Orthogonal Reception Characteristics for the DS/SS Signals with Time-shifted m-Sequences

Kyung Hoon Baek*, Kwangmin Hyun**, Dongweon Yoon**, Sang Kyu Park**
* Div. of Info. and Comm., Dong-Ah Broadcasting College, Ansung, Korea, 456-717
Tel : +81-31-670-6600 E-mail: khbaek@dabc.ac.kr
**Div. of Electrical and Computer Engineering, Hanyang Univ. Seoul, Korea, 133-791
Tel : +81-2-2290-0365 Fax : +81-2-2281-9912 E-mail: skpark@hanyang.ac.kr

Abstract: This paper proposes an orthogonal reception structure for DS/SS communication with time-shifted m-sequences, and compares the performances of the proposed and conventional receiver. This structure provides two important characteristics to reference user signal with not only increment of auto-correlation value but also cancel of the cross-correlation value out to zero between the reference user and other user signals. In addition, the structure can be easily implemented with the conventional receiver adding an additional integrator path in parallel and an adder that sums the conventional path output and the new path output signal. Hence, the proposed structure can be applied for channel impulse response measurement, and efficiently used for multi-user interference signal cancellation and channel capacity increment by flexible structural inter-working operation, connection or disconnection, of the new path to conventional receiver structure.

m-Sequence, Orthogonal PN sequence, Spread Spectrum, Multi-user Interference, Channel Impulse Response

1. INTRODUCTION

In spread spectrum (SS) communication, PN sequences play very important role of user signal identification and other user signal interference reduction. Even though it is possible to discriminate the reference user signal from multi-user signal with PN sequence characteristics, because the residue cross-correlation value, the imperfect orthogonal characteristic of the sequence, among the PN sequences act as mutual interference to degrade the SS receiver performance, reducing the residue is very important to improve the receiver performance. Generally, the m-sequence is very representative one among several PN sequences, and the modified types of the m-sequence are researched and proposed, such as Gold, Kasami, etc., to make new orthogonal PN sequence.

m-sequence is the most common PN sequence for various kinds of the real applications because this sequence has several useful characteristics for real world such as simple sequence generating structure, periodic sequence generation, time-shifting property, and correlation property. In practice, the Qualcomm Company successfully commercialized the IS-95 direct sequence code division multiple access system using time-shifted m-sequence. While the m-sequence is very commonly used for the applications, because the sequence is not a perfect orthogonal sequence with non-zero cross-correlation value between the sequences, long period sequence is selected to reduce the negative cross-correlation effect. Where as, if the specific application requires perfect orthogonal characteristic, other sequences like Walsh code are used instead of the m-sequence.

One of the important characteristics of the orthogonal sequence is zero cross-correlation value between sequences. If the selected sequence for DS-SS communication application is not perfect orthogonal means that the cross-correlation values is not zero, the residue cross-correlation value will affect to degrade the receiver performance as a mutual interference component. m-sequence has two important characteristics are related to receiver performance. First, the m-sequence contains one more one than zero in the one period N. This means that the integrator output over one period sequence is 1. Second, the periodic sequence correlation value is two-valued, N and -1. This means that auto-correlated value is N and cross-correlated value is -1 [3], [4].

In this paper, we propose and analyze the orthogonal reception process of the DS/SS receiver when the imperfect orthogonal sequence, the time-shifted m-sequence, is used using above mentioned m-sequence characteristics. In chapter II, we introduce the orthogonal reception receiver model and show the proposed receiver works as a perfect orthogonal sequence reception process, canceling the residue cross-correlated value out to zero. Using the calculated equation from the chapter II, in chapter III, the numerical analysis will be performed to compare the receiver signal to noise ratio performance between the conventional and the proposed receiver. And, we refer to the characteristics of the proposed receiver as a conclusion in chapter IV.

2. ORTHOGONAL RECEPTION PROCESS MODEL

In this paper, we adopt the common SS communication receiver model with time-shifted

m-sequence over additive white Gaussian noise (AWGN) channel. The processing gain of the model is one period of the sequence, $N=T_b/T_c$ where T_b is information bit duration and T_c is chip duration of the sequence. Also, we assume that the carrier and chip phase of the received all user signals are synchronized when we assume that the signals are transmitted simultaneously by the time synchronized base station. Fig. 1 shows the proposed receiver structure. The received signal $r(t)$ is converted to base-band converted signal, and then divided into two and passed through the conventional path and the proposed path. Whereas the conventional path performs despreading and correlating work, the proposed path performs only integrating work over one period of sequence. Hence, we can say that the outputs from two paths, $y_{Conv.}(t)$ and $y_{Prop.}(t)$, are added to $y_{Total}(t)$.

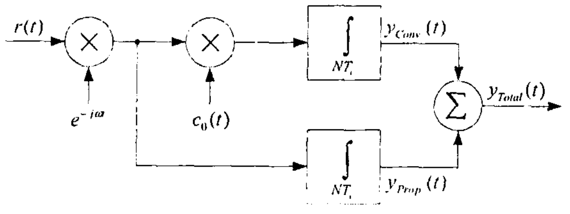

Fig. 1. Orthogonal Receiver Structure

The received signal is composed of M user signals and additive Gaussian noise (AWGN), and can be expressed as (1).

$$r(t)=\sum_{k=0}^{M-1}c_k[\xi(t)]e^{j\omega t}+n_0(t)\,,\ \xi(t)=t+nT_c+\tau \qquad (1)$$

where $c_k(t)$ is complex m-sequence of the kth user (the reference user is k=0); n is an arbitrary integer over one period of the sequence; τ is phase delay over one chip period; ω is carrier frequency; and $n_0(t)$ is complex AWGN of which one-side power spectrum density is N_0 [5]. And we assume that the transmitted one bit energy is $E_b=T_b$. Hence, the signal output in Fig. 1 can be written as

$$y_{Total}(t)=y_{Conv.}(t)+y_{Prop.}(t) \qquad (2)$$

where $y_{Conv.}(t)$ is the same with the conventional receiver output, and $y_{Prop.}(t)$ is the new added path output signal.

2.1 Conventional Receiver Model Analysis

When the M user signals in (1), presented at the receiver including the reference signal, is passed through the conventional receiver, the output will be expressed as (3).

$$\begin{aligned} y_{Conv.}(t) &= \int_{NT_c}c_0{}^*(t)\sum_{k=0}^{M-1}c_k[\xi(t)]dt+\int_{NT_c}n(t)c_0{}^*(t)dt \\ &= \int_{NT_c}c_0{}^*(t)c[\xi(t)]dt+\int_{NT_c}c_0{}^*(t)\sum_{k=0}^{M-1}c_k[\xi(t)]dt \\ &+\int_{NT_c}n(t)c_0{}^*(t)dt = s'_{Conv.}(t)+n'_{Conv.}(t) \end{aligned} \qquad (3)$$

where $n(t)=n_0(t)e^{-j\omega t}$; $c_0(t)$ is the complex m-sequence generated by the local m-sequence generator of the reference receiver, and it's conjugate term is $c_0^*(t)$; $s'_{Conv.}(t)$ is the reference user signal component shown in (4); and $n'_{Conv.}(t)$ is composed of AWGN and other user signal components written in (4).

$$s'_{Conv.}(t)=\int_{NT_c}c_0{}^*(t)c[\xi(t)]dt\ \cdot$$

$$n'_{Conv.}(t)=\int_{NT_c}c_0{}^*(t)\sum_{k=1}^{M-1}c_k[\xi(t)]dt+\int_{NT_c}n(t)c_0{}^*(t)dt\ \cdot \qquad (5)$$

From (4), we get the real part of the signal component and calculate it as in (6)

$$\Re\{s'_{Conv.}(t)\}=\begin{cases} NT_c\,,\ if\ n=N,\tau=0 \\ \{N-(N+1)\Delta\}T_c\,,0<\Delta<1 \\ \quad ,\ if\ n=N,\tau\neq 0 \\ -T_c\,,\ if\ n\neq N,0<\tau<T_c \end{cases}. \qquad (6)$$

In (5), the first item means the accumulated cross-correlated value between the reference user and the other user signals, and it can be calculated as in (7) using cross-correlation property of the m-sequence.

$$\int_{NT_c}c_0{}^*(t)\sum_{k=1}^{M-1}c_k[\xi(t)]dt=\sum_{k=1}^{M-1}(-T_c)=-(M-1)T_c\ \cdot \qquad (7)$$

To find the noise power, the variance of the $n'_{Conv.}(t)$ can be computed as in (8).

$$\begin{aligned} E\{(\Re[n'_{Conv.}(t)])^2\} &= [(M-1)T_c]^2 \\ &+\frac{1}{2}\left\{\iint_{NT_c}N_0\delta(t-\zeta)E\{\Re[c_0{}^*(t)c_0(\zeta)]\}\right\} \end{aligned}\cdot \qquad (8)$$

Therefore, in the presence of multiple user signals, the accumulated cross-correlated value, $-(M-1)T_c$, affects the reference signal as an interference component. Combining (6) and (9), assuming that chip timing is correctly synchronized, the output SNR performance $SNR_{Conv.}$ of the conventional receiver can be calculated as shown in (9).

$$\begin{aligned} SNR_{Conv.} &= \frac{[s'_{Conv.}(t)]^2}{E\{(\Re[n'_{Conv.}(t)])^2\}} \\ &= \frac{2(NT_c)^2}{N_0NT_c+[(M-1)T_c]^2}\ ,\ if\ n=N,\tau=0 \end{aligned} \qquad (9)$$

2.2 The Proposed Orthogonal Receiver

When the received signal is the same as (1), we know that the output signal has passed through the added path in parallel. The output signal $y_{Prop.}(t)$ helps the orthogonal process can be expressed as in (10).

$$\begin{aligned} y_{Prop.}(t) &= \int_{NT_c}\sum_{k=0}^{M-1}c_k[\xi(t)]e^{j\omega t}dt+\int_{NT_c}n(t)dt \\ &= s'_{Prop.}(t)+n'_{Prop.}(t) \end{aligned} \qquad (10)$$

where $n'_{Prop.}(t)=\int_{NT_c}\sum_{k=1}^{M-1}c_k[\xi(t)]dt+\int_{NT_c}n(t)dt$, and

$s'_{Prop.}(t)=\int_{NT_c}c_0[\xi(t)]dt$.

Also, according to the m-sequence property, $s'_{Prop.}(t)$ and the first item of the $n'_{Prop.}(t)$ results in T_c and (M-1)T_c respectively. The proposed receiver output $y'_{Total}(t)$ is the sum of the conventional receiver path output $y'_{Conv.}(t)$ in (3) and the proposed path output $y'_{Prop.}(t)$ in (10), resulting in (11).

$$y_{Total}(t)=y_{Conv.}(t)+y_{Prop.}(t)=s'_{Total}(t)+n'_{Total}(t) \qquad (11)$$

where the signal component of the adder output $s'_{Total}(t)=s'_{Prop.}(t)+s'_{Conv.}(t)$; noise and interference component $n'_{Total}(t)=n'_{Prop.}(t)+n'_{Conv.}(t)$.

From (11) we can calculate the real part of the signal component $s'_{Total}(t)$ as in (12) adding $s'_{Conv.}(t)$ value in (6) and $s'_{Prop.}(t)$ value T_c. This means that the signal component output of the proposed receiver $s'_{Total}(t)$ is increased to the amount of the one chip duration T_c than $s'_{Conv.}(t)$.

$$\Re\{s'_{Total}(t)\} = \begin{cases} (N+1)T_c, \ if\ n = N, \tau = 0 \\ \{(N+1)(1-\Delta)\}T_c, 0<\Delta<1 \\ \quad , if\ n = N, \tau \neq 0 \\ 0, if\ n \neq N, 0 < \tau < T_c \end{cases} \quad (12)$$

When we consider the noise and interference component of the proposed receiver $n'_{Total}(t)$, the accumulated cross-correlated component of the $n'_{Conv.}(t)$ and the integrated component of the $n'_{Prop.}(t)$ have the same absolute values but opposite signs. Hence, because these two values cancel each other out, the $n'_{Total}(t)$ can be simplified as in (13).

$$\begin{aligned} n'_{Total}(t) &= \int_{NT_c} n(t)c_0*(t)dt + \int_{NT_c} n(t)dt \\ &= \int_{NT_c} n(t)[c_0*(t)+1]dt \end{aligned} \quad (13)$$

To get the noise power, we compute the variance of the $n'_{Total}(t)$, shown in (14).

$$\begin{aligned} &E\{(\Re[n'_{Conv.}(t)])^2\} \\ &= \Re\left\{E\left[\int_{NT_c} n(t)[c_0*(t)+1]dt \int_{NT_c} n(\zeta)[c_0*(\zeta)+1]d\zeta\right]\right\} \\ &= N_0(N+1)T_c \end{aligned} \quad (14)$$

Using (12) and (14), the output SNR of the proposed receiver SNR_{Total} can be calculated as in (15).

$$\begin{aligned} SNR_{Total} &= \frac{[s'_{Total}(t)]^2}{E\{(\Re[n'_{Total}(t)])^2\}} \\ &= \frac{(N+1)T_c}{N_0}, \ if\ n = N, \tau = 0 \end{aligned} \quad (15)$$

When we look at the proposed receiver SNR performance in (15) with time-shifted m-sequence and the existence of multiple users, we cannot find the other user interference component that is canceled by the opposite value from the new added path. Therefore, the proposed receiver output SNR performance will be a proportionally increasing curve in accordance with an increase in E_b/N_0.

3. PERFORMANCE COMPARISON AND RESULTS

3.1 Comparison of the Output SNR Performance

In the presence of multiple users, the relative output SNR ratio performance SN_{Ratio} can be calculated as the SNR ratio of the proposed receiver SNR in (15) to the conventional receiver SNR in (9), shown in (16).

$$\begin{aligned} SN_{Ratio} &= \frac{SNR_{Total}}{SNR_{Conv.}} \\ &= \frac{(N+1)T_c}{N_0} \cdot \frac{2(NT_c)^2}{N_0 NT_c + [(M-1)T_c]^2} \\ &= \frac{1}{2} + \frac{1}{2N} + \frac{(N+1)(M-1)^2}{N^3} \cdot \frac{E_b}{N_0} \\ &\quad , if\ n = N, \tau = 0 \end{aligned} \quad (16)$$

If the ratio is 1, the proposed receiver performance shows the same as that of the conventional receiver. And, if the ratio is more than 1, the proposed receiver performance is better than that of the conventional receiver.

From (16), if we consider that only one user signal exists at the proposed receiver, letting $M=1$, the SNR performance ratio will result in (17).

$$\frac{SNR_{Total}}{SNR_{Conv.}} = \frac{1}{2} + \frac{1}{2N} \quad , if\ n = N, \tau = 0 \quad (17)$$

In this case, we can only be satisfied that the received signal constellation distance is far away from the amount of the chip duration T_c. In contrast to this merit, we have to put up with the degradation of the relative SNR performance to the conventional receiver because of the negative effect by the increased noise component through the added path. But, if there are multiple user signals at the proposed receiver, we can expect to improve the SNR performance as an amount of the sum of the second and third item of (16). It means that the sum of the second and third item is larger than 1/2, then the proposed receiver has better relative SNR performance than that of the conventional receiver. Hence, to consider the relative performance, we need to observe from all directions such as processing gain, given E_b/N_0, and the number of users.

From (16), we can compute the ratio R of the number of users to processing gain by means of the relative performance ratio SN_{Ratio}, processing gain, and channel E_b/N_0, expressed in (18).

$$R = \frac{M}{N} = \frac{1}{N} + \sqrt{\frac{(2SN_{Ratio}-1)N-1}{2(N+1)} \cdot \frac{N_0}{E_b}}\ ] \quad , M \geq 1, SN_{Ratio} > 0.5 \quad (18)$$

The ratio R means an amount of the multi-user interference in the presence of the M user signals with given processing gain N, and this will act as the performance gain item through the orthogonal processing operation through the new path opposite to the performance loss by the added AWGN.

Results of the Numerical Analysis

In this section, we review characteristics and performances of the proposed orthogonal reception process. To compare the proposed receiver to the conventional receiver performances, we numerically analyze the output SNR performance. We also test the relative SNR performance between the receivers. While the proposed receiver gets the performance improvement by the signal component increment and the interference cancellation gain, we cannot ignore the increased AWGN component through the new path. To get better performance than that of the conventional receiver, the proposed receiver should gain more by the orthogonal process than loss by the added AWGN effects. That is, because channel E_b/N_0 and number of users change the performance gain and the loss, we use the relative performance test. In addition, if we consider these parameter changes, we can certify the characteristics of the proposed receiver.

Fig. 2 shows the absolute SNR performance in dB scale of the two receivers at given processing gains of 127, changing E_b/N_0 and number of users. This figure shows that the proposed receiver performance is proportional to the change of the E_b/N_0, but the conventional receiver performance is saturated at a certain amount of E_b/N_0. In the high E_b/N_0 case, because the multi-user interference term affects the performance more dominantly than the AWGN component, the performance comes to saturation. The proposed receiver shows better performance when the gain-effect of removing the multi-user interference is larger than the loss-effect of the AWGN. However the conventional receiver performance is better than that of the proposed receiver at low E_b/N_0 and small-accumulated cross-correlated value. That is, as the accumulated cross-correlated value is increased as the proposed receiver performance is improved over that of the conventional receiver. When the E_b/N_0 is high, the amount of the AWGN flowed into the added path comes to be decreased, and the proposed receiver performance can be highly improved because effect of the multi-user interference is larger than that of the AWGN.

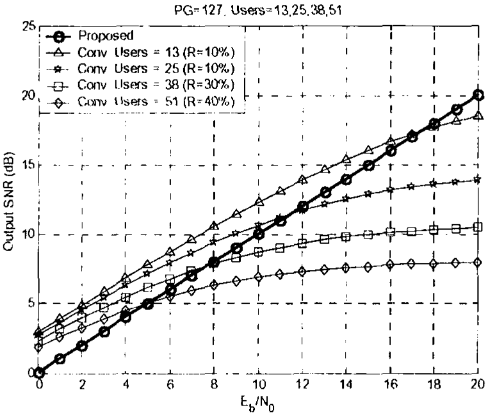

Fig. 2. SNR performances in *dB* scale of the two receivers in accordance with changing E_b/N_0 and number of users at given processing gain N=127.

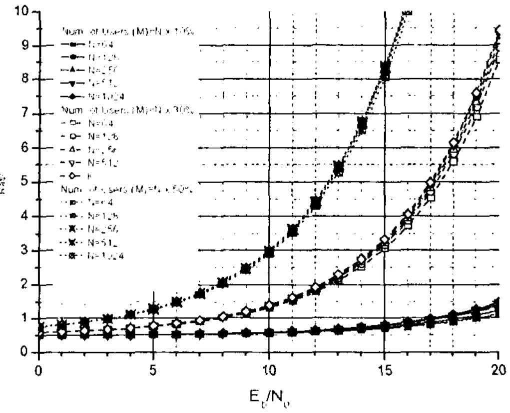

Fig. 3. SN_{Ratio} verse E_b/N_0 value with different number of users

Fig. 3 shows SN_{Ratio} (16) performance relationship with E_b/N_0, the number of users, and number of PN chips. This plots reveal that the SN_{Ratio} performance is improved when the number of users are increased or the SNR is high. It is because the AWGN noise or user interference is reduced with the orthogonal reception.

Fig. 4 indicates the output SNR ratio SN_{Ratio}, which is a relative performance ratio between two receivers affected by changing the number of users and E_b/N_0 value with a given processing gain N=127. At the figure, we can see that, when the number of users and E_b/N_0 value are large, the proposed receiver performance is better than that of the conventional receiver relatively. In detail, if the numbers of users are increased at the same E_b/N_0, the conventional receiver performance is degraded because of the accumulated cross-correlated value. Also, if the E_b/N_0 value is increased with the same number of users, this receiver performance will become almost saturated because of the influence of the accumulated cross-correlated value rather than AWGN effect. But, although the conventional receiver performance is degraded or saturated in accordance with the parameter changes, the proposed receiver performance is relatively improved to the conventional receiver by removing the cross-correlated value through the orthogonal process when the effect of the multi-user interference is more dominant term than AWGN.

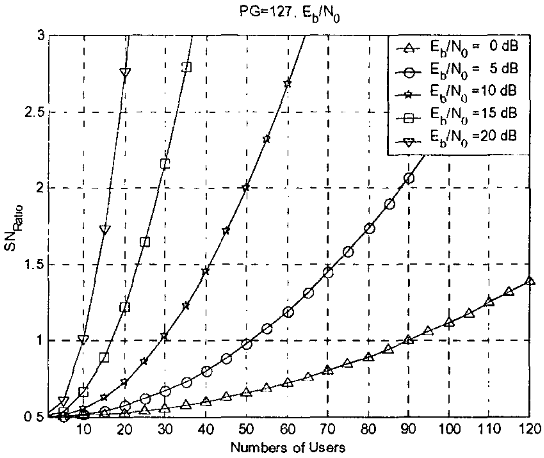

Fig. 4. The relative performance of the output SNR ratio SN_{Ratio} in accordance with changing the number of users and E_b/N_0 value at given processing gain N=127

4. CONCLUSIONS

In this paper, we proposed a simple receiver structure including the orthogonal process that makes the imperfect orthogonal time-shifted *m*-sequence have orthogonal characteristics at the receiver through the orthogonal process, and analyzed this receiver's characteristics and performances. In the case of the reception of the time-shifted *m*-sequence, and because the cross-correlated value over one period of the sequence between the reference user and other user code and the integrated value over the same period of the other user code have the same absolute value but opposite signs, the proposed receiver completely cancels the cross-correlated value by the integrated value and leads to the orthogonal process.

When we compared the output SNR performances between the conventional and the proposed receiver, we could not ignore the influence at the proposed reception process by the additional AWGN component added through the new path at the low E_b/N_0 or in the presence of a small amount of users. But, when the number of users is so increased as to degrade or saturate the conventional receiver performance, the proposed receiver performance can be improved by means of removing the cross-correlated value, canceling out the effect of the performance degradation by AWGN.

Therefore, the proposed receiver structure is composed of the conventional receiver path and the new added path in parallel; which cancel out the cross-correlated value between user signals so it can be applied to multi-user cancellation or capacity increase scheme and to the specific application such as channel impulse response measurements that the sequence orthogonal property is a more important factor than SNR performance.

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