Multiple Access Interference Rejection Code: LS Code

Dong Wook Roh and Dong Ku Kim

Abstract: **A new code, LS code, was proposed for the IMT-2000 CDMA system. The code has special properties during a specific time interval: 1) perfect autocorrelation, and 2) perfect crosscorrelation. Perfect autocorrelation means maximum autocorrelation for zero time-offset and zero autocorrelation for all other times during a specific time interval. Moreover, perfect crosscorrelation means that the crosscorrelation has zero value during the time of interest. If you have zero crosscorrelation during a certain time, you can remove all the MAI within that time. However, the detailed properties of LS code and its exact generation method have been previously unknown. Therefore, we investigate the LS code in regards to its exact generating method, properties, and performances in this paper.**

Index Terms: **LS code, MAI, MAI rejection code, IFW (Interference Free Window).**

I. INTRODUCTION

In the conventional CDMA (Code Division Multiple Access) system, the MAI (Multiple Access Interference) depends on the crosscorrelation value with the time-offset. If you have zero crosscorrelation within the time interval of interest, you can remove all the MAI in that period. The code that removes the MAI during a certain interval can be called the MAI rejection code.

In 3GPP2 ($3^{\rm rd}$ Generation Partnership Project 2), the IMT-2000 system using one of the MAI rejection codes, the LS (Large Synchronization) code, was introduced. [1],[2] Some similar codes are already open to the public [3]–[5], however, the exact generation method and the detailed properties have been unknown until now. [6]–[8] We only get the code outputs of length 16, 32, 64, 128. [1] In this paper, we will describe the LS code in regards to its generating method, and properties and provide simulation results.

II. LS CODE GENERATION

A. Generation of LS code without IFW

A.1 LS code matrix; LS^N

LS code with length $N(=2^m)$ has the number of N codes ($m = 2,\ 3,\ 4,\ \cdots$). A LS code matrix where each row vector represents the LS code is defined as follows:

$$LS^N = \begin{bmatrix} C^N & S^N \\ C^N & -S^N \end{bmatrix} = \begin{bmatrix} LS_0^N \\ \vdots \\ LS_{N-1}^N \end{bmatrix}, \tag{1}$$

where LS^N is a $N \times N$ matrix, LS_k^N $(k = 0, \cdots, N-1)$ is a row vector expressing the k-th LS code. C^N and S^N are $\frac{N}{2} \times \frac{N}{2}$ sub-matrix constituting LS^N, S can be generated with C^N, and C^N will be defined recursively using $C^{\frac{N}{2}}$ in the later section.

A.2 C component; C^N

Since the minimum length of LS code is 4, the initial matrix for C component is C^4. Moreover, C^N can be generated recursively using $C^{\frac{N}{2}}$. To specify C^N, C^4 and $C^{\frac{N}{2}}$ are defined as follows:

$$C^4 = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix},\ C^{\frac{N}{2}} = \begin{bmatrix} C_1^{\frac{N}{2}} \\ C_2^{\frac{N}{2}} \\ \vdots \\ C_{\frac{N}{4}}^{\frac{N}{2}} \end{bmatrix}, \tag{2}$$

where $C^{\frac{N}{2}}$ is a $\frac{N}{4} \times \frac{N}{4}$ matrix, $C_i^{\frac{N}{2}}$ $(i = 1, 2, \cdots, \frac{N}{4})$ is a i-th row vector with length $1 \times \frac{N}{4}$. Sub-matrix C^N making up the LS code matrix is defined recursively using pre-defined $C^{\frac{N}{2}}$ and each row vector of C^N is given by the expression below.

$$C_i^N = \begin{cases} \begin{bmatrix} C_{2k+1}^{\frac{N}{2}} & C_{2k+2}^{\frac{N}{2}} \end{bmatrix}, & \text{where } i = 4k+1 \\ \begin{bmatrix} C_{2k+1}^{\frac{N}{2}} & -C_{2k+2}^{\frac{N}{2}} \end{bmatrix}, & \text{where } i = 4k+2 \\ \begin{bmatrix} C_{2k+2}^{\frac{N}{2}} & C_{2k+1}^{\frac{N}{2}} \end{bmatrix}, & \text{where } i = 4k+3 \\ \begin{bmatrix} C_{2k+2}^{\frac{N}{2}} & -C_{2k+1}^{\frac{N}{2}} \end{bmatrix}, & \text{where } i = 4k+4, \end{cases} \tag{3}$$

where $k = 0, 1, 2, \cdots, \frac{N}{8} - 1$ (i.e. $i = 1, 2, \cdots, \frac{N}{2}$)

A.3 S component; S^N

S^N can be created using pre-defined C^N and is given by (4)

$$C^N = \begin{bmatrix} C_1^N \\ C_2^N \\ \vdots \\ C_{\frac{N}{4}-1}^N \\ C_{\frac{N}{4}}^N \\ C_{\frac{N}{4}+1}^N \\ C_{\frac{N}{4}+2}^N \\ \vdots \\ C_{\frac{N}{2}-1}^N \\ C_{\frac{N}{2}}^N \end{bmatrix} \quad S^N = \begin{bmatrix} C_{\frac{N}{4}+1}^N \\ C_{\frac{N}{4}+2}^N \\ \vdots \\ C_{\frac{N}{2}-1}^N \\ C_{\frac{N}{2}}^N \\ C_1^N \\ C_2^N \\ \vdots \\ C_{\frac{N}{4}-1}^N \\ C_{\frac{N}{4}}^N \end{bmatrix}, \tag{4}$$

where C^N and S^N are $\frac{N}{2} \times \frac{N}{2}$ matrix.

Manuscript received August 17, 2001; approved for publication by Jong-Seon No, Division I Editor, May 9, 2002.

D. W. Roh and D. K. Kim are with Department of Electrical and Electronic Engineering Yonsei University, Seoul, Korea, e-mail: dwroh@lge.com and dkkim@yonsei.ac.kr.

1229-2370/03/$10.00 © 2003 KICS

Fig. 1. LS code structure without guard component.

Fig. 2. LS code structure with guard component.

B. Generation of LS code with IFW

In order to make an IFW(Interference Free Window), guard component with the value of zero should be inserted in both locations; at the end of S^N and between C^N and S^N. Owing to the guard component with the length L_{GUARD}(L_{GUARD} is a positive integer), the total LS code length has increased to the $N(=2^m)+2\times L_{GUARD}$. LS code matrix with the guard component is as shown below.

$$LS^{N+2\times L_{GUARD}} = \begin{bmatrix} C^N & 0^{L_{GUARD}} & S^N & 0^{L_{GUARD}} \\ C^N & 0^{L_{GUARD}} & -S^N & 0^{L_{GUARD}} \end{bmatrix} = \begin{bmatrix} LS_0^{N+2\times L_{GUARD}} \\ \vdots \\ LS_{N-1}^{N+2\times L_{GUARD}} \end{bmatrix}, \quad (5)$$

where $LS^{N+2\times L_{GUARD}}$ is a $N\times(N+2\times L_{GUARD})$ matrix, $LS_0^{N+2\times L_{GUARD}}$ $(k=0,\cdots,N-1)$ is a $1\times(N+2\times L_{GUARD})$ row vector expressing the k-th LS code. C^N and S^N are $\frac{N}{2}\times\frac{N}{2}$ sub-matrix defined in the generation of LS^N and $0^{L_{GUARD}}$ is a zero matrix with the dimension of $\frac{N}{2}\times L_{GUARD}$.

III. LS CODE PROPERTIES

A. Length of LS code

The length of LS code without the guard component is $2^m(m=2,3,4,\cdots)$ and the structure is shown in Fig. 1.

In order to get an IFW, the guard component should be inserted in both locations; at the end of the LS code without guard and between the C and S component. The resultant LS code length increases to the $N(=2^m)+2\times L_{GUARD}$ because of two guard component of length $2\times L_{GUARD}$(L_{GUARD} is an integer). The structure of LS code with the guard is given in Fig. 2.

B. Number of LS codes

The number of LS codes without IFW of length $N(=2^m)$ is N. Also, the number of LS codes with IFW of length $N(=2^m)+2\times L_{GUARD}$ is N.

C. Autocorrelation Property

The autocorrelation of LS code of length $N(=2^m)+2\times L_{GUARD}$ has the maximum $N(=2^m)$ when the time-offset is zero, and has zero value when the time-offset is in the interval $[-L_{GUARD}, L_{GUARD}]$ except 0.

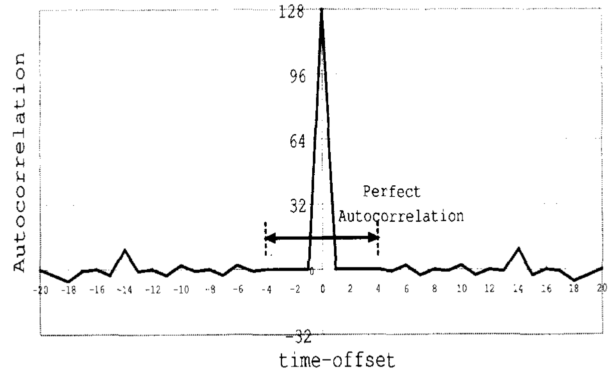


Fig. 3. Autocorrelation of $LS_0^{128+2\times 4}$.

To investigate precisely, the aperiodic autocorrelation of k-th LS code $LS_k^{N+2\times L_{GUARD}}$ is defined as follows:

$$A_k(\tau) = \begin{cases} \sum_{j=0}^{N+2\times L_{GUARD}-1-\tau} LS_k^{N+2\times L_{GUARD}}(j) \\ \quad \times LS_k^{N+2\times L_{GUARD}}(j+\tau), \\ \quad \text{where } 0\le\tau\le N+2\times L_{GUARD}-1 \\ \sum_{j=0}^{N+2\times L_{GUARD}-1+\tau} LS_k^{N+2\times L_{GUARD}}(j-\tau) \\ \quad \times LS_k^{N+2\times L_{GUARD}}(j), \\ \quad \text{where } -(N+2\times L_{GUARD}-1)\le\tau\le 0 \\ 0, \quad \text{otherwise,} \end{cases} \quad (6)$$

where $LS_k^{N+2\times L_{GUARD}}(j)$ is the j-th code value of k-th LS code, τ is the time-offset of autocorrelation. The autocorrelation property of LS code of length $N(=2^m)+2\times L_{GUARD}$ is summarized in (7) and (8).

1) When $L_{GUARD}=0$

$$A_k(\tau) = \begin{cases} N, & \tau=0 \\ \text{Not fixed}, & \text{otherwise.} \end{cases} \quad (7)$$

2) When $L_{GUARD}\ge 0$

$$A_k(\tau) = \begin{cases} N, & \tau=0 \\ 0, & 1\le|\tau|\le L_{GUARD} \\ \text{Not fixed}, & \text{otherwise.} \end{cases} \quad (8)$$

From the equations above, the autocorrelation property of LS code within the time-offset interval of $[-L_{GUARD}, L_{GUARD}]$ has a perfect characteristic. For instance, the LS code $LS_0^{128+2\times 4}$ of length $128+2\times 4$ has the autocorrelation property shown in Fig. 3.

D. Crosscorrelation Property

The aperiodic crosscorrelation between k-th LS code $LS_k^{N+2\times L_{GUARD}}$ and l-th LS code $LS_l^{N+2\times L_{GUARD}}$ of length is defined in (9).

$$C_{k,l}(\tau) = \begin{cases} \sum_{j=0}^{N+2\times L_{GUARD}-1-\tau} LS_k^{N+2\times L_{GUARD}}(j) \\ \qquad \times LS_l^{N+2\times L_{GUARD}}(j+\tau), \\ \quad \text{where } 0 \le \tau \le N+2\times L_{GUARD}-1 \\ \sum_{j=0}^{N+2\times L_{GUARD}-1+\tau} LS_k^{N+2\times L_{GUARD}}(j-\tau) \\ \qquad \times LS_l^{N+2\times L_{GUARD}}(j), \\ \quad \text{where } -(N+2\times L_{GUARD}-1) \le \tau \le 0 \\ 0, \quad \text{otherwise,} \end{cases} \tag{9}$$

where $LS_k^{N+2\times L_{GUARD}}(j)$ is the j-th code value of k-th LS code, and τ is the time-offset of crosscorrelation.

The number of LS codes of length $N(=2^m)+2\times L_{GUARD}$ is N. If you assign a whole number of LS codes to a set, then you can define the set as IRS (Interference Rejection Set) or interference free set denoted by l_0^N.

$$l_0^N = \{LS_0^{N+2\times L_{GUARD}}, LS_1^{N+2\times L_{GUARD}}, \cdots, LS_{N-1}^{N+2\times L_{GUARD}},\} \tag{10}$$

where l_0^N is the first set with N number of elements.

If you divide the IRS l_0^N into two parts, then you can get two IRSs with the 2^{m-1} elements: $l_0^{2^{m-1}}$,$l_1^{2^{m-1}}$. If you repeat the above method until the number of each set becomes 2^{m-g}, you can have a total of 2^g IRSs: $l_0^{2^{m-g}}, l_1^{2^{m-g}}, \cdots, l_{2^g-1}^{2^{m-g}}$. Each IRS is shown in (11).

$$\begin{aligned} l_0^{2^{m-g}} &= \{LS_0^{N+2\times L_{GUARD}}, LS_1^{N+2\times L_{GUARD}}, \cdots, \\ &\quad LS_{2^{m-g}-1}^{N+2\times L_{GUARD}}\} \\ l_1^{2^{m-g}} &= \{LS_{2^{m-g}}^{N+2\times L_{GUARD}}, LS_{2^{m-g}+1}^{N+2\times L_{GUARD}}, \cdots, \\ &\quad LS_{2^{m-g}+2^{m-g}-1}^{N+2\times L_{GUARD}}\} \\ l_2^{2^{m-g}} &= \{LS_{2\times 2^{m-g}}^{N+2\times L_{GUARD}}, LS_{2\times 2^{m-g}+1}^{N+2\times L_{GUARD}}, \cdots, \\ &\quad LS_{2\times 2^{m-g}+2^{m-g}-1}^{N+2\times L_{GUARD}}\} \\ &\vdots \\ l_k^{2^{m-g}} &= \{LS_{k\times 2^{m-g}}^{N+2\times L_{GUARD}}, LS_{k\times 2^{m-g}+1}^{N+2\times L_{GUARD}}, \cdots, \\ &\quad LS_{k\times 2^{m-g}+2^{m-g}-1}^{N+2\times L_{GUARD}}\} \\ &\vdots \\ l_{2^g-1}^{2^{m-g}} &= \{LS_{(2^g-1)\times 2^{m-g}}^{N+2\times L_{GUARD}}, LS_{(2^g-1)\times 2^{m-g}+1}^{N+2\times L_{GUARD}}, \cdots, \\ &\quad LS_{(2^g-1)\times 2^{m-g}+2^{m-g}-1}^{N+2\times L_{GUARD}}\}, \end{aligned} \tag{11}$$

where $l_k^{2^{m-g}}$ is k-th IRS with the 2^{m-g} elements. The crosscorrelation between two distinctive LS codes selected from one IRS $l_k^{2^{m-g}}$ $(k=0,1,2,\cdots,2^{m-g}-1)$ is given by (12).

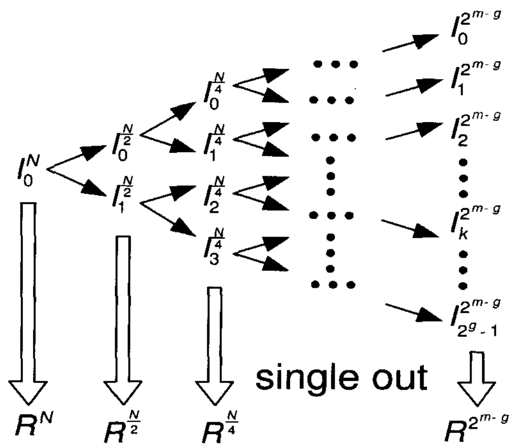


Fig. 4. Expansion of interference rejection set tree and selection of representative interference rejection set.

$$C(\tau) = \begin{cases} 0, & |\tau| \le L_{IFW} \\ & \text{where } L_{IFW} = \min(2^g-1, L_{GUARD}) \\ \text{Not fixed,} & \text{otherwise,} \end{cases} \tag{12}$$

where L_{IFW} is a constant that represents the time interval with zero crosscorrelation value, which is the minimum between the guard length L_{GUARD} and 2^g-1.

If you select two codes in one IRS, you can get a desired crosscorrelation property in (12). But if you choose the 1st code from one IRS and the 2nd code from another IRS, then you cannot have the above crosscorrelation characteristic. Therefore, you should choose only one IRS to keep the desired crosscorrelation property. The selected IRS $l_k^{2^{m-g}}$ from $l_0^{2^{m-g}}, l_1^{2^{m-g}}, l_2^{2^{m-g}}, \cdots, l_{2^g-1}^{2^{m-g}}$ can be defined as the representative interference rejection set: $R^{2^{m-g}}$. The representative IRS $R^{2^{m-g}}$ is given as follows:

$$R^{2^{m-g}} = \left\{r_0^{2^{m-g}}, r_1^{2^{m-g}}, \cdots, r_{2^{m-g}-1}^{2^{m-g}}\right\} \tag{13}$$

where $R^{2^{m-g}} = \left\{l_0^{2^{m-g}}, l_1^{2^{m-g}}, l_2^{2^{m-g}}, \cdots, \text{or } r_{2^g-1}^{2^{m-g}}\right\}$

The crosscorrelation between $r_k^{2^{m-g}}$ and $r_l^{2^{m-g}}$ $(k = 0,1,2,\cdots,2^{m-g}-1)$ in the set is shown in (14).

$$C_{k,l}(\tau) = \begin{cases} 0, & |\tau| \le L_{IFW} \\ & \text{where } L_{IFW} = \min(2^g-1, L_{GUARD}) \\ \text{Not fixed,} & \text{otherwise,} \end{cases} \tag{14}$$

where L_{IFW} is a constant that represents the time interval with the zero crosscorrelation value, which is the minimum between the guard length L_{GUARD} and 2^g-1.

From equations above, the crosscorrelation property of LS code within the time-offset interval of $[-L_{IFW}, L_{IFW}]$ has a perfect characteristic.

The relationship of IRS to representative IRS is shown in Fig. 4.

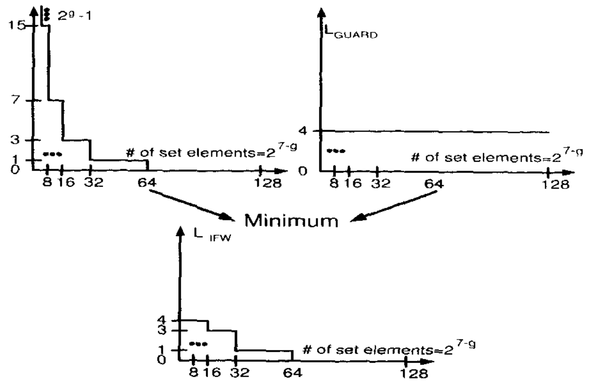


Fig. 5. Determination of L_{IFW}.

For example, the LS code with the length $128 + 2 \times 4$ has the crosscorrelation property shown in Fig. 5. As shown in Fig. 5, you can determine the time interval with zero crosscorrelation value by selecting the minimum between $2^g - 1$ and L_{GUARD}. In Fig. 5, the x-axis represents the number of elements in the selected set, which is $128/2^g (= 2^{7-g})$. The y-axis of the upper-left graph in Fig. 5 is $2^g - 1$, that of the upper-right graph means L_{GUARD}, and that of the lower graph stands for L_{IFW} which is the minimum value between $2^g - 1$ and L_{GUARD}.

If you select 32 LS codes from the example above, which the representative IRS is $R^{2^{7-2}} = l_0^{2^{7-2}}$ given by (15), you can get the crosscorrelation between $LS_0^{128+2\times4}$ and $LS_1^{128+2\times4}, \cdots, LS_{31}^{128+2\times4}$. The crosscorrelation is shown in Fig. 5. Let me take another example. When you choose shown in (16) as a representative IRS, you can obtain the crosscorrelation between $LS_0^{128+2\times4}$ and $LS_1^{128+2\times4}, \cdots, LS_{15}^{128+2\times4}$ as illustrated in Fig. 7. As compared with that of Fig. 6, the IFW length in Fig. 7 increases from [-3,3] to [-4,4], while the number of available LS codes decreases from 32 to 16.

$$R^{2^{7-2}} = l_0^{2^{7-2}} = \{LS_0^{128+2\times4}, LS_1^{128+2\times4}, \cdots, LS_{31}^{128+2\times4}\}, \quad (15)$$

$$R^{2^{7-3}} = l_0^{2^{7-3}} = \{LS_0^{128+2\times4}, LS_1^{128+2\times4}, \cdots, LS_{15}^{128+2\times4}\}. \quad (16)$$

E. Orthogonality

The number of orthogonal codes of length $N (= 2^m)$ is N.

The number of orthogonal codes of length $N (= 2^m) + 2 \times L_{GUARD}$ is N as well.

F. Interference Rejection Property

Interference rejection property is based on the crosscorrelation property. The IFW (Interference Free Window) is defined as the time interval $[-L_{IFW}, L_{IFW}]$ with zero crosscorrelation value. In the conventional CDMA system, the MAI (Multiple Access Interference) value depends on the crosscorrelation value with the time-offset. If you have zero crosscorrelation within the time interval of interest, you can remove all the MAI within that period. Here, the IFW means the time interval where the MAI can be removed.

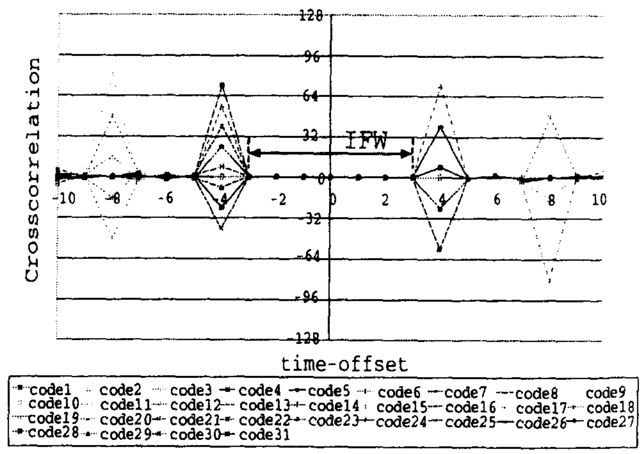


Fig. 6. Crosscorrelation between $LS_0^{128+2\times4}$ and $LS_1^{128+2\times4}, \cdots, LS_{31}^{128+2\times4}$.

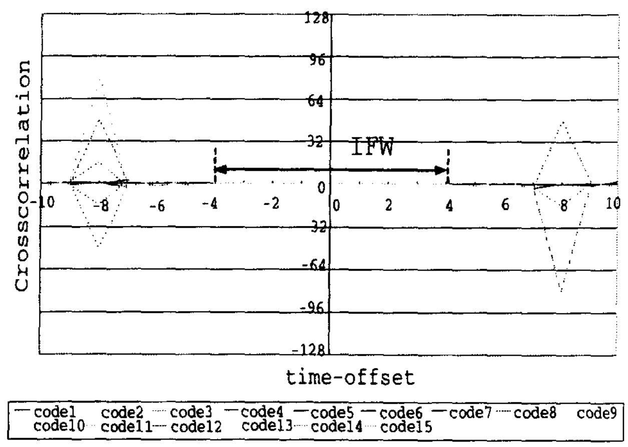


Fig. 7. Crosscorrelation between $LS_0^{128+2\times4}$ and $LS_1^{128+2\times4}, \cdots, LS_{15}^{128+2\times4}$.

Since the IFW is inversely proportional to the number of elements in the representative IRS and is confined by the guard length, you should decrease the number of available codes and increase the length of the guard component in order to lengthen the IFW

IV. SIMULATION

The CDMA systems with LS code and conventional Walsh code for spreading code are compared, using simulation under the multi-path channel environments. The system model parameters and channel model parameters used for the link level simulation are listed below in Table 1 and 2 respectively. The detailed channel model parameters are based on the ITU-R M.1225. [9] The uncoded BER result for the Pedestrian B channel and Vehicular B channel are illustrated in Fig. 8 and Fig. 9 respectively. The x axis of the Fig. 8 and 9 represents EbNo, the y axis stands for uncoded BER.

In Fig. 8, the simulation is performed under the pedestrian B channel. Fig. 8 shows that the performances using LS code with guard interval 4 and 14 are superior to that of Walsh code. At the uncoded BER of 10^{-2}, the gain is about 2.5dB. Since the chip

Table 1. System models for simulation.

	System using LS code	System using Walsh code
Spreading code	LS code	Walsh code
Spreading factor	128	128
Guard inerval(L_{GUARD})	4 or 14	None
IFWL_{GUARD}	4 or 14	None
Spreading	Complex spreading	
Modulation	QPSK modulation	
Channel estimation	Ideal channel estimation	
Channel power control	No	
Chip rate	3.6864Mcps	

Table 2. Channel environments for simulation.

	Pedestrian B	Vehicular B
Mobile speed	3 km/h	50 km/h
Channel modeling	based on the ITU-R M.1225	
Carrier frequency	2GHz	

rate is 3.6864 Mcps, the maximum delay of Pedestrian B channel is approximately 14 chips long. Therefore, the LS code with guard interval 4 cannot eliminate all the interference caused by the multi-path environment, while the LS code with guard interval 14 is able to get rid of all the interference. The LS code with guard interval 4 supports the IFW length 4 so that the maximum delay of Pedestrian B channel is out of the IFW length. However, the performance curves of LS code with guard interval 4 and LS code with guard interval 14 overlap each other in Fig 8. The performance with guard interval 14 is slightly better than that of guard interval 4, but the gain is negligible. That is because most of the power in the resolvable multi-paths is concentrated onto the paths whose delays are within the IFW length 4. In Pedestrian B channel, about 87% of power is concentrated within the delay length 4.

Fig. 9 depicts the uncoded BER performance under Vehicular B channel. The system using LS code with guard interval 4 shows advantage over that of Walsh code. At the uncoded BER of 10^{-2}, the gain is about 1.6dB.

Simulation results show that the LS code with guard interval 4 could support the gains for both Pedestrian B and Vehicular B channel environments even if the IFW length is not larger than the maximum multi-path delay length. That is because most of power is concentrated on the paths with small delay. The performance of LS code is largely dependent on the paths with dominant powers. Once most of the power in the multi-paths lies within the designed IFW, the performance gain can be achieved. Therefore, both maximum delay spread and power profiles should be considered carefully when selecting the IFW length.

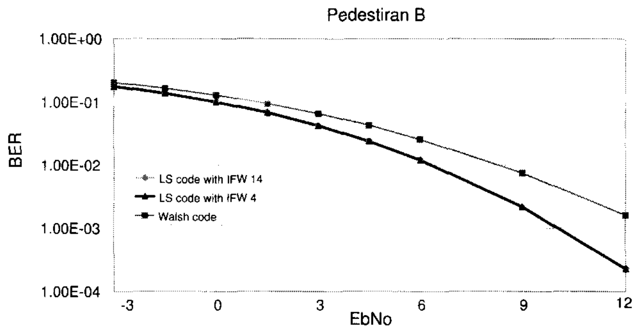


Fig. 8. Uncoded BER performance under Pedestrian B channel.

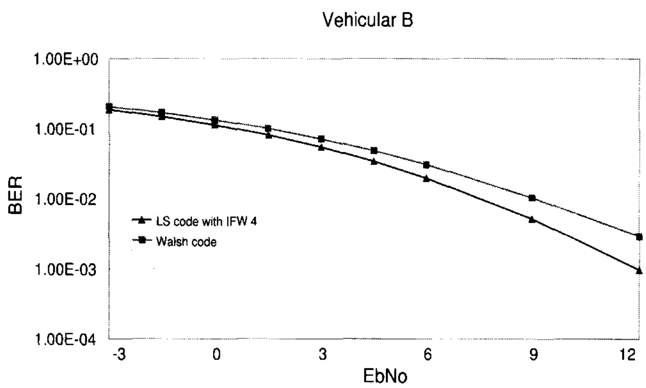


Fig. 9. Uncoded BER performance under Vehicular B channel.

V. CONCLUSION

In this paper, we've investigated the LS code in regards to its exact generation method and properties, and performances using simulations.

LS code is one of the MAI rejection codes and has special properties during a specific time interval i.e., IFW: 1) perfect autocorrelation, and 2) perfect crosscorrelation. Perfect autocorrelation means maximum autocorrelation for zero time-offset and zero autocorrelation for other times during IFW. Moreover, perfect crosscorrelation means that crosscorrelation is zero during IFW. If you have zero crosscorrelation during IFW, all the MAI within IFW can be removed. However, there is a trade-off between IFW length and the available number of LS codes. Since the IFW is inversely proportional to the number of elements in the representative IRS and is confined by the guard length, you should decrease the number of available codes and increase the length of the guard component in order to lengthen the IFW.

The performance of LS code is largely dependent on the paths with dominant powers. Once most of the power in the multi-paths is concentrated within the designed IFW length, the performance gain can be achieved. Therefore, both maximum delay spread and power profiles should be considered carefully when selecting the IFW length according to the channel in which the designed system is used.

REFERENCES

[1] C00-LAS-20000713-003 Hawaii-Phys Layer (Draft 2.1 - 7-11-00), 3GPP2 Contribution, July. 2000.

[2] D. Li, "A high spectrum efficient multiple access code," *APCC/OECC'99*, 1999.

[3] P. Z. Fan and L. Hao, "Generalized orthogonal sequences and their applications in synchronous CDMA systems," *IEICE Trans. Fundamentals*, vol. E83-A, no. 11, pp. 1–16, Nov. 2000.

[4] P. Z. Fan, N. Suehiro, N. Kuroyanagi, and X. M. Deng, "A class of binary sequences with zero correlation zone," *IEE Electron. Lett.*, vol. 35, no. 10, pp. 777–779, 1999.

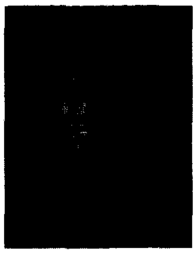
[5] X. H. Tang and P. Z. Fan, "Bounds on aperiodic and odd correlations of spreading sequences with low and zero correlation zone,"*Electron. Lett.*, vol. 37, no. 19, pp. 1201–1203, Sept. 2001.

[6] D. W. Roh, "Multiple access interference rejection code: LS code," *JCCI(Joint Conf. Commun. Inform.) 2001*, Korea, 2001.

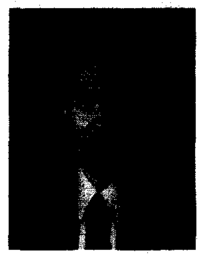
[7] D. W. Roh, "LS code pair setting and sequential allocation methods," *IEEK Conf. Summer 2001*, Korea, 2001.

[8] D. W. Roh, "Multiple access interference reduction code: quasi-LS code," *KICS Conf. Summer 2001*, Korea, 2001.

[9] ITU, Recommendation ITU-R M.1225, Guidelines for evaluation of radio transmission technologies for IMT-2000.



Dong Wook Roh received the B. Eng. and M. Eng. degrees from Yonsei University in 1998 and 2000, respectively. Since joining LG Electronics in 2000, he has been working in the field of standardization of third generation CDMA system. He is currently pursuing the Ph.D degree at the Yonsei University. His current research interest includes adaptive modulation and coding, OFDM and MIMO.



Dong-Ku Kim received B. Eng. degree from Hankook Aviation University in Korea on 1983 and M. Eng and Ph.D. degrees from University of Southern California in 1985 and 1992 respectively. He has been a research engineer of Cellular Infrastructure Group, Motorola for two year since 1992. Since 1994, he has been with the Electrical and Electronic Engineering Department, Yonsei University in Seoul, where he is currently an Associate Professor. His main research interests are MIMO, scheduling schemes for EVDV, wireless LAN MAC, and CDMA technologies. He has been a director of QUALCOMM Yonsei CDMA Research Lab and deputy director of Radio Communication Research Center in Yonsei University. He is currently chief editor for transaction on telecommunication of Korea Institute of Electronic Engineers.