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Multilevel Multiuser Detection System in a Multi-Cell MFSK/FH-CDMA Environment

Sung-chul Kang*, Ryuji Kohno* *Regular Members*

ABSTRACT

This paper proposes a multiuser detection system *in a multi-cell* M-ary Frequency Shift Keying(MFSK)/frequency hopping(FH)-Code Division Multiple Access(CDMA) environment, in which the channel model is an OR-channel and in the reverse link. We have proposed a multiuser detection system *in a single cell* [2]. However, this system is not adequate to detect multiuser *in a multi-cell environment*. Therefore, we propose a multiuser detection system based on 3 level OR decision with two thresholds. The proposed detection system can delete inter-cell interference as well as intra-cell interference, receive the weakened desired signal and reject the false alarm. Computer simulation shows the performance improvement.

I. Introduction

Recently, Spread Spectrum(SS) techniques are applied to satellite communication, land mobile communication, wireless LAN and so on. SS systems are categorized into Direct Sequence(DS)-CDMA system and FH-CDMA system. The channel model is regarded as an OR channel and a time-frequency matrix (Fig. 3) is used to analyze the performance of the proposed system. An FH-CDMA System has a 'HIT' which occurs when the hopping frequency of the desired signal coincides with that of the undesired signal. To cancel a hit in FH-CDMA, there is a method using an address code presented by Bell Labs. [1], which is used as a FH series to separate each user in a cell. We have proposed a multiuser detection system [2] and the paper dealt with it *in a single cell*. However, this paper deals with a multiuser detection system *in a multi-cell environment*. In order to distinguish these methods, we call the conventional system of reference [2] 2 level OR decision system ('2OR' system) because OR operation is done with the received signal(one level) if a receiving signal is higher than or equal to a threshold and it(the other level) is rejected if it is lower than the threshold. The multilevel multiuser detection system is proposed, which is a 3 level OR decision system ('3OR' system). Where the 3 levels are the upper level (matrix C1), the middle level(matrix C2) and the lower level(rejected) formed by using two thresholds. Also OR decision means that when a lot of signals from users are transmitted simultaneously logical OR operation are done with the received signals in a receiver, for example, $0+1=1$, $0+0=0$, $1+0=1$, $1+1=1$, $1+1+1=1$, ..., $1+1+1+1+$, ..., $+1=1$. It is explained how to cancel the inter-cell interference and how to catch the desired signal weakened by fading. Section 2 discusses the environment of multiuser detection system, the generation of FH series, a manner to assign an address code set as a FH series and a method

*Yokohama National University, Japan
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of deciding two thresholds. Section 3 proposes and investigates a multiuser detection system. Section 4 describes system performance and section 5 presents the conclusions.

Ⅱ. Multiuser Detection System Environment

2.1 Background

We have proposed a multiuser detection system based on 2OR system in a single cell [2]. However, in a radio channel, some signals can be lost ("deletion"), some signals ("false alarm") that we didn't transmit can appear due to noise and/or fading, and there can be interference come from the inter-cells as well as intra-cell. In this case, the 2OR system is not appropriate to catch the weakened desired-signals and to delete the false alarm and the interference. Therefore, the 3 level multiuser detection system (Fig. 1) is proposed.

2.2 Generation of FH series

G. Einarsson proposed an address assignment method for a time-frequency-coded spread spectrum system [4]. The messages intended for a particular user are distinguished by a specific signal pattern called the address. He considered a system where an address is a sequence of L tones, chosen from M possible frequencies. It can be described as a pattern of assigning addresses to the users using an algebraic approach which provides M distinct addresses that guarantee minimum interference among M or fewer system users. He proposed the following way of generating a set of M addresses.

Let

$$R_m = (\gamma_m, \gamma_m\alpha, \gamma_m\alpha^2, \ldots, \gamma_m\alpha^{L-1}), \qquad (1)$$

where γ_m is an element of GF(M) assigned to user m and α is a fixed primitive element of GF(M). The maximum number of addresses obtained is equal to M and the maximum possible value is equal to M-1.

2.3 Reassignment of FH series

In DS/CDMA, if a frequency set is assigned to a cell once, the frequency set can be not assigned to a neighbor cell. It can be assigned to another cell that is sufficiently distant from the cell. We assume in FH/CDMA that if an address code set is assigned to a

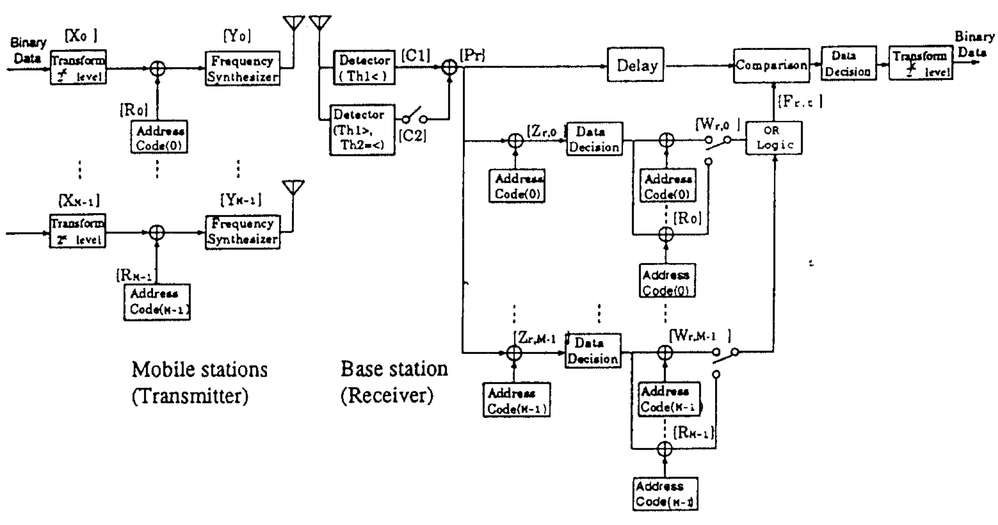


Fig. 1 System model

cell, the address code set could be reassigned to another cell which is sufficiently distant from the cell. The distance is considered when it is reassigned to another cell in order to use spectrum effectively [6]. The address code set used in the cell '6' is reassigned in another cell '6''. Let the shape of the cell be hexagonal and the radius of the cell be R as figure 2. If the distance between a cell and the cell to which we reassign it again is D,

$$D=\sqrt{3K}\times R, \tag{2}$$

$$K=\frac{(3\sqrt{3}/2\times D^2)/3}{3\sqrt{3}/2\times R^2}$$
$$=\frac{1}{3}(D/R)^2=i^2+ij+j^2,$$

where K is the frequency reuse pattern and i, j are shift parameters

2.4 Decision of two thresholds

We calculate the power in a mobile radio environment [7]. The received power, $P_r(dB_m)$ at the suburban area can be expressed as:

$$P_r=-54dB-38.4\log r_1+\alpha_0, \tag{3}$$

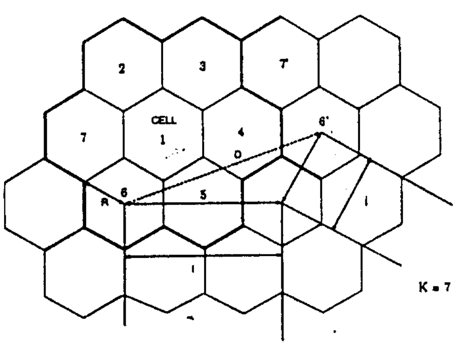


Fig. 2 Cell reuse pattern

where the base-station transmitted power is 10W (40dBm), the antenna gain is 6dB with respect to a half-wave dipole and the antenna height is 30.48 m. The mobile antenna is a quarter-wavelength whip with a height of 3.05 m above ground. r_1 is in kilometers and α_0 is an adjustment factor. This formula is referred in order to decide the two thresholds defined in subsection 3.1.

Ⅲ. Multilevel Multiuser Detection System

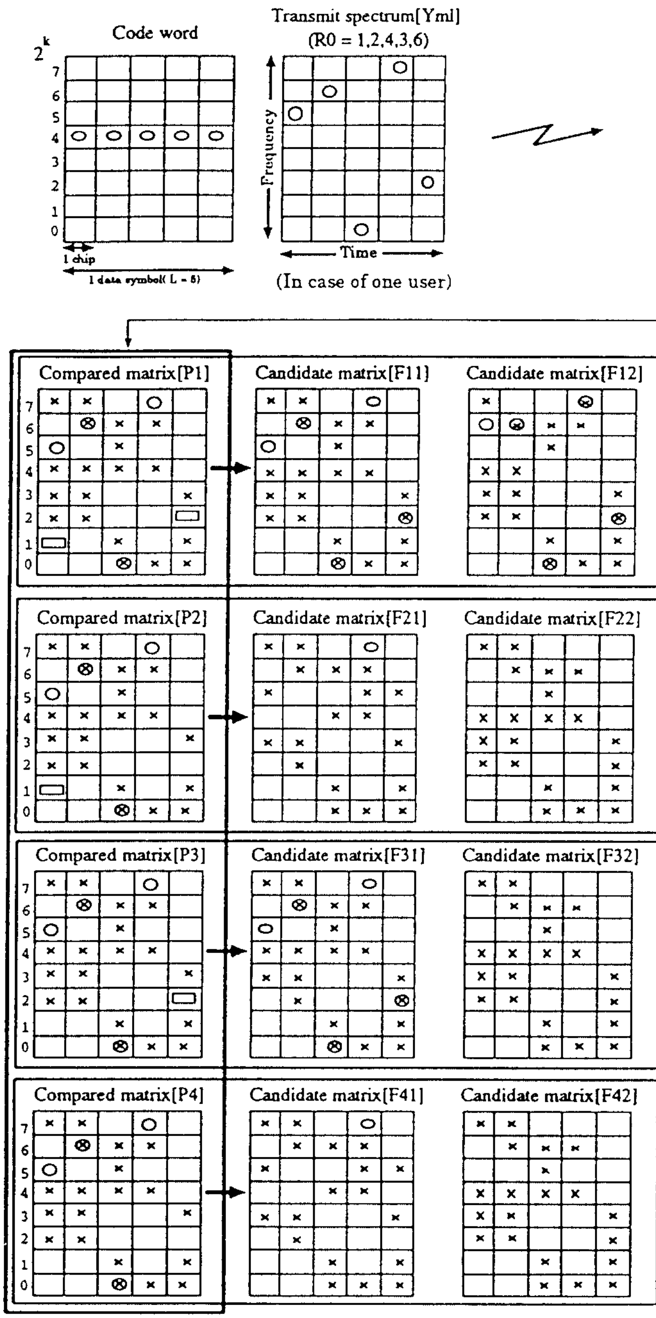
Frequency resources are limited and we have tried to enhance the spectrum efficiency. Also we have studied so that, if possible, there could be more users within a limited band. Therefore a system is proposed to enhance the spectrum efficiency and to increase the number of users.

3.1 Multilevel multiuser detection system

If we consider the interference in a multi-cell environment, we can think that the interference is due not only to the signal coming from inter-cells but also to the signal coming from another mobile stations in intra-cell. In general, the power level of the signal coming from intra-cell at the base station is larger than that coming from inter-cells because power is in inverse proportion to the distance. The 3OR system is proposed with two thresholds: high threshold, (T_{h1}) and low threshold, (T_{h2}) (Fig. 1). We make T_{h1} the threshold of the 2OR system and T_{h2} a higher power level than that coming from a mobile station within the cell using the same address code set. The best T_{h2} is decided through computer simulations. By using T_{h1}, the desired signal of the intra-cell is detected and the interference coming from inter-cells is rejected. By using T_{h2}, the weakened desired-signal is detected, which it can be missed because of noise and/or fading within intra-cell and distinguish the undesired signal coming from the inter-cells and reject it. As a result, the bit error rate(BER) can be reduced by using this system.

3.2 Algorithm of the 3OR system

The 3OR algorithm is used, which is defined as



[P]	m	0 1 2 3 4 5	Hamming Distance of [P] and [F]
[P1]	[F11]	4 6 1 7 2 1	1
	[F12]	4 6 2 7 2 1	5
	[F13]	5 6 1 7 2 1	2
	[F14]	5 6 2 7 2 1	6
[P2]	[F21]	5 6 1 0 2 1	7
	[F22]	5 6 1 7 2 1	5
	[F23]	5 6 2 0 2 1	6
	[F24]	5 6 2 7 2 1	5
[P3]	[F31]	4 6 1 7 2 1	0
	[F32]	5 6 1 7 2 1	2
[P4]	[F41]	5 6 1 0 2 1	6
	[F42]	5 6 1 7 2 1	4

Fig. 3 Multilevel multiuser detection process(an example of 6 users)

follows and the configuration of the system as shown in Figure 1.

(1) Mobile station

In a mobile station $M_m(m=0, 1, ..., M-1)$, source data bits are sent to the encoder and changed to 2^k level codewords. One codeword is sent L times to the adder. The duration of one chip, $Tc=T/L$ and the duration of a data bit is T. The data, $X_{m,l}=(X_{m,0}, X_{m,1}, ..., X_{m,L-1})$ is added to the address code, $R_{m,l}=(R_{m,0}, R_{m,1}, ..., R_{m,L-1})$ in order to get $Y_{m,l}=(Y_{m,0}, Y_{m,1}, ..., Y_{m,L-1})$, which is transmitted (Fig. 3).

$$Y_{m,l}=X_{m,l}+R_{m,l}, \quad for \quad l=0, 1, ..., L-1 \tag{4}$$

where the subscript letter 'l' is omitted in general because 'l' decides only the address code length. The synthesizer transmits an MFSK signal corresponding to Y_m with 2^k levels.

(2) Base station

We assume that the address codes is known, which is assigned to the mobile stations. 6 users is used to explain how to detect in figure 3. If the signals are equal to or higher than T_{h2} and less than T_{h1}, matrix C_2 is made with them. If the signals are equal to or higher than T_{h1} matrix C_1 is made with them. Matrix C_1 is added to zero, one, two, etc. of matrix C_2 to obtain all combinations of the compared vector matrix, P_r (Figs. 1 and 3), $P_r=(p_{r,0}, p_{r,1}, ..., p_{r,L-1})$ for $r=1, 2, ..., 2^{N-1}$.

The address codes, R_m are subtracted from the compared vector matrix to make the data matrix, where the address codes are the same things as those used in mobile stations. If it is done so, the data matrix, $Z_{r,m}=(Z_{r,m,0}, Z_{r,m,1}, ..., Z_{r,m,L-1})$ is as follows.

$$\begin{pmatrix} Z_{r,0} \\ Z_{r,1} \\ \vdots \\ Z_{r,M-1} \end{pmatrix} = \begin{pmatrix} P_r \\ P_r \\ \vdots \\ P_r \end{pmatrix} - \begin{pmatrix} R_0 \\ R_1 \\ \vdots \\ R_{M-1} \end{pmatrix} \tag{5}$$

If the row which contains the most of signals in the data matrix, $Z_{r,m}$ is $i_m(1 \le i_m \le 2^k)$ and then let i_m be a candidate data of M_m, $\hat{X}_{r,m}=(\hat{X}_{r,m,0}, \hat{X}_{r,m,1}, ..., \hat{X}_{r,m,i_m-1})$. If there is only one row containing maximum entries in the data matrix, $Z_{r,m}$, it is encoded in a receiver again with the same address codes that the mobile stations used to make the candidate matrix, $W_{r,m}$ without noise and interference (Eq. 6). However, if there are over two rows containing maximum entries in the data matrix, $Z_{r,m}$, they are encoded each other in a receiver again with the address codes and make over two candidate matrices, $W_{r,m}$. OR operation is done with the matrices, $W_{r,m}$ of all mobile stations in intra-cell

$$\begin{pmatrix} W_{r,0} \\ W_{r,1} \\ \vdots \\ W_{r,M-1} \end{pmatrix} = \begin{pmatrix} \hat{X}_{r,0} \\ \hat{X}_{r,1} \\ \vdots \\ \hat{X}_{r,M-1} \end{pmatrix} + \begin{pmatrix} R_0 \\ R_1 \\ \vdots \\ R_{M-1} \end{pmatrix} \tag{6}$$

to make a completed candidate matrix [Fr, t] (Figs. 1 and 3). The number of candidate matrices depend on the number of rows containing maximum entries in the data matrix, $Z_{r,m}$. It must be found, which candidate matrix is the same matrix that the mobile stations transmitted. The Hamming distance (Table in figure 3) is computed between one compared matrix, [Pr] and each candidate matrix, [Fr, t] to estimate the matrix transmitted by the mobile stations. As the candidate matrix is decoded, which has the shortest Hamming distance, the data transmitted by the desired mobile station can be gotten.

Ⅳ. System Performance

The simulation parameters of this system are defined in table Ⅰ. The mobile stations are distributed uniformly in every cell and address codes are assigned to each mobile station. Each station has the same power and transmits MFSK/FH-CDMA signal simultaneously. Decoding is performed by the same method we have proposed [2]. The performance due to changing S/N ratio is shown, 10dB and 25dB respectively. The above procedure is repeated as changing the distribution of mobile station in the cell to get the average BER. The symbol 'Th#' in figures 4, 5 and 6 means the threshold level normalized by the effective noise voltage. A random code is used to make it easy to compare with 2OR system because they used a random code [2]. However, if we use Einarsson's code described in section 2.2, it is shown that the BER is more improved than that of a random code (Fig. 6)

Table Ⅰ. Simulation parameters

Structure of cell	hexagonal
Radius of cell	100m
NO. of reassigned cells	9 cells
NO. of cells	43 cells
Distribution of mobile stations	uniform
Bandwidth of spread spectrum	1.28MHz
data transmission rate	32 kbit/s
$k(2^k)$	4(16)
code length	10
Noise	AWGN
SNR	10dB, 25dB

Ⅴ. Conclusions

3OR system is investigated in a multi-cell environment and compared with the 2OR system by computer simulations. The performance of the proposed system is analyzed. It is shown that if 2OR system is used in the multi-cell environment, channel efficiency is decreased because it is impossible to cancel the interference coming from inter-cells and to receive the desired signals weakened by fading. Therefore, the 3OR system is proposed to solve this problem. It is shown in figures 4 and 5 that the BER of 3OR system is more improved than that of 2OR system. It means that the inter-cell interference as well as the intra-cell interference is canceled by 3OR system and the desired signals weakened by fading is caught. It is shown that the improvement for most BER is about two users.

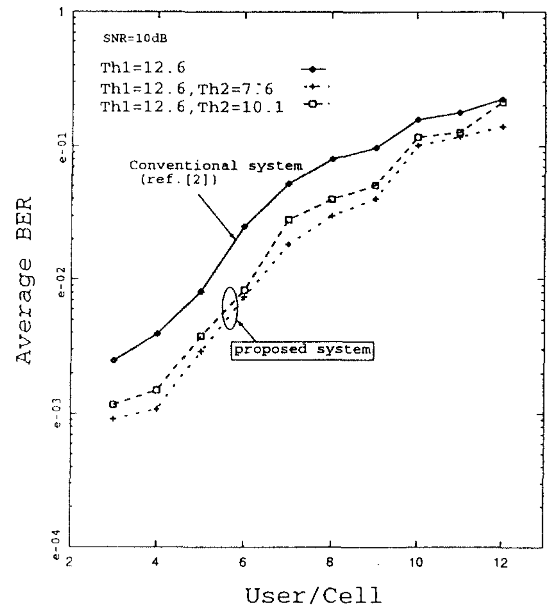


Fig. 4 BER comparing 3OR with 2OR (SNR = 10dB)

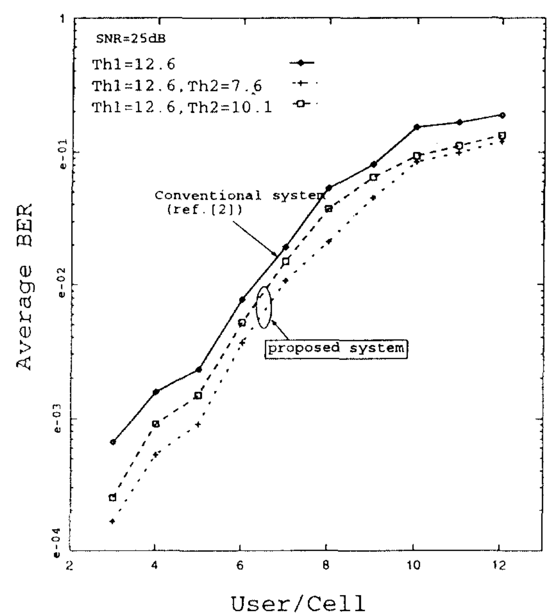


Fig. 5 BER comparing 3OR with 2OR (SNR = 25dB)

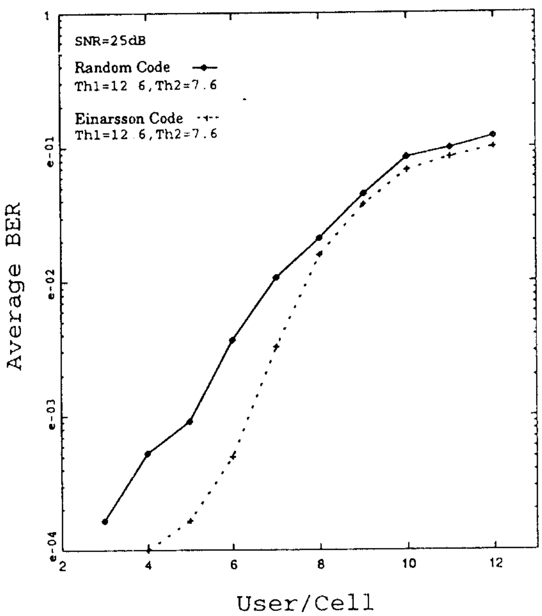


Fig. 6 BER comparing Einarson code with Random code used as address code (SNR = 25dB)

We simulate respectively as we change the SNR(10dB, 25dB). It is confirmed that the BER of 10dB is more improved (Fig 5). It means that it has good performance in the inferior environment. Also when T_{h2} is lower, the BER performance becomes better, but the computational complexity is increased. It is also shown that the BER is still further improved if Einarsson's code is chosen as FH series (Fig. 6).

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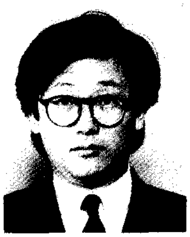


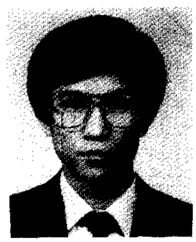
Ryuji Kohno

Ryuji Kohno was born in Kyoto, Japan March 1956. He received the B.E. and M.E. degrees in computer engineering from Yokoham National University in 1979 and 1981, respectively, and the Ph.D. degree in electrical engineering from the University of Tokyo in 1984.

He joined in the Department of Electrical Engineering, Toyo University in 1984 and became an Associate Professor in 1986. During 1988-1997 he was an Associate Professor in the Division of Electrical and Computer Engineering, Yokohama National University. Since April 1998 he becomes a Full Professor in the same division. During 1984-1985 he was a Visiting Scientist in the Department of Electrical Engineering, the University of Toronto.

At the present, he is the Chairman of the Society of Spread-Spectrum Technology of the IEICE(Institute of Electronics, Information, Communications Engineers). He is currently an Editor of the IEEE Transactions on Communications, of the IEEE Transactions on Information Theory, and of the IEICE Transactions on Fundamentals of Electronics, Communications, and Computer Sciences. He also plays a role of a Director of IEICE Tokyo Chapter, a Director of the Soceity of Information Theory and its Applications, a Secretary of IEEE Communication Society, Asia Pacific Region (Region 10) Technical Committee etc. He was an editor of the IEICE Transactions on Communications (English Volume) for six years. He was the Chairman of the Technical Program Committee of 1992 IEEE International Symposium on Spread-Spectrum Techniques and Applications(ISSSTA'92), the Vice-Chairman of the Technical Program Committee of 1993 International Symposium on Personal Indoor and Mobile Radio Communications(PIMRC'93), an executive organizer of 1993 IEEE International Workshop on Information theory(ITW'93), the Co-chairman of 1996 IEEE International Workshop on Intelligent Signal Processing & Communication Systems and so on.

His current research interests lie in the areas of adaptive signal processing, coding theory, spread spectrum system, and their applications to various kinds of practical communication systems. He is a member of IEEE, EURASIP, IEICE, IEE of Japan, IPS of Japan. He wrote technical books entitled "Spread Spectrum Techniques and Applications", "Digital Signal Processing", "Data Communication Systems" and is currently writting the book entitled "Advanced Spread Spectrum Techniques and Applications" etc.



Sung-chul Kang Regular Member

Sung-chul Kang was born in Jeonlanamdo, KOREA on March 19 1955. He received B.E. degree in electronic engineering from Soongsil University in 1982 and the M.E. and Ph.D. degree in electronic engineering from Yonsei University in 1985 and 1997. respeetively. He has joined in the Minstry of Information and Communications in 1978 and He has joined as the Faculty of Yokohama National University in Japan from 1995. His current research interests lie in the areas of Spread Spectrum, especially Freguency Hopping/CDMA.