Frame Synchronization Confirmation Technique Using Pilot Pattern

Young-Joon Song

Abstract: **A new frame synchronization confirmation technique using a pilot pattern for both uplink and downlink channels is proposed for W-CDMA (Wideband Code Division Multiple Access) system. It is shown that by using this technique, we can cancel the side lobe for autocorrelation functions of the frame synchronization words of pilot pattern except at middle shift. All the frame synchronization words of the pilot pattern have the maximum out-of-phase autocorrelation value "4" with two peak values equal in magnitude and opposite in polarity at zero and middle shifts. Due to this side lobe cancellation effect, therefore, the autocorrelation function of the frame synchronization words becomes ideal for the frame synchronization confirmation since double maximum correlation values equal in magnitude and opposite polarity at zero and middle shifts can be achieved. This property can be used to double-check frame synchronization timing and thus, improve the frame synchronization confirmation performance.**

Index Terms: **W-CDMA, pilot pattern, frame synchronization confirmation, side lobe, autocorrelation function.**

I. INTRODUCTION

Recently, ARIB (Association for Radio Industry and Business) in Japan, ETSI (European Telecommunications Standards Institute) in Europe, T1 in U.S.A., and TTA (Telecommunication Technology Association) in Korea have mapped out a third generation mobile communication system based on a core network and radio access technique of an existing global system for mobile communications (GSM) to provide various types of services including audio, video and data services. They have agreed on a partnership study for the presentation of a technical specification on the evolved next generation mobile communication system and named a project for the partnership study as a third generation partnership project (3GPP).

The 3GPP is classified into three part technical studies. The first part is a 3GPP system structure and service capability based on the 3GPP specification. The second part is a study of a universal terrestrial radio access network (UTRAN), which is a radio access network (RAN) applying wideband CDMA (Code Division Multiple Access) technique based on a frequency division duplex (FDD) mode, and a TD-CDMA technique based on a time division duplex (TDD) mode. The third part is a study of a core network evolved from a second generation GSM, which has third generation networking capabilities, such as mobility management and global roaming.

This paper proposes a frame synchronization confirmation technique for 3GPP system using frame synchronization words of pilot patterns. The UE (User Equipment) establishes downlink chip synchronization and frame synchronization based on the P-CCPCH (Primary Common Control Physical Channel) synchronization timing, the frame offset group, and slot offset group notified from the network [1]. The frame synchronization shall be confirmed using the frame synchronization word [2]. The network establishes uplink channel chip synchronization and frame synchronization based on the frame offset group and slot offset group [1]. The frame synchronization shall also be confirmed using the frame synchronization word [2]. The frame synchronization word of the pilot pattern can detect synchronization status, which can be used in RRC (Radio Resource Control) connection establishment and release procedures of Layer 2 [3].

It is shown that we can obtain a side lobe cancellation effect except at middle shift by applying the proposed technique for autocorrelation functions of the pilot pattern in W-CDMA system. This property can be used to double-check frame synchronization timing and subsequently, improve the frame synchronization confirmation performance. The frame synchronization confirmation is performed in downlink DPCH (Dedicated Physical Channel), S-CCPCH (Secondary Common Control Physical Channel), and uplink DPCH. Since the principle of frame synchronization confirmation is the same for such channels, this paper shows the performance of frame synchronization confirmation only for downlink DPCH over AWGN (Additive White Gaussian Noise) channel.

This paper is organized as follows. Section II gives some definitions and basic properties of binary sequences. Section III describes a sequence generation method for frame synchronization. Frame structure and modulation for downlink channel is depicted in Section IV, and frame synchronization words and its side lobe cancellation effect is described in Section V. Section VI presents the performance evaluation of frame synchronization confirmation using the computer simulation in the downlink DPCH over AWGN channel. Finally, Section VII concludes the study for frame synchronization confirmation in W-CDMA system.

II. DEFINITIONS AND BASIC PROPERTIES

Let $\mathbf{S} = (s_i) = (s_0, s_1, \cdots, s_{n-1})$ be an n-tuple binary sequence over $\mathrm{GF}(2) = \{0, 1\}$ and T denote a cyclic shift left operator such that $T\mathbf{S} = (s_1, s_2, \cdots, s_0)$. If T is applied i times

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Y.-J. Song is with Advanced Telecomm. Research Lab., LG Information & Communications, Ltd., LG R&D Complex, 533 Hogye-dong, Dongan-gu, Anyang, 431-080 Kyongki, Korea, e-mail: youngjsong@lgic.co.kr.

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to $\mathbf{S}$, the result is $T^i\mathbf{S} = (s_i, s_{i+1}, \cdots, s_{i-1})$, where i is any integer. For two integers i and j, $T^i\mathbf{S} = T^j\mathbf{S}$ if $i \equiv j \pmod n$ [4].

The periodic autocorrelation function is defined by [4], [5]

$$R_s(\tau) = \sum_{i=0}^{n-1} \chi(s_i) \cdot \chi(s_{(i+\tau)(\text{mod } n)}), \tag{1}$$

where $\chi(\cdot)$ is the unique isomorphism of the addition group $\{0, 1\}$ onto the multiplication group $\{-1, 1\}$. We call $R_s(0)$ the "in-phase autocorrelation value" and $R_s(\tau)$'s ($\tau \neq 0$) the "out-of-phase autocorrelation values [6]." If the autocorrelation function of a sequence is given by

$$R_s(\tau) = \begin{cases} n, & \tau = 0 \\ -n, & \tau = n/2 \\ 0, & \text{elsewhere} \end{cases}, \tag{2}$$

then the sequence is said to have an "ideal frame synchronization property" since we can double-check frame synchronization with minimum false alarm probability.

Now let $\mathbf{S}_1 = (s_{1,i})$ and $\mathbf{S}_2 = (s_{2,i})$ be n-tuple binary sequences over GF(2). The two sequences are similarly expressed as $\mathbf{S}_1 = (s_{1,0}, s_{1,1}, \cdots, s_{1,n-1})$ and $\mathbf{S}_2 = (s_{2,0}, s_{2,1}, \cdots, s_{2,n-1})$. Two sequences $\mathbf{S}_1$ and $\mathbf{S}_2$ are said to be "cyclically equivalent" if there exists an integer j such that $\mathbf{S}_1 = T^j\mathbf{S}_2$. Otherwise, they are said to be "cyclically distinct [6]." Then the periodic crosscorrelation function between the two sequences is defined as

$$R_{1,2}(\tau) = \sum_{i=0}^{n-1} \chi(s_{1,i}) \cdot \chi(s_{2,(i+\tau)(\text{mod } n)}). \tag{3}$$

We note that $R_{1,2}(\tau)$ is simply expressed as the number of agreements minus the number of disagreements of the sequences $\mathbf{S}_1$ and $\mathbf{S}_2$ for each τ and is given by [5]

$$\begin{aligned} &R_{1,2}(\tau) \\ &\quad = (\text{number of agreements}) - (\text{number of disagreements}) \\ &\quad = n - 2\,||\mathbf{S}_1 + T^\tau \mathbf{S}_2||, \end{aligned} \tag{4}$$

where $||\mathbf{S}||$ is the number of ones in the n-tuple binary sequence $\mathbf{S}$. The periodic autocorrelation function of sequence S is $n - 2\,||\mathbf{S} + T^\tau\mathbf{S}||$ and the number of disagreements between the sequence $\mathbf{S}$ and its shifted replica $T^\tau\mathbf{S}$ is $||\mathbf{S} + T^\tau\mathbf{S}|| = 2K$, where non-negative integer K is given by

$$\begin{aligned} K = &\,||\mathbf{S}|| \\ &- (\text{number of concident ones between } \mathbf{S} \text{ and } T^\tau\mathbf{S}). \end{aligned} \tag{5}$$

Then the autocorrelation function becomes [7]

$$R_s(\tau) = n - 4 \cdot K. \tag{6}$$

III. IDEAL FRAME SYNCHRONIZATION SEQUENCE GENERATION

In this section, a general method to find frame synchronization words for 3GPP system based on one ideal frame synchronization sequence is proposed. The side lobe cancellation effect except at middle shift plays a central role in the sequence design. The following lemmas will be very useful for the sequence design as well as frame synchronization confirmation technique.

Lemma 1: Let $\mathbf{A} = (a_i)$ be a sequence of even period. Furthermore, let $\mathbf{S}_1 = (s_{1,i})$ and $\mathbf{S}_2 = (s_{2,i})$ be sequences obtained by decimating $\mathbf{A}$ and $T\mathbf{A}$ by 2,respectively. Then we have

$$R_a(2\tau) = R_1(\tau) + R_2(\tau), \tag{7}$$

$$R_a(2\tau+1) = R_{1,2}(\tau) + R_{2,1}(\tau+1), \tag{8}$$

where $R_1(\tau)$ and $R_2(\tau)$ are the autocorrelation functions of sequence $\mathbf{S}_1$ and $\mathbf{S}_2$, respectively.

Proof: Since two sequences $\mathbf{S}_1 = (s_{1,i})$ and $\mathbf{S}_2 = (s_{2,i})$ are obtained by decimating $\mathbf{A}$ and $T\mathbf{A}$ by 2 and the even period of sequence $\mathbf{A}$ can be given by $N = 2n$, we can easily find that

$$s_{1,z(\text{mod } n)} = a_{2z(\text{mod } N)}, \tag{9}$$

$$s_{2,z(\text{mod } n)} = a_{(2z+1)(\text{mod } N)}, \tag{10}$$

where z is an integer. Hence the autocorrelation functions of the sequences become

$$\begin{aligned} R_1(\tau) &= \sum_{z=0}^{n-1} \chi(s_{1,z}) \cdot \chi(s_{1,(z+\tau)(\text{mod } n)}) \\ &= \sum_{z=0}^{n-1} \chi(a_{2z}) \cdot \chi(a_{2(z+\tau)(\text{mod } N)}), \end{aligned} \tag{11}$$

$$\begin{aligned} R_2(\tau) &= \sum_{z=0}^{n-1} \chi(s_{2,z}) \cdot \chi(s_{2,(z+\tau)(\text{mod } n)}) \\ &= \sum_{z=0}^{n-1} \chi(a_{(2z+1)}) \cdot \chi(a_{(2z+1+2\tau)(\text{mod } N)}), \end{aligned} \tag{12}$$

$$\begin{aligned} R_1(\tau) + R_2(\tau) &= \sum_{z=0}^{n-1} \big[\chi(a_{2z}) \cdot \chi(a_{(2z+2\tau)(\text{mod } N)}) \\ &\quad + \chi(a_{2z+1}) \cdot \chi(a_{(2z+1+2\tau)(\text{mod } N)})\big] \\ &= \sum_{i=0}^{N-1} \chi(a_i) \cdot \chi(a_{(i+2\tau)(\text{mod } N)}) \\ &= R_a(2\tau). \end{aligned} \tag{13}$$

By the definition of the crosscorrelation function, we also obtain

$$\begin{aligned} R_{1,2}(\tau) &= \sum_{z=0}^{n-1} \chi(s_{1,z}) \cdot \chi(s_{2,(z+\tau)(\text{mod } n)}) \\ &= \sum_{z=0}^{n-1} \chi(a_{2z}) \cdot \chi(a_{(2z+2\tau+1)(\text{mod } N)}), \end{aligned} \tag{14}$$

$$\begin{aligned} R_{2,1}(\tau+1) &= \sum_{z=0}^{n-1} \chi(s_{2,z}) \cdot \chi(s_{1,(z+\tau+1)(\text{mod } n)}) \\ &= \sum_{z=0}^{n-1} \chi(a_{(2z+1)}) \cdot \chi(a_{(2z+1+2\tau+1)(\text{mod } N)}), \end{aligned} \tag{15}$$

$$R_{1,2}(\tau) + R_{2,1}(\tau+1) = \sum_{i=0}^{N-1} \chi(a_i) \cdot \chi(a_{(i+2\tau+1)(\mathrm{mod}\ N)}) = R_a(2\tau+1). \quad (16)$$

□

Lemma 1 explains the method to obtain autocorrelation function for a sequence of even period from its two decimated sequences. This property can be used for generating the binary sequences with optimal frame synchronization property. Now let $\mathbf{A} = (a_i)$ be a sequence of $N = 2 \cdot n$ made out from two n-tuple binary sequences of $\mathbf{S}_1 = (s_{1,i})$ and $\mathbf{S}_2 = (s_{2,i})$ using $s_{1,z(\mathrm{mod}\ n)} = a_{2z(\mathrm{mod}\ N)}$ and $s_{2,z(\mathrm{mod}\ n)} = a_{(2z+1)(\mathrm{mod}\ N)}$, where z is an integer. If $s_{1,i} = s'_{1,(i+n/2)(\mathrm{mod}\ n)}$ and $s_{2,i} = s'_{2,(i+n/2)(\mathrm{mod}\ n)}$, then $a_i = a'_{(i+n)(\mathrm{mod}\ N)}$, where $a'_i \equiv (a_i + 1)(\mathrm{mod}\ 2)$.

Lemma 2: Let $\mathbf{A} = (a_i)$ be a sequence of length $N = 2 \cdot n$ over GF(2) with $a_i = a'_{(i+n)(\mathrm{mod}\ N)}$. Then we have

$$R_a(\tau) = -R_a(\tau+n), \quad \text{for all } \tau. \quad (17)$$

The proof of Lemma 2 is not shown here because it can be easily obtained from the definition of autocorrelation function.

If $s_i = s'_{(i+n/2)(\mathrm{mod}\ n)}$ holds for an n-tuple binary sequence $\mathbf{S} = (s_i)$, then the autocorrelation function of the sequence has two maximum values equal in magnitude and opposite in polarity at zero and middle shifts. Further, if such a sequence has zero out-of-phase coefficient, then the sequence has the ideal frame synchronization property.

The sequence $\mathbf{S} = (0,0,1,1)$ is only one cyclic distinct sequence with ideal frame synchronization property and its autocorrelation function is

$$R(\tau) = \begin{cases} 4, & \tau = 0 \\ -4, & \tau = 2 \\ 0, & \text{elsewhere} \end{cases}. \quad (18)$$

Two sequences $\mathbf{S}_1$ and $\mathbf{S}_2$ with the same period n are called "almost complementary set" if their corresponding autocorrelation functions have the complementary property except at zero and middle time shifts, that is, $R_1(\tau) + R_2(\tau) = 0,\ \tau \neq 0,\ n/2$. Furthermore, if two autocorrelation functions have two maximum values equal in magnitude and opposite in polarity at zero and middle shifts, then summing such two autocorrelation functions induces the following ideal frame synchronization property:

$$R_1(\tau) + R_2(\tau) = \begin{cases} 2n, & \tau = 0 \\ -2n, & \tau = n/2 \\ 0, & \text{elsewhere} \end{cases}. \quad (19)$$

This property will be very useful for designing the frame synchronization words of 3GPP system because it gives us the ideal frame synchronization property.

Henceforth, based on almost complementary set of sequences, we discuss a general method to find another almost complementary set of sequences whose out-of-phase autocorrelation value at middle shift is equal to in-phase autocorrelation value with opposite polarity. If $\mathbf{S}_2$ is the cyclic shifted version of the ideal frame synchronization sequence $\mathbf{S}_1 = (0,0,1,1)$, then two sequences constitute the almost complementary set and the addition of two autocorrelation functions shows the ideal frame synchronization property.

Table 1. Autocorrelation functions of almost complementary set of period 8.

Sequence \ Delay	0	1	2	3	4	5	6	7
(0,0,0,0,1,1,1,1)	8	4	0	-4	-8	-4	0	4
(0,1,0,0,1,0,1,1)	8	-4	0	4	-8	4	0	-4

Let $\mathbf{S}_1 = (0,0,1,1)$ and $\mathbf{S}_2 = T^j \mathbf{S}_1,\ 0 \le j \le 3$, and construct the sequence $\mathbf{A} = (a_i)$ of period $N = 2 \cdot n = 8$ using $s_{1,z(\mathrm{mod}\ n)} = a_{2z(\mathrm{mod}\ N)}$ and $s_{2,z(\mathrm{mod}\ n)} = a_{(2z+1)(\mathrm{mod}\ N)}$. Then by (7), the autocorrelation function of the sequence $\mathbf{A}$ has two maximum values equal in magnitude and opposite in polarity at zero and middle shifts with zero out-of-phase coefficient for every even time shifts except at middle shift. The autocorrelation value of the sequence $\mathbf{A}$ at odd time shift can be obtained by (8). In more detail, if we set $\mathbf{S}_2 = T^3 \mathbf{S}_1 = (1,0,0,1)$, then $R_{1,2}(0) = 0,\ R_{2,1}(1) = 4,\ R_{1,2}(1) = -4,\ R_{2,1}(2) = 0,\ \mathbf{A} = (0,1,0,0,1,0,1,1)$, and thus we find that

$$\begin{aligned} R_a(0) &= 2R_1(0) = 8, \\ R_a(1) &= R_{1,2}(0) + R_{2,1}(1) = 4, \\ R_a(2) &= 2R_1(1) = 0, \\ R_a(3) &= R_{1,2}(1) + R_{2,1}(2) = -4. \end{aligned}$$

By Lemma 2, $R_a(i),\ 4 \le i \le 7$, can be easily given by $R_a(i) = -R_a(i+4)$ since $a_i = a'_{(i+4)(\mathrm{mod}\ 8)}$. Similarly, if we select $\mathbf{S}_1 = \mathbf{S}_2 = (0,0,1,1)$, then $\mathbf{A} = (0,0,0,0,1,1,1,1)$. Two autocorrelation functions of sequences $(0,1,0,0,1,0,1,1)$ and $(0,0,0,0,1,1,1,1)$ are described in Table 1 and we see that two sequences constitute the almost complementary set. Thus by adding two autocorrelation functions, we obtain the ideal frame synchronization property.

Now we see that there is a generalized algorithm to find the sequences whose out-of-phase coefficient at even time shifts is zero except for middle shift and maximum out-of-phase coefficient values at odd time shifts is a multiple of four. Since minimizing the maximum out-of-phase coefficient is very important in the sequence design, choosing the sequences whose maximum out-of-phase coefficient is four is desired. The following algorithm is used to find such sequences.

Step 1 – Choose an almost complementary sequence set $(\mathbf{S}_1, \mathbf{S}_2)$ of period n.

Step 2 – Construct $\mathbf{A} = (a_i)$ of period $N = 2n$ by $a_{2z(\mathrm{mod}\ N)} = s_{1,z(\mathrm{mod}\ n)}$ and $a_{(2z+1)(\mathrm{mod}\ N)} = s_{2,z(\mathrm{mod}\ n)}$.

Step 3 – Select the sequence $\mathbf{A} = (a_i)$ if the maximum out-of-phase coefficient at odd time shifts is four. Otherwise, go to step 1.

Steps 1 and 2 are related to finding sequences whose out-of-phase coefficient at even time shifts is zero except for middle shift and maximum out-of-phase coefficient values at odd time shifts is a multiple of four. Step 3 is used to discard sequences whose maximum out-out-phase coefficient is greater than four.

Table 2. Almost complementary sets of sequences of period 8, 16, and 32.

Sequence	Class	Period
0 0 0 0 1 1 1 1	C	8
0 1 0 0 1 0 1 1	D	8
1 1 0 1 1 1 1 1 0 0 1 0 0 0 0 0	E	16
1 0 1 1 0 0 0 0 0 1 0 0 1 1 1 1	E	16
1 0 0 0 1 0 1 0 0 1 1 1 0 1 0 1	F	16
1 1 1 0 0 1 0 1 0 0 0 1 1 0 1 0	F	16
1 1 0 1 1 1 0 0 0 0 1 0 0 0 1 1	G	16
0 1 0 0 0 0 1 1 1 0 1 1 1 1 0 0	G	16
0 1 1 1 0 1 1 0 1 0 0 0 1 0 0 1	H	16
1 1 1 0 1 0 0 1 0 0 0 1 0 1 1 0	H	16
0 0 0 1 1 0 0 1 0 1 0 0 0 0 0 0 1 1 1 0 0 1 1 0 1 0 1 1 1 1 1 1	I	32
0 1 0 1 1 0 0 1 1 1 0 0 0 0 0 0 1 0 1 0 0 1 1 0 0 0 1 1 1 1 1 1	I	32
0 0 1 1 0 1 1 0 1 0 1 0 0 0 0 0 1 1 0 0 1 0 0 1 0 1 0 1 1 1 1 1	J	32
0 1 0 1 0 0 1 0 0 1 1 0 0 0 0 0 1 0 1 0 1 1 0 1 1 0 0 1 1 1 1 1	J	32
0 0 0 1 0 1 0 0 1 1 0 0 0 0 0 0 1 1 1 0 1 0 1 1 0 0 1 1 1 1 1 1	K	32
0 0 1 1 0 1 0 1 1 1 0 0 0 0 0 0 1 1 0 0 1 0 1 0 0 0 1 1 1 1 1 1	K	32
0 0 1 1 0 1 0 1 0 0 1 0 0 0 0 0 1 1 0 0 1 0 1 0 1 1 0 1 1 1 1 1	L	32
0 1 1 0 1 0 1 0 0 1 1 0 0 0 0 0 1 0 0 1 0 1 0 1 1 0 0 1 1 1 1 1	L	32
0 0 1 0 1 0 0 0 1 1 0 0 0 0 0 0 1 1 0 1 0 1 1 1 0 0 1 1 1 1 1 1	M	32
0 0 1 1 1 0 1 0 1 1 0 0 0 0 0 0 1 1 0 0 0 1 0 1 0 0 1 1 1 1 1 1	M	32
0 0 1 0 1 0 1 1 0 0 1 0 0 0 0 0 1 1 0 1 0 1 0 0 1 1 0 1 1 1 1 1	N	32
0 1 1 0 0 1 0 1 0 1 1 0 0 0 0 0 1 0 0 1 1 0 1 0 1 0 0 1 1 1 1 1	N	32
0 0 0 0 1 0 0 1 0 0 0 1 0 0 0 0 1 1 1 1 0 1 1 0 1 1 1 0 1 1 1 1	O	32
0 0 0 0 1 0 0 0 1 0 0 1 0 0 0 0 1 1 1 1 0 1 1 1 0 1 1 0 1 1 1 1	O	32
0 0 0 1 0 1 1 0 1 0 0 0 1 0 0 0 1 1 1 0 1 0 0 1 0 1 1 1 0 1 1 1	P	32
0 1 0 0 1 0 1 1 1 0 0 0 1 0 0 0 1 0 1 1 0 1 0 0 0 1 1 1 0 1 1 1	P	32

Table 3. Classification of autocorrelation functions.

Class	Autocorrelation function, $R(\tau)$, $0 \leq \tau < n/2$															
C	8	4	0	-4												
D	8	-4	0	4												
E	16	4	0	4	0	-4	0	-4								
F	16	-4	0	-4	0	4	0	4								
G	16	4	0	-4	0	4	0	-4								
H	16	-4	0	4	0	-4	0	4								
I	32	4	0	-4	0	4	0	-4	0	4	0	-4	0	4	0	-4
J	32	-4	0	4	0	-4	0	4	0	-4	0	4	0	-4	0	4
K	32	4	0	-4	0	-4	0	-4	0	4	0	4	0	4	0	-4
L	32	-4	0	4	0	4	0	4	0	-4	0	-4	0	-4	0	4
M	32	4	0	-4	0	4	0	4	0	-4	0	-4	0	4	0	-4
N	32	-4	0	4	0	-4	0	-4	0	4	0	4	0	-4	0	4
O	32	4	0	4	0	4	0	4	0	-4	0	-4	0	-4	0	-4
P	32	-4	0	-4	0	-4	0	-4	0	4	0	4	0	4	0	4

Since the autocorrelation function of a sequence and its cyclic shifted version is same, if $(\mathbf{S}_1, \mathbf{S}_2)$ is an almost complementary set, then so is $(T^i\mathbf{S}_1, T^j\mathbf{S}_2)$, $0 \leq i, j \leq n-1$. For example, since $\mathbf{S}_1 = (0,0,0,0,1,1,1,1)$ and $\mathbf{S}_2 = (0,1,0,0,1,0,1,1)$ constitute the almost complementary set, we can obtain sequences derived from the above 3-step algorithm. The constructed sequences are shown in Table 2. Similarly, we can also obtain almost complementary sets of sequences of period 32 using the complementary property of sequences of period 16. The sequences are also described in Table 2. All sequences are classified by the autocorrelation functions defined in Table 3.

IV. CHANNEL STRUCTURE

In this section downlink DPCH (Dedicated Physical Channel) is considered since the same frame synchronization confirmation technique can be applied to the other channels such as uplink DPCH and downlink S-CCPCH (Secondary Common Control Physical Channel) [2]. Fig. 1 shows the frame structure of downlink DPCH. There are two types of downlink dedicated physical channels, the downlink DPDCH (Dedicated Physical Data Channel) and the downlink DPCCH [2].

Within one downlink DPCH, dedicated data generated at Layer 2 is time-multiplexed with control information generated at Layer 1. The Layer 1 control information consists of the known pilot bits to support channel estimation for coherent detection, transmit power-control (TPC) commands, and an optional transport-format combination indicator (TFCI). Each frame of length 10 ms is split into 16 slots, each of length T_{slot} = 0.625 ms, corresponding to one power-control period. A super-frame corresponds to 72 consecutive frames, i.e., the super-frame length is given by 720 ms. The parameter k is related to the spreading factor SF of the physical channel as $SF = 512/2^k$. The spreading factor may thus range from 512 down to 4 [2].

Fig. 2 describes the spreading and modulation for the downlink DPCH. Data modulation is QPSK where each pair of two bits are serial-to-parallel converted and mapped to the I and Q

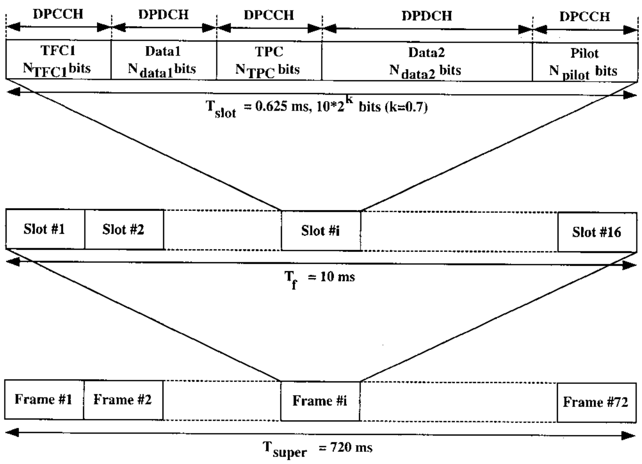

Fig. 1. Frame structure for downlink DPCH.

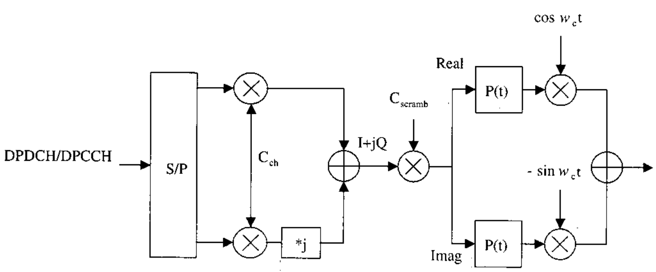

Fig. 2. Spreading/modulation for downlink DPCH.

branches, respectively. The I and Q branches are then spread to the chip rate with the same channelization code $C_{\rm ch}$ and subsequently scrambled by the scrambling code $C_{\rm scramb}$. The scrambling code is Gold code generated by the following two preferred primitive polynomials over GF(2) [8].

$$x(X) = X^{18} + X^7 + 1, \tag{20}$$

$$y(X) = X^{18} + X^{10} + X^7 + X^5 + 1. \tag{21}$$

Finally, $P(t)$ in Fig. 2 represents an impulse response of the root raised cosine shaping filter with a roll off factor of 0.22.

V. PILOT PATTERN IN W-CDMA SYSTEM

Table 4 shows the proposed new pilot symbol patterns on downlink DPCCH with $N_{\rm pilot} = 4, 8,$ and 16. The shadowed parts of the table can be used for frame synchronization words, and the value of pilot symbol other than the frame synchronization word is "11." Now define the shadowed column pilot patterns of Table 4 as follows.

Table 6 describes the mapping relationship between the 8 words of Table 5 and shadowed column pilot symbol patterns of Table 4. The 8 frame synchronization words of Table 5 are the same as the almost complementary sets of sequences of period 16 in Table 2. Thus the sequences can be divided into 4 classes $E = \{C_1, C_5\}$, $F = \{C_2, C_6\}$, $G = \{C_3, C_7\}$, $H = \{C_4, C_8\}$ according to the autocorrelation functions of Table 3.

We find the following relationships between the autocorrelation functions for the different classes of frame synchronization words.

$$R_{\rm E}(\tau) = R_{\rm F}(\tau) = R_{\rm G}(\tau) = R_{\rm H}(\tau) \text{ for even } \tau, \tag{22}$$

$$R_{\rm E}(\tau) = -R_{\rm F}(\tau) \text{ for odd } \tau, \tag{23}$$

$$R_{\rm G}(\tau) = -R_{\rm H}(\tau) \text{ for odd } \tau, \tag{24}$$

$$R_i(\tau) + R_i(\tau + 8) = 0,\ i \in \{\text{E,F,G,H}\} \text{ for all } \tau, \tag{25}$$

$$R_{\rm E}(\tau) + R_{\rm F}(\tau) = R_{\rm G}(\tau) + R_{\rm H}(\tau) \text{ for all } \tau. \tag{26}$$

From the above equations, we obtain the following important equation

$$\sum_{i=1}^{2\alpha} R_i(\tau) = \alpha \cdot (R_{\rm E}(\tau) + R_{\rm F}(\tau)),\ 1 \le \alpha \le 4 \tag{27}$$

where $R_i(\tau)$ is the autocorrelation function of sequence C_i, $1 \le i \le 8$. The addition of two autocorrelation functions $R_{\rm E}(\tau)$ and $R_{\rm F}(\tau)$, or $R_{\rm G}(\tau)$ and $R_{\rm H}(\tau)$ becomes the function with two peak values equal in magnitude and opposite in polarity at zero and middle shifts, and all zero values except at zero and middle shifts. From (27), we obtain the Fig. 3, which describes the side lobe cancellation effect of autocorrelation functions of 4 frame synchronization words from classes E, F, G, and H.

Table 4. New pilot pattern of Downlink DPCH.

	$N_{\rm pilot} = 4$		$N_{\rm pilot} = 8$				$N_{\rm pilot} = 16$							
Symbol #	0	1	0	1	2	3	0	1	2	3	4	5	6	7
Slot #1	11	11	11	11	11	10	11	11	11	10	11	11	11	01
2	11	10	11	10	11	11	11	10	11	11	11	01	11	11
3	11	00	11	00	11	01	11	00	11	01	11	11	11	01
4	11	10	11	10	11	11	11	10	11	11	11	10	11	00
5	11	11	11	11	11	10	11	11	11	10	11	00	11	01
6	11	10	11	10	11	11	11	10	11	11	11	01	11	00
7	11	11	11	11	11	01	11	11	11	01	11	00	11	10
8	11	10	11	10	11	00	11	10	11	00	11	01	11	11
9	11	00	11	00	11	01	11	00	11	01	11	00	11	10
10	11	01	11	01	11	00	11	01	11	00	11	10	11	00
11	11	11	11	11	11	10	11	11	11	10	11	00	11	10
12	11	01	11	01	11	00	11	01	11	00	11	01	11	11
13	11	00	11	00	11	01	11	00	11	01	11	11	11	10
14	11	01	11	01	11	00	11	01	11	00	11	10	11	11
15	11	00	11	00	11	10	11	00	11	10	11	11	11	01
16	11	01	11	01	11	11	11	01	11	11	11	10	11	00

Table 5. New frame synchronization words.

Frame Synchronization Words
$C_1 = (1101111100100000)$
$C_2 = (1000101001110101)$
$C_3 = (1101110000100011)$
$C_4 = (0111011010001001)$
$C_5 = (1011000001001111)$
$C_6 = (1110010100011010)$
$C_7 = (0100001110111100)$
$C_8 = (1110100100010110)$

Table 6. Mapping relationship between the 8 sequences of Table 2 and shadowed column pilot patterns of Table 1.

Symbol rate	Symbol Number	CH	Corresponding column sequence
$N_{\text{pilot}} = 4$	1	I-CH	C_1
		Q-CH	C_2
$N_{\text{pilot}} = 8$	1	I-CH	C_1
		Q-CH	C_2
	3	I-CH	C_3
		Q-CH	C_4
$N_{\text{pilot}} = 16$	1	I-CH	C_1
		Q-CH	C_2
	3	I-CH	C_3
		Q-CH	C_4
	5	I-CH	C_5
		Q-CH	C_6
	7	I-CH	C_7
		Q-CH	C_8

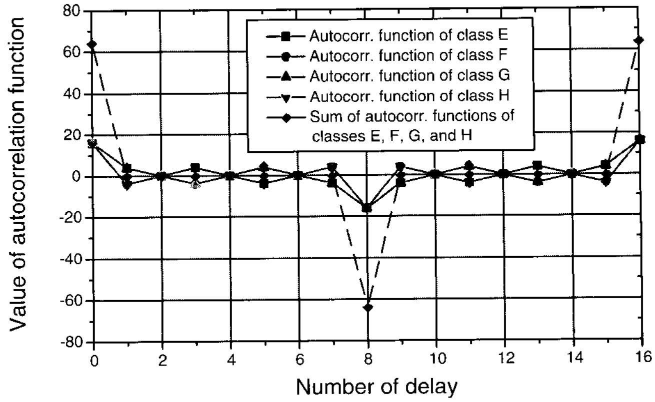

Fig. 3. Autocorrelation functions of class E, F, G, and H, and sum of the autocorrelation functions.

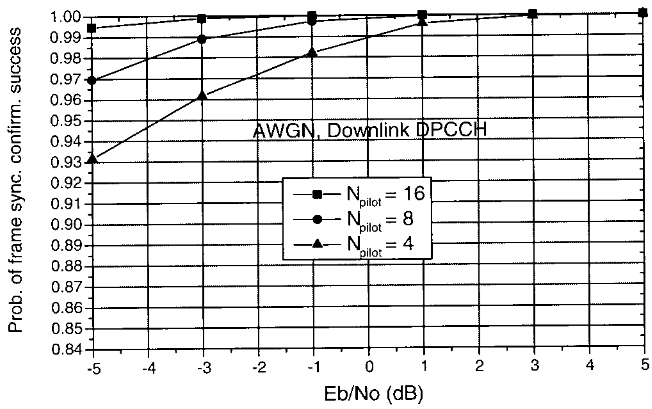

Fig. 4. Probability of frame synchronization confirmation success.

VI. SIMULATION RESULTS

Since the frame synchronization word of a pilot pattern is used for frame synchronization confirmation [2], we first define the following events and parameters for performance evaluation of frame synchronization confirmation using the side lobe cancellation technique:

- $\mathbf{H_1}$ the event that output of correlator exceeds the predetermined threshold when the code phase offset between the received shadowed column frame synchronization word and its corresponding receiver stored frame synchronization word is 0 or 8, respectively;
- $\mathbf{H_2}$ the event that the output of correlator exceeds the predetermined threshold when the code phase offset between the received shadowed column frame synchronization word and its corresponding receiver stored frame synchronization word is not 0 and 8;
- $\mathbf{H_3}$ one event of $\mathbf{H_1}$ and no event of $\mathbf{H_2}$ for one frame;
- $\mathbf{P_D}$ probability of a detection;
- $\mathbf{P_{FA}}$ probability of a false alarm;
- $\mathbf{P_S}$ probability of success in a frame synchronization confirmation for one frame.

Hence, the probability of detection and a false alarm can be expressed as:

$$\mathbf{P_D} = \text{Prob}(\mathbf{H_1}), \tag{28}$$

$$\mathbf{P_{FA}} = \text{Prob}(\mathbf{H_2}). \tag{29}$$

Finally, the probability of success in a frame confirmation for one frame becomes $\mathbf{P_S} = \text{Prob}(\mathbf{H_3})$, and it is given by

$$\mathbf{P_S} = \mathbf{P_D}(1 - \mathbf{P_{FA}})^{14}. \tag{30}$$

From (30), we see that the $\mathbf{P_S}$ is greatly affected by the probability of a false alarm. Fig. 4 shows the probability of frame synchronization confirmation success as a function of E_b/N_0 ratio (E_b = energy per bit, N_0 = noise power spectral density) on downlink DPCCH over AWGN (Additive White Gaussian Noise) channel. Table 7 summarizes the parameters for simulation studies under AWGN channel. The pilot pattern can be used for frame synchronization confirmation since about 99% of frame synchronization confirmation success rate was achieved at $E_b/N_o = 0$ dB.

VII. CONCLUSION

In this document we proposed a new side lobe cancellation technique for autocorrelation using a new pilot pattern in W-CDMA system. We showed that the pilot pattern in W-CDMA system are suitable for frame synchronization confirmation by using the proposed method which inherits a property of giving

Table 7. Parameters for simulation performance evaluation over AWGN channel.

Parameters	Downlink
Slot per frame	16
Number of bits in the DPDCH per each slot	4/8/16
Spreading factor (DPDCH)	512/256/16
Spreading factor (DPCCH)	512/256/16
Modulation	QPSK
3 dB bandwidth	4.096 MHz
Shaping filter	Root raised cosine roll off 0.22
Power amplifier	Ideal
Propagation channel	AWGN
Normalized threshold	0.78125

two maximum values equal in magnitude and opposite in polarity at zero and middle shifts. This property can be used to double-check the frame synchronization timing and reduce the synchronization search time. The frame synchronization performance under AWGN channel using the proposed technique was presented, and we found that the pilot pattern is suitable for the frame synchronization since about 99% of frame synchronization confirmation success rate was achieved at $E_b/N_o = 0$ dB.

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Young-Joon Song is currently a Senior Research Engineer at the Advanced Telecommunication Research Laboratory, LG Information & Communications, Ltd, where for the ten years he has performed research on AMPS, GSM and CDMA systems. He received the B.S., M.S., and Ph.D. degrees from Hanyang University, Korea, in 1987, 1994, and 1999, respectively. His area of interest is wireless communication system design and system performance evaluation.