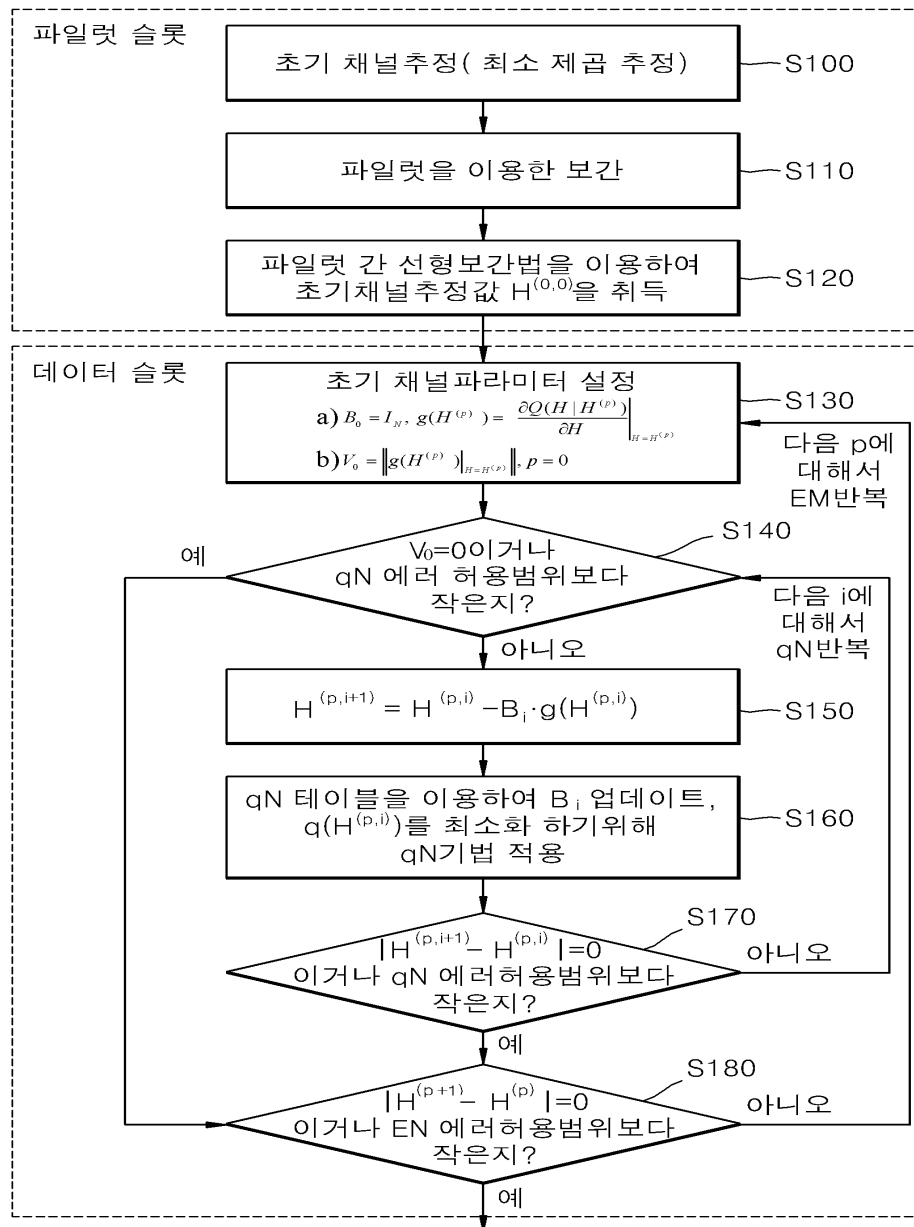
역행렬 계산을 위해서 3차식 계산을 해야 함

2

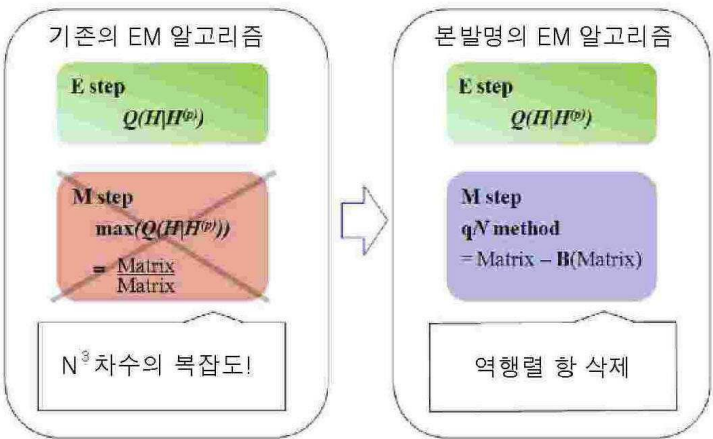
기법	$\mathbf{B}_{p+1}$
BFGS	$\mathbf{B}_p + \frac{\Delta_p \Delta_p^T}{\Delta_p^T \delta_p} - \frac{\mathbf{B}_p \delta_p (\mathbf{B}_p \delta_p)^T}{\delta_p^T \mathbf{B}_p \delta_p}$
SR1	$\mathbf{B}_p + \frac{(\Delta_p - \mathbf{B}_p \delta_p)(\Delta_p - \mathbf{B}_p \delta_p)^T}{(\Delta_p - \mathbf{B}_p \delta_p)^T \delta_p}$
DFP	$\left(I - \frac{\Delta_p \delta_p^T}{\Delta_p^T \delta_p} \right) \mathbf{B}_p \left(I - \frac{\delta_p \Delta_p^T}{\Delta_p^T \delta_p} \right) + \frac{\Delta_p \Delta_p^T}{\Delta_p^T \delta_p}$
Broyden-Family	$(1 - \varphi_p) \mathbf{B}_{p+1}^{BFGS} + (\varphi_p) \mathbf{B}_{p+1}^{DFP}, \varphi_p \in [0, 1]$
Broyden	$\left(I - \frac{\Delta_p \delta_p^T}{\Delta_p^T \delta_p} \right) \mathbf{B}_p \left(I - \frac{\delta_p \Delta_p^T}{\Delta_p^T \delta_p} \right) + \frac{\Delta_p \Delta_p^T}{\Delta_p^T \delta_p}$

$$\Delta_p = \frac{\partial Q(H | H^{(p+1)})}{\partial H} - \frac{\partial Q(H | H^{(p)})}{\partial H}, \delta_p = H^{(p+1)} - H^{(p)}$$

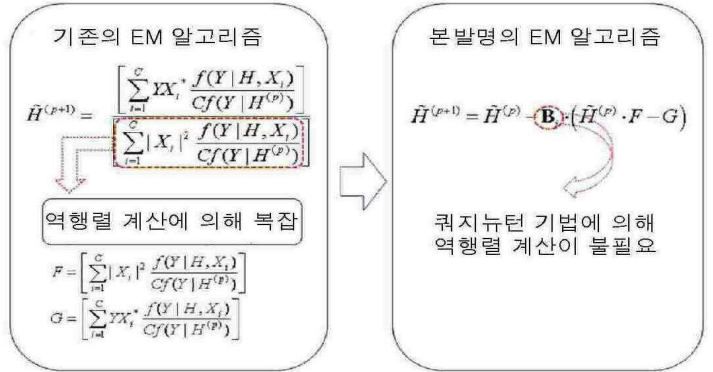
3a



3b



3c



4

Path No.	Rural Area (4 path)		Rural Area (6 path)	
	Delay(μs)	Power (dB)	Delay(μs)	Power (dB)
0	0	0	0	0
1	0.2	-2	0.1	-4
2	0.4	-10	0.2	-8
3	0.6	-20	0.3	-12
4			0.4	-16
5			0.5	-20

5

Path No.	Typical Urban (6 path)		Typical Urban (12 path)	
	Delay(μ s)	Power (dB)	Delay(μ s)	Power (dB)
0	0	-3	0.0	-4
1	0.2	0	0.2	-3
2	0.4	-2	0.4	0
3	0.6	-6	0.6	-2
4	2.4	-8	0.8	-3
5	5.0	-10	1.2	-5
5			1.4	-7
5			1.8	-5
5			2.4	-6
5			3.0	-9
5			3.2	-11
5			5.0	-10

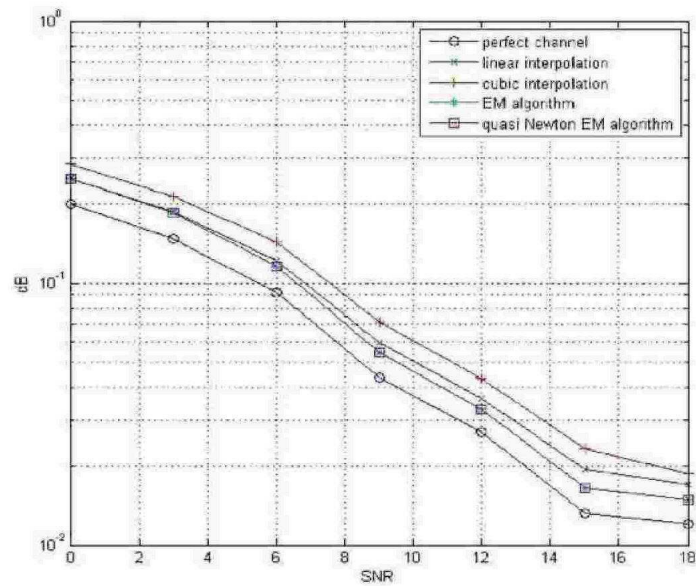
6

Path No.	Hilly Terrain (6 path)		Hilly Terrain (12 path)	
	Delay(μ s)	Power (dB)	Delay(μ s)	Power (dB)
0	0.0	0	0.0	-10
1	0.4	-2	0.2	-8
2	1.0	-4	0.4	-6
3	1.6	-7	0.8	-4
4	5.0	-6	1.6	0
5	6.6	-12	2.2	0
5			3.2	-4
5			5.0	-8
5			6.0	-9
5			7.2	-10
5			8.2	-12
5			10	-14

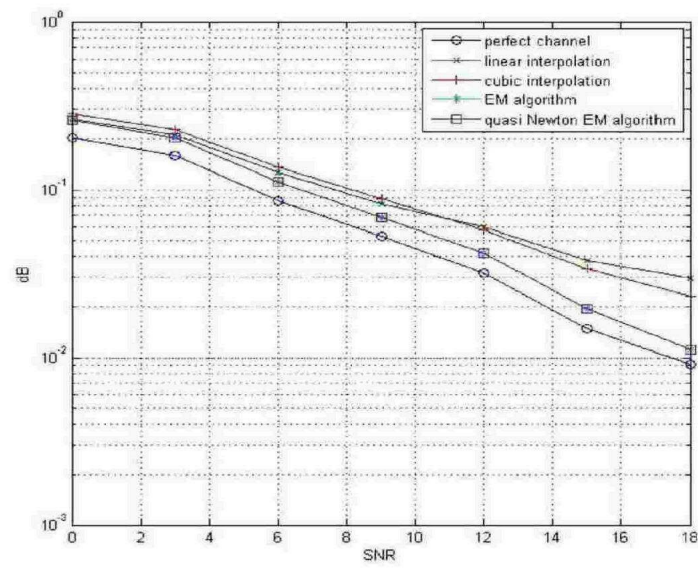
7

기법		수렴까지의 반복회수 (p,i)					복잡도 (at 20 dB) M=FFT size (2K, 4K, 8K)
		0 dB	5 dB	10 dB	15 dB	20 dB	
EM		98	65	26.4	6.84	2	$O_{EM}(N^3)*2$
EM-MMSE		2	2	2	2	2	$O_{EM-MMSE}(N^3)*2$
쿼지 뉴턴	BFGS	1455.8	784.03	101.48	65.11	57.38	$O_{BFGS}(N^2)*57.38$
	SR1	1455.8	784.03	101.48	65.11	57.38	$O_{SR1}(N^2)*71.43$
	DFP	17318	699.23	518.19	65.11	57.38	$O_{DFP}(N^2)*57.53$
	Broyden	28547	25856	11727	3802	2740	$O_{BR}(N^2)*2470$
	Broyden-family	1984.5	1190	151.23	66.8	58.19	$O_{BrF}(N^2)*58.91$

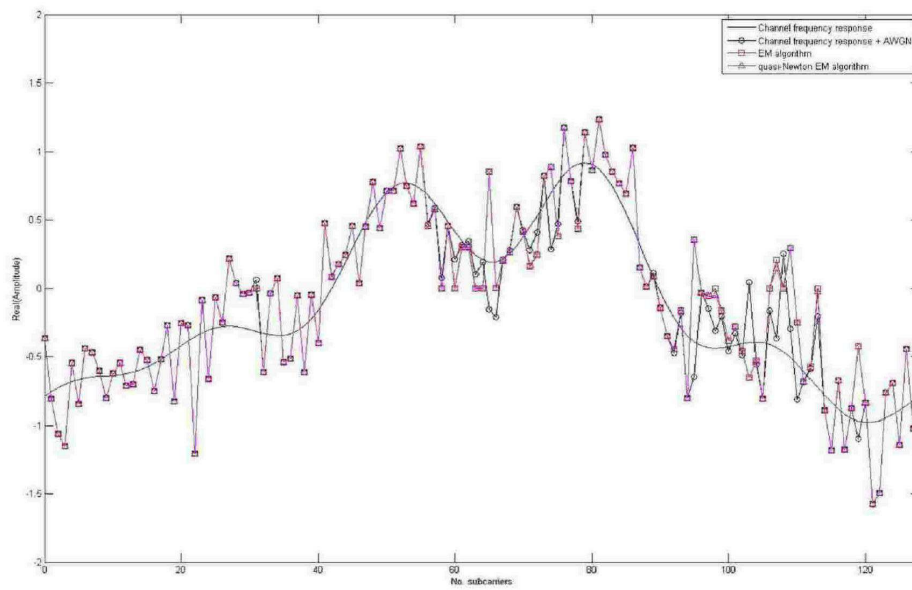
8



9



10



11

