

# Estimation of Propagation Structure by means of Hopfield Neural Network

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## 1. Introduction

In order to develop the spatial-temporal equalization technique for 3G/4G mobile communication system, it is necessary to grasp indoor or outdoor propagation structure. In recent year, it is proposed to apply the artificial neural network (ANN) to DOA estimation [1]-[2]. The purposes are to direct narrow beam to the terminals after detecting the directions. In this paper, we propose an algorithm using an ANN to estimate coupled DOA and TOA of multiple incident waves.

## 2. Algorithm

In Hopfield neural network shown as Fig.1, the conditions are renewed as energy expressed by next Lyapunov function is minimized [3].

$$E = -\frac{1}{2} \sum_{p=1}^P \sum_{q=1}^P w_{pq} v_p v_q - \sum_{p=1}^P I_p v_p \quad (1)$$

And, input signal of each neuron  $u_p$  satisfies with next differential equation.

$$R_p C_p \frac{du_p}{dt} = \sum_{q \neq p} R_p w_{pq} v_q - u_p + R_p I_p \quad (2)$$

Here,  $w_{pq}$  is inverse of  $R_{pq}$ .  $v_q$  is a response of neuron and it is decided by next sigmoid function.

$$v_q = f(u_q) = \frac{1}{2} \{ 1 + \tanh(\beta u_q) \} \quad (3)$$

Here,  $\beta$  is neuron gain.

In order to estimate propagation parameters, we define category  $p$ . A wave subject to category  $p$  has delay of  $i$  symbols and direction of arrival of  $(\theta_j, \theta_k)$ .  $\theta_j$  and  $\theta_k$  are defined as  $\theta_j = (j-1)50/J(\text{deg.})$  and  $\theta_k = (k-1)50/K(\text{deg.})$ , respectively.  $J$  and  $K$  are category numbers of azimuth and elevation angle, respectively. When  $N$  data of frequency domain from a rectangular array of  $M_1 \times M_2$  elements are used, incident signal  $s_p^{m_1 m_2 n}$  to the array antenna is expressed by

$$s_p^{m_1 m_2 n} = a_p(t-iT) \exp \left\{ j2\pi \left[ f_c + \left( n - \frac{N+1}{2} \right) \Delta f \right] \frac{\Delta x}{c} \left[ m_1 - \frac{M_1+1}{2} \right] \cos \phi_j \sin \theta_k \right\} \\ \exp \left\{ j2\pi \left[ f_c + \left( n - \frac{N+1}{2} \right) \Delta f \right] \frac{\Delta y}{c} \left[ m_2 - \frac{M_2+1}{2} \right] \sin \phi_j \sin \theta_k \right\} \quad (4)$$

$a_p(t)$  is time sequence complex signal,  $T$  is symbol rate of time sequence signal,  $f_c$  is carrier frequency,  $\Delta f$  is frequency spacing,  $\Delta x$  and  $\Delta y$  are element spacing in the

direction of x and y-axis. In order to get signal in the frequency domain, we transform time sequence signal to frequency domain by FFT as shown to Fig.2. Quantity of which signal of all the categories contribute to (m<sub>1</sub>, m<sub>2</sub>, n)th received signal is expressed by next formula.

$$x_{m_1 m_2 n}(t) = \sum_{p=1}^P w_p^{m_1 m_2 n} s_p^{m_1 m_2 n}(t) \quad (5)$$

In case of estimating such parameters as propagation, it is necessary to set each weight  $w_p^{m_1 m_2 n}$  properly by minimizing the square root error "Es" between received signal vector  $y = [y_{111} \dots y_{M_1 M_2 N}]^T$  and vector  $x = [x_{111} \dots x_{M_1 M_2 N}]^T$  [2].

$$E_s = \|y - x\| = \text{Re} \left[ \sum_q^P \sum_{r \neq q}^P (s_q^H s_r) w_q w_r - \sum_q^P (2y^H s_q - s_q^H s_r) w_q \right] \quad (6)$$

Here, Vector  $s_q$  is defined by

$$s_q = [s_q^{111} \dots s_q^{m_1 m_2 n} \dots s_q^{M_1 M_2 N}]^T \quad (7)$$

From Formula (1) and (6), weight  $w_q$  and  $I_q$  can be expressed by next formulas.

$$w_q = \text{Re} [s_q^H s_r] \quad I_q = \text{Re} \left[ y^H s_q - \frac{1}{2} s_q^H s_r \right] \quad (8)$$

$w_q$  makes zero when  $q=r$ . Weight matrix among neurons is expressed by next formula

$$W = \begin{pmatrix} 0 & w_{12} & \dots & w_{1P} \\ w_{21} & 0 & \dots & w_{2P} \\ \dots & \dots & \dots & \dots \\ w_{P1} & w_{P2} & \dots & 0 \end{pmatrix} \quad (9)$$

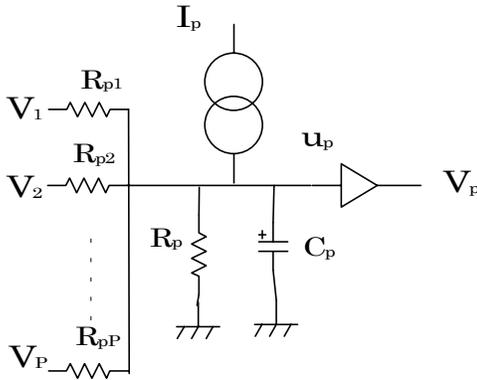


Fig.1 Hopfield neural network

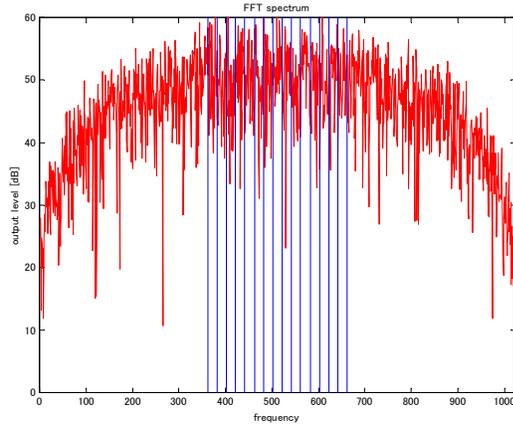


Fig.2 signal in the frequency domain

## 2. Simulation

We have defined 180 categories, that is (I, J, K)=(6, 6, 5). And we have used signal modulated PN9 sequence by QPSK as the incident wave. 10 sampling points in the frequency domain received by 8x8 elements planer array antenna have been used for input data. Fig3 shows one example of coupled DOA and TOA estimation results. In

this case, 2 waves with  $(\theta, \phi, T)=(10^\circ, 40^\circ, 0 \text{ symbols})$  and  $(30^\circ, 40^\circ, 1 \text{ symbols})$  are incident. Then, category parameters  $(i, j, k)$  are  $(1,2,5)$  and  $(2,4,5)$ , respectively. 2 neurons subject to each category ignite. Fig.4 shows another example of 3 incident waves with  $(\theta, \phi, T)=(0^\circ, 0^\circ, 0 \text{ symbols}), (0^\circ, 30^\circ, 2 \text{ symbols})$  and  $(20^\circ, 0^\circ, 1 \text{ symbols})$ .

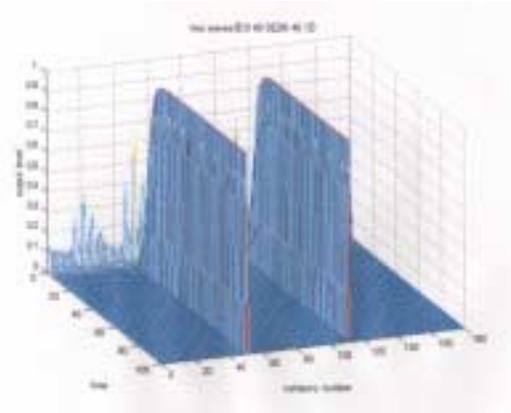


Fig.3 Estimation result  
 $(10^\circ, 40^\circ, 0 \text{ symbols})$   
 $(30^\circ, 40^\circ, 1 \text{ symbols})$

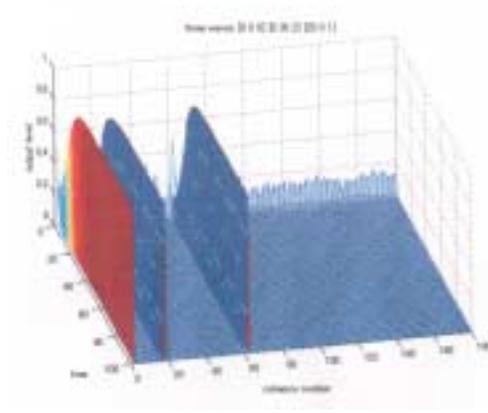


Fig.4 Estimation result  
 $(0^\circ, 0^\circ, 0 \text{ symbols}), (0^\circ, 30^\circ, 2 \text{ symbols})$   
 $(20^\circ, 0^\circ, 1 \text{ symbols})$ .

Category number  $P$  can be expressed by next formula.

$$P=(j-1)*30+(k-1)*5+i \tag{10}$$

We have evaluated how to ignite neurons in the case that signals not belong to the set categories are incident. Fig.5 shows relation between incident azimuth angle and estimated DOAs in case of 2 waves. In this case,  $\theta=0^\circ$  for each waves and one wave arrives at delay of 4 symbols compared to the another. It is clear that neurons subject to the nearest categories ignite

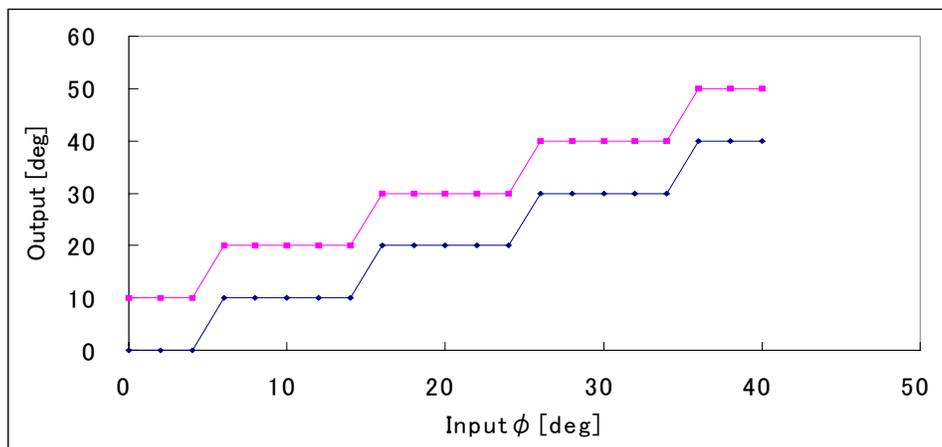


Fig.5 Relation between incident azimuth angle and estimated result (2 waves case)

And, we have investigated reliability of the estimated results. We assumed 2 waves with the same amplitude. Parameter set of one wave is established at either of  $(0^\circ, 0^\circ, 0 \text{ symbols}), (10^\circ, 10^\circ, 0 \text{ symbols}) \dots (50^\circ, 50^\circ, 0 \text{ symbols})$ . Then, the other wave is established

at all the rest of categories in order. We have trial sets of 179x6 in the end. Number of wrong estimating results has been counted. We also have applied CNR as a parameter to the investigation. Fig.6 shows the results. In this figure, black line shows the case that parameters of both waves were able to estimated correctly, and red line shows the case that parameters of only one wave were able to estimated.

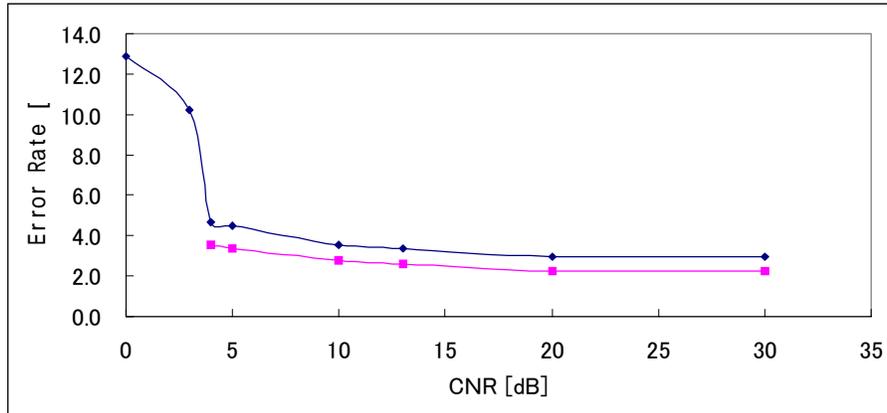


Fig.6 Reliability of estimation

When CNR is better than 10dB, the error rate is less than 4%. However, it does not fall less than 3.5% even if CNR was better than 30dB. In the wrong results, there were some case that one middle neuron ignites. For example, a neuron subject to (10° 30° 0 symbols) ignites when 2 waves with (10° 40° 0 symbols) and (10° 20° 0 symbols) are incident. Though we can improve the reliability by increasing number of parameters ( $M_1$ ,  $M_2$ ,  $N$ ), the calculating load and hardware size increase.

#### 4. Conclusions

We have proposed a new algorithm to estimate coupled azimuth, elevation angle and delay of multiple incident waves. It is applied Hopfield neural network, which is not need to learn preliminary. We have plans to expand to coupled azimuth, elevation angle, delay and relative power estimation and to improve reliability of estimation without expansion of hardware size.

#### References

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- [3] M. T. Hagan, H. B. Demuth and M. H. Beale, "Neural Network Design," PWS Publishing Company, 1995.