รายการอ้างอิง

1. Chouly, A. Brajal, A. and Jourdan, S. Orthogonal multicarrier techniques applied to direct sequence spread spectrum CDMA systems. IEEE Global Telecommunications Conference, 1993 (GLOBECOM '93). 3 (29 Nov. – 2 Dec. 1993) : 1723-1728
2. Yee, N. Linnartz, J. and Fettweis, G. Multi-carrier CDMA in indoor wireless radio networks. IEEE International Symposium on Personal Indoor and Mobile Radio Communications, 1993 (PIMRC '93). 1 (Sep. 1993) : 109–113
3. Kondo, S. and Milstein, L. On the use of multicarrier direct sequence spread spectrum systems. IEEE Military Communications Conference, 1993 (MILCOM '93). 1 (11-14 Oct. 1993) : 52-56
4. Prasad, R. and Hara, S. An overview of multi-carrier CDMA. Proceedings of IEEE 4th International Symposium on Spread Spectrum Techniques and Applications. 1 (Sep. 1996) : 107-114
5. Hara, S. and Prasad, R. Design and Performance of Multicarrier CDMA System in Frequency-Selective Rayleigh Fading Channels. IEEE Transactions on Vehicular Technology. 48, 5 (Sep. 1999) : 1584-1595
6. Hara, S. and Prasad, R. Multicarrier techniques for 4G mobile communications. Artech House, 2003.
7. Fazel, K. and Kaiser, S. Multi-carrier and spread spectrum systems. USA: John Wiley & Sons, 2003.
8. Verdú, S. Multiuser Detection. UK: Cambridge University Press, 1998.
9. Lee, Y.H. and Bar-Ness, Y. Transmission power adaptations in MC-CDMA communications over Rayleigh fading channels. IEEE Wireless Communications and Networking Conference, 2004 (WCNC. 2004). 3 (Mar. 2004) : 1589–1594
10. Zhu, J. and Bar-Ness, Y. Power allocation algorithm in MC-CDMA. IEEE International Conference on Communications, 2002 (ICC. 2002). 2 (May. 2002) : 931-935
11. Gao, L. and Wong, T.F. Joint transmitter-receiver adaptive forward-link DS-CDMA system. IEEE Global Telecommunications Conference, 2001 (GLOBECOM '01). 2 (Nov. 2001) : 1297-1301
12. Concha, J.I. and Ulukus, S. Optimization of CDMA signature sequences in multipath

channels. IEEE VTS 53rd Vehicular Technology Conference, 2001 (VTC. 2001 Spring) 3 (May. 2001) : 1978–1982

13. Scaglione, A. Barbarossa, S. and Giannakis, G.B. Filterbank transceivers optimizing information rate in block transmissions over dispersive channels. IEEE Transaction on Information Theory. 5 (Apr. 1999) : 1019-1032
14. Scaglione, A. Stoica, P. Barbarossa, S. Giannakis, G.B. and Sampath, H. Optimal designs for space-time linear precoders and decoders. IEEE Transactions on Signal Processing. 50, 5 (May. 2002) : 1051-1064
15. Jang, W.M. Vojcic, B.R. and Pickholtz, R.L. Joint transmitter-receiver optimization in synchronous multiuser communications over multipath channels. IEEE Transactions on Commununications. 46 (Feb. 1998) : 269–278
16. Serbetli, S. and Yener, A. Transceiver optimization for multiuser MIMO systems. IEEE Transactions on Signal Processing. 52 (Jan. 2004) : 214–226
17. Palomar, D.P. Lagunas, J.M. and Cioffi, J.M. Optimum linear joint transmit-receiver processing for MIMO channels with QoS constraints. IEEE Transactions on Signal Processing. 52, 5 (May 2004) : 1179-1197
18. Nee, R.V. and Prasad, R. OFDM for Wireless Multimedia Communications. London: Artech House, 2002.
19. Pahlavan, K. and Levesque, A.H. Wireless information networks. USA: John Wiley & Sons, 2005.
20. Lee, W.C.Y. Mobile communications engineering. Singapore: McGraw-Hill, 1977.
21. Proakis, J. Digital Communications. New York: McGraw-Hill, 1989.
22. Goldsmith, A. Wireless Communications. UK: Cambridge University Press, 2005.
23. Horn, R.A. and Johnson, C.R. Matrix Analysis. UK: Cambridge University Press, 1990.
24. Gulub, G. and Loan, A.V. Matrix Computations. USA: Johns Hopkins University Press, 1996.
25. Luenberger, D.G. Optimization by Vector Space Methods. New York: John Wiley & Sons, 1969.
26. Boyd, S. and Vandenberghe, L. Convex optimization. UK: Cambridge University Press, 2004.
27. Luo, Z.-Q. and Yu, W. An Introduction to Convex Optimization for Communications and Signal Processing. IEEE Journal on Selected Areas in Communicatios. 24,.8 (Aug. 2006)

: 1426-1438

28. Gershman, A.B. and Sidiropoulos, N.D. Space-Time Processing for MIMO Communications. USA: John Wiley & Sons, 2005.

29. Rockafellar, R.T. Lagrange multipliers and optimality. SIAM Rev. 35, 2 (1993) : 183-238

30. Nesterov, Y. and Nemirovski, A. Interior-point polynomial algorithms in convex programming. USA: SIAM Publications, 1994.

31. Sturm, J.F. Using SeDuMi 1.02, a MATLAB toolbox for optimization over symmetric cones. Optimization Methods and Software. 11–12 (1999) : 625–653

32. Patzold, M. Mobile Fading Channels. UK: John Wiley & Sons, 2002.

33. Sturm, J.F. SeDuMi 1.1, a MATLAB toolbox for optimization over symmetric cones. Available at http://sedumi.mcmaster.ca/ (Sep. 2006)

34. Chen, Y. and Tellambura, C. Performance Analysis of Maximum Ratio Transmission with Imperfect Channel Estimation. IEEE Communications Letters. 9,4 (Apr. 2005) : 322-324

ภาคผนวก

ผลงานของผู้เขียนที่ได้รับการตีพิมพ์แล้ว

1. Saetang, P., Kunaruttapruk, S, and Jitapunkul S. Power allocation optimization for uplink MC-CDMA systems. 2006 IEEE International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS 2006), Japan, Dec 2006: 75-78.

ISPACS
2006

2006 International Symposium on Intelligent Signal
Processing and Communication Systems (ISPACS2006)
Yonago Convention Center, Tottori, Japan

Power allocation optimization for uplink MC-CDMA systems

Prajak Saetang, Suwich Kunaruttanapruk and Somchai Jitapunkul
Digital Signal Processing Research Laboratory, Department of Electrical Engineering,
Chulalongkorn University, Pathumwan Bangkok 10330 Thailand
prajak.sa@student.chula.ac.th, mrsuwich@yahoo.com and somchai.j@chula.ac.th

Abstract—**In this paper, we consider the joint transmitter and receiver for uplink MC-CDMA systems. The equation of the MMSE joint transmitter-receiver is expressed. We apply an optimization technique by rewriting the equation of the joint transmitter and receiver for uplink MC-CDMA systems as second-order cone programming (SOCP) which can efficiently be solved numerically by the existing polynomial convergence software packages. Numerical examples show that the joint transmitter-receiver optimization yields the lower BER compared with the MMSE receiver for both perfect channel estimation and imperfect channel estimation case.**

I. INTRODUCTION

Multicarrier Code Division Multiple Access (MC-CDMA) [1] is a promising approach to the challenge of providing high data rates wireless communication. It combines the benefits of CDMA and orthogonal frequency division multiplexing (OFDM). The CDMA scheme is a prominent multiple-access technique and the OFDM scheme is robust to frequency selective fading.

The good performance of downlink MC-CDMA is illustrated in [2]. Conversely, the uplink MC-CDMA has shortcomings compared with the downlink system, that the signals of different users experience different fading channels. This situation deteriorates the orthogonality among different spreading codes, leading to the multiple access interference (MAI). Several techniques have been proposed to mitigate the interference. On the receiver side, several schemes such as multiuser detection (MUD) and interference cancellation techniques [3] have been proposed to suppress MAI. On the transmitter side, many techniques, based on optimal allocation of the transmit power with respect to channel coefficients, have been proposed to combat fading channel [4]. These schemes require the channel state information (CSI) at the transmitter.

Recently, joint transmitter-receiver optimization has been considered to improve the overall performance. In [5], joint transmitter-receiver optimization approach is proposed for multiple input multiple output (MIMO) systems. This scheme finds the joint optimum linear precoder and decoder in order to minimize mean square error (MSE) of received output. In addition, the joint optimum transmission schemes was proposed for CDMA systems by using iterative algorithms to search for the optimum signature sets [6],[7].

In this paper, we apply an optimization technique for uplink MC-CDMA systems. First, the equation of the uplink MC-CDMA system including precoder at transmitter and linear decoder at receiver based on minimum mean square error (MMSE) criteria is expressed. Then, we rewrite the equation of joint transmitter and receiver for uplink MC-CDMA systems as second-order cone programming (SOCP) [8] and solved it numerically by interior-point methods e.g. SeDuMi [9]. SeDuMi is available as a Matlab toolbox for solving optimization problems over symmetric cones. Also, we compare this scheme with conventional uplink MC-CDMA systems that uniformly distribute transmit power over all subcarriers and use MMSE MUD technique at the receiver.

This paper is organized as follows. In Section 2, we describe the joint transmitter and receiver for uplink MC-CDMA systems. In Section 3, we apply the optimization technique to find linear precoder and decoder jointly. Section 4 provides numerical results. Finally, some conclusions are given in Section 5.

II. SYSTEM MODEL

In this paper, consider a quasi-synchronous uplink MC-CDMA system where arrival delay of each user signal at the receiver front end is maintained within the cyclic prefix interval. Multiple mobile users transmitting data to a base station experience different fading channels.

A. Transmitter

In MC-CDMA, there are N evenly spaced subcarriers shared by all the users. Each user is assigned a spreading code with length chips. k-th user's information symbol b_k is replicated into N parallel copies. After each copy is multiplied by a chip from the corresponding signature sequence $\mathbf{c}_k = (c_k[1], c_k[2], \ldots, c_k[N])^T$, it is mapped onto one of the subcarries, all of which are to be transmitted in parallel. The modulation is performed by using inverse discrete Fourier transform (IDFT) to convert the parallel chips into serial form for transmission.

The complex equivalent baseband transmitted signal can be written as

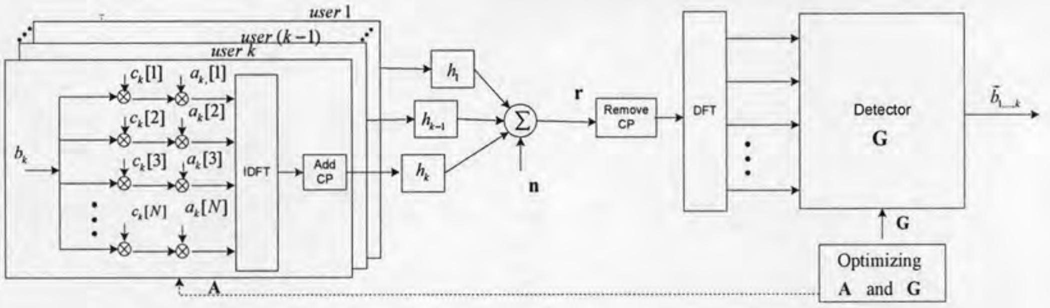

Fig. 1. Joint transmitter-receiver for uplink MC-CDMA systems.

$$s_k(t)=\sum_{i=-\infty}^{\infty} s_k^i(t-iT_s) \qquad (1)$$

where

$$s_k^i(t)=\frac{1}{N}\sum_{n=1}^{N} c_k[n]a_k[n]b_k[i]e^{\frac{j2\pi(t-T_{CP})}{T_B}} p_T\left(\frac{t}{T_S}\right),$$

$\mathbf{c}_k=(c_k[1],c_k[2],...,c_k[N])^T$ is signature sequences of length N of user k-th , $\mathbf{a}_k=(a_k[1],a_k[2],...,a_k[N])^T$ is precoder, T_S is a MC-CDMA symbol duration, T_{CP} is a CP duration, $T_B=T_S-T_{CP}$ is the duration of the MC-CDMA symbol without the CP, and $p_T(t)$ is a rectangular waveform defined as

$$p_T(t)=\begin{cases}1, & 0\le t\le 1\\ 0, & otherwise.\end{cases} \qquad (2)$$

B. Channel Model

We consider a frequency-selective fading channel in an uplink channel that each mobile user transmits data from a different location. Then, the receiver at the base station estimates the channel matrices of all the users and the noise correlation collectively known as the channel state information (CSI). The channel of each user is modeled as a wide sense stationary uncorrelated scattering (WSSUS) multipath channel with L paths. The channel impulse response is described by

$$h_k(\tau,t)=\sum_{l=1}^{L}\alpha_{k,l}\delta(t-\tau_l(t)) \qquad (3)$$

where $\alpha_{k,l}$ is the complex-value channel gain for l-th path of the k-th user. $\tau_l(t)$ is the time delay for l-th path.

C. Receiver

The received signal is an aggregation of the linear convolution of each transmitted signal with the corresponding channel impulse response. The received signal in the complex baseband representation in time domain can be expressed as

$$r(t)=\sum_{k=0}^{K-1} r_k(t)+n(t) \qquad (4)$$

where

$$r_k(t)=\sum_{l=0}^{L-1}\alpha_{k,l}\sum_{i=-\infty}^{\infty}s_k^i(t-\tau_k(l)-iT_S).$$

With use of cyclic prefix to avoid ISI and applying IDFT and DFT operation, the channel matrix is circulant and diagonal. The received signal based on a matrix representation in frequency domain can be expressed as

$$\mathbf{r}=\sum_{l=1}^{K}\mathbf{H}_l\mathbf{A}_l\mathbf{C}_l b_l+\mathbf{n} \qquad (5)$$

where $\mathbf{H}_k=diag(H_k[1],H_k[2],...,H_k[N])$, which $H_k[i]$ is the frequency response of user k 's channel at the ith point on the FFT grid $\omega_i=2\pi i/n$, $\mathbf{C}_k=diag(c_k[1],c_k[2],...,c_k[N])$, $\mathbf{A}_k=diag(a_k[1],\ a_k[2],...,a_k[N])$, b_k is the data symbol of user kth is replicated into N parallel copies of subcarriers and $\mathbf{n}$ is an additive complex Gaussian noise with zero mean and variance σ^2.

In general, the approach to maximize the signal-to-interference-plus-noise ratio (SINR) is the MMSE receiver. The MMSE receiver performs an appropriate $\mathbf{G}_k$ to estimated the data of user k as $\hat{b}_k=\mathbf{G}_k\mathbf{r}$,thus

$$\begin{aligned}\hat{b}_k &= \mathbf{G}_k\left(\sum_{l=1}^{K}\mathbf{H}_l\mathbf{A}_l\mathbf{C}_l b_l+\mathbf{n}\right)\\ &= \sum_{l=1}^{K}\mathbf{G}_k\mathbf{H}_l\mathbf{A}_l\mathbf{C}_l b_l+\mathbf{G}_k\mathbf{n}\\ &= (\mathbf{G}_k\mathbf{H}_k\mathbf{A}_k\mathbf{C}_k-1)b_k+\sum_{\substack{l=1,\\ l\neq k}}^{K}\mathbf{G}_k\mathbf{H}_l\mathbf{A}_l\mathbf{C}_l b_l+\mathbf{G}_k\mathbf{n}.\end{aligned} \qquad (6)$$

The covariance of the error of user k as

$$E\{e_k e_k^H\} = E\{(\hat{b}_k - b_k)(\hat{b}_k - b_k)^H\} \tag{7}$$

By replacing (6) on (7) and the fact that the data of each user and the noise are mutually uncorrelated. We will get the covariance of the error of user k as following

$$\begin{aligned} E\{ee_k^H\} &= (\mathbf{G}_k\mathbf{H}_k\mathbf{A}_k\mathbf{C}_k - 1)(\mathbf{G}_k\mathbf{H}_k\mathbf{A}_k\mathbf{C}_k - 1)^H \\ &+ \sum_{\substack{l=1 \\ l\neq k}}^{K} (\mathbf{G}_k\mathbf{H}_l\mathbf{A}_l\mathbf{C}_l)(\mathbf{G}_k\mathbf{H}_l\mathbf{A}_l\mathbf{C}_l)^H \\ &+ \mathbf{G}_k\mathbf{R}\mathbf{G}_k^H. \end{aligned} \tag{8}$$

III. THE JOINT TRANSMITTER-RECEIVER OPTIMIZATION

In this section, we apply optimization to find precoder and decoder. The formulation of joint transmitter-receiver to minimize the total MSE under the power constraints of the transmitter coefficient $\mathbf{A}_k$ can be written in general optimizing problem as

$$\begin{aligned} &\underset{\{\mathbf{A}_k,\mathbf{G}_k\},k=1,2,\ldots,K}{\text{minimize}} \quad \text{trace}\left(\sum_{k=1}^{K} E\{e_k e_k^H\}\right) \\ &\text{subject to} \quad \text{trace}(\mathbf{A}_k\mathbf{A}_k^H) \le p_k, \quad k=1,2,\ldots,K. \end{aligned} \tag{9}$$

The objective of the above equation is to jointly find $\mathbf{A}_k$ (at the transmitter) and $\mathbf{G}_k$ (at the receiver) that will result in the minimum total MSE in the context of multiuser. The constraint is that $\text{trace}(\mathbf{A}_k\mathbf{A}_k^H)$, which is the sum of all the subcarrier power of each user, is limited to p_k as same as in the conventional case.

Since the receiver $\mathbf{G}_k$ are unconstraint, we firstly eliminate $\mathbf{G}_k$ by considering that regardless of $\mathbf{A}_k$, the linear MMSE receiver $\mathbf{G}_k$ can be written as a function of any $\mathbf{A}_k$ as

$$\mathbf{G}_k = \mathbf{C}_k^H\mathbf{A}_k^H\mathbf{H}_k^H\mathbf{W} \tag{10}$$

where

$$\mathbf{W} = \left(\sum_{k=1}^{K}(\mathbf{H}_k\mathbf{A}_k\mathbf{C}_k\mathbf{C}_k^H\mathbf{A}_k^H\mathbf{H}_k^H) + \sigma^2\mathbf{I}\right)^{-1}$$

and $\mathbf{W}$ is the covariance of received signal. By introducing a variable $\mathbf{U}_k = \mathbf{A}_k\mathbf{A}_k^H$, we can rewrite optimization problem in (10) as

$$\begin{aligned} &\underset{\{\mathbf{U}_k\}}{\text{minimize}} \quad \text{trace}\left(\left(\sum_{k=1}^{K}(\mathbf{H}_k\mathbf{C}_k\mathbf{U}_k\mathbf{C}_k^H\mathbf{H}_k^H) + \sigma^2\mathbf{I}\right)\sigma^2\mathbf{I}\right) \\ &\text{subject to} \quad \text{trace}(\mathbf{U}_k) \le p_k, \quad k=1,2,\ldots,K. \\ &\qquad\qquad \mathbf{U}_k \succ 0 \end{aligned} \tag{11}$$

It should be noted that $\mathbf{U}_k$ is positive semidefinite. Since the channel $\mathbf{H}_k$ and signature sequence $\mathbf{C}_k$ of each user are known and diagonal, we can rearrange this optimization problem to second-order cone programming (SOCP) [8] formulation as

$$\begin{aligned} &\underset{\mathbf{W},\{\mathbf{U}_k\}}{\text{minimize}} \quad \sum_{i=1}^{N}\sigma_i^2\mathbf{w} \\ &\text{subject to} \quad \sum_{i=1}^{N}\mathbf{u}_k[i] \le p_k, \quad k=1,2,\ldots,K \\ &\qquad\qquad \mathbf{w}+\mathbf{z} \ge \left\| \begin{bmatrix} \mathbf{w}-\mathbf{z} \\ 2\nu \end{bmatrix} \right\| \\ &\qquad\qquad \mathbf{u}_k[i] \ge 0, \quad i=1,2,\ldots,N, \quad k=1,2,\ldots,K \\ &\qquad\qquad \nu \ge 1. \quad (\nu \text{ is additional variable}) \end{aligned} \tag{13}$$

where
$$\mathbf{z} = \sum_{k=1}^{K}\left(\left|H_k[i]C_k[i]\right|^2\mathbf{u}_k[i]\right) + \sigma_i^2.$$

Accordingly, the optimized $\mathbf{U}_k$ of all users have been determined. The precoder $\mathbf{A}_k$ at transmitter can be obtained by factorization of as $\mathbf{U}_k = \mathbf{A}_k\mathbf{A}_k^H$. The corresponding decoder $\mathbf{G}_k$ at receiver can be obtained by substituting $\mathbf{A}_k$ into (10).

IV. SIMULATION RESULTS

In the simulation, we consider the MC-CDMA systems with 32 subcarriers for BPSK modulated data transmission. Each user is assigned an unique Walsh-Hadamard sequence of length $N = 32$ as a signature sequence. Each user experiences a 3-paths Rayleigh channel in which each path coefficient is modeled as a zero-mean complex Gaussian random variable with variance 0.5 per dimension and all path coefficients are normalized equal to 1.

In Fig. 2, we compare joint transmitter-receiver optimization with conventional MMSE receiver. It is observed that the joint transmitter-receiver optimization gives the lower bit error rate (BER). The 2.5 dB SNR gain of the proposed algorithm is observed over a broad range of BERs compared with the MMSE receiver case.

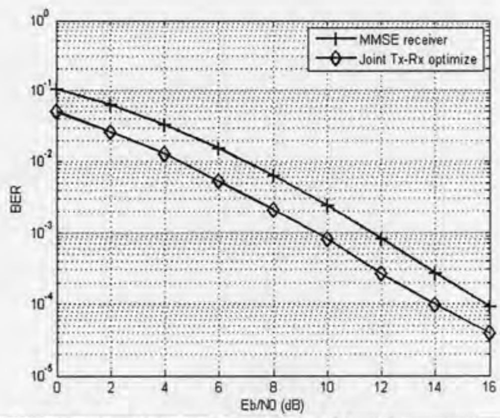

Fig. 2. The BER performance comparison of the joint transmitter-receiver optimization

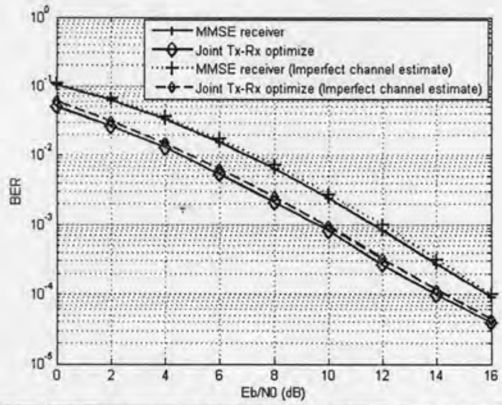

Fig. 3. The BER performance of the joint transmitter-receiver optimization in the presence of the imperfect channel estimate.

We assumed a perfect knowledge of channel estimate or CSI during the design stage. However, in a realistic scenario, the channel knowledge is generally imperfect. Fig. 3., illustrates the BER curve of the joint transmitter-receiver optimization under the imperfect channel estimation environment is presented. We model the estimated channel as

$$\hat{h}_k = (1+\alpha_k)\,\mathrm{Re}(h_k) + j(1+\beta_k)\,\mathrm{Im}(h_k) \qquad (13)$$

where h_k is the actual impulse response of the k-th user's channel, α_k and β_k are independent zero-mean white Gaussian processes of standard deviation 0.3, $\mathrm{Re}(\cdot)$ and $\mathrm{Im}(\cdot)$ denote the real and imaginary parts, respectively. Therefore, we have a Gaussian relative error with a standard deviation of 30% which can be seen as moderate error occur in channel estimation part.

It is clear form Fig. 3, that the performance of the proposed is marginally degraded by imperfect channel estimation. Therefore, the proposed scheme is quite robust to the channel estimation error.

V. CONCLUSION

We introduce an joint optimization technique to an uplink MC-CDMA system. The proposed system includes precoder at a transmitter and linear decoder at a receiver. The formulation of joint transmitter-receiver based on minimum mean square error was expressed. We adopt second-order cone programming in order to solve the optimization problem. From simulation results, the joint optimized transmitter-receiver outperforms conventional uplink MC-CDMA that use MMSE receiver. The effect of imperfect channel estimation was also presented. Simulation results show that the proposed scheme is robust to channel estimation error.

ACKNOWLEDGMENT

The work reported in this paper was supported by the Cooperation Project between the Department of Electrical Engineering and Private Sector for Research and Development.

REFERENCES

[1] N. Yee, J.P. Linnartz, and G. Fettweis, "Multi-carrier CDMA in indoor wireless radio networks," *IEEE PIMRC 1993*, pp. 109–113, Sep. 1993.

[2] R. Prasad and S. Hara, "An overview of multi-carrier CDMA," *IEEE Commun. Mag.*, vol. 35, pp. 126–133. Dec. 1997.

[3] S. Verdu, *Multiuser Detection*, Cambridge University Press, UK., 1998.

[4] Y.H. Lee and Y. Bar-Ness, "Transmission power adaptations in MC-CDMA communications over Rayleigh fading channels," *WCNC 2004*, vol. 3, pp. 1589–1594, Mar. 2004.

[5] S. Serbetli and A. Yener, "Transceiver optimization for multiuser MIMO systems," *IEEE Trans. Signal Process.*, vol. 52, pp. 214–226, Jan. 2004.

[6] J.I. Concha and S. Ulukus, "Optimization of CDMA signature sequences in multipath channels," *VTC 2001*, vol. 3, pp. 1978–1982, May. 2001.

[7] W.M. Jang, B.R. Vojcic, and R.L. Pickholtz, "Joint transmitter-receiver optimization in synchronous multiuser communications over multipath channels," *IEEE Trans. Commun.*, vol. 46, pp. 269–278, Feb. 1998.

[8] S. Boyd and L. Vandenberghe, *Convex optimization*, Cambridge University Press, UK., 2004.

[9] J.F. Sturm, "Using SeDuMi 1.02, a MATLAB toolbox for optimization over symmetric cones," *Optimization Methods and Software*, vol. 11–12, pp. 625–653, 1999.

ประวัติผู้เขียนวิทยานิพนธ์

นายประจักษ์ แซ่ตั้ง เกิดวันที่ 20 เมษายน พ.ศ. 2520 ที่จังหวัดกรุงเทพมหานคร เข้ารับการศึกษาในหลักสูตรวิศวกรรมศาสตรบัณฑิต มหาวิทยาลัยสงขลานครินทร์ ในปีการศึกษา 2540 สำเร็จการศึกษาปริญญาวิศวกรรมศาสตรบัณฑิต สาขาวิศวกรรมไฟฟ้าจาก มหาวิทยาลัยสงขลานครินทร์ ในปีการศึกษา 2544 และเข้าศึกษาต่อในหลักสูตรวิศวกรรมศาสตรมหาบัณฑิต สาขาวิศวกรรมไฟฟ้า ที่จุฬาลงกรณ์มหาวิทยาลัย ในปีการศึกษา 2546