IS-2000 시스템을 위한 SS-OTD에 관한 연구

정회원 윤 현 구*, 육 종 관*, 박 한 규*

A Novel Transmit Diversity Technique for IS-2000 Systems

Hyun-goo Yoon*, Jong-gwan Yook*, and Han-kyu Park* *Regular Members*

요 약

본 논문에서는 IS-2000 시스템에 적합한 심볼 분할 OTD (orthogonal transmit diveristy)를 제안하였다. 심볼 분할 OTD는 Meyer[1]가 제안한 심볼 분할과 OTD를 결합하여 최대 경로 다이버시티 및 시간 다이버시티 이득을 얻기에 IS-2000 순방향 성능을 개선시킬 수 있다. 이를 IS-2000 표준의 순방향 fundamental 채널에 대하여 시뮬레이션을 통해 확인하였다. 그리고, 그 결과를 기존의 IS-2000 표준에서 채택된 OTD와 STS (space-time spreading)의 성능과 비교하였다. 본 논문에서 제안한 방법을 IS-2000 시스템에 적용할 경우, 1% FER (frame error rate)을 얻기 위한 송신전력이 OTD의 경우보다 0.5-7.7dB 정도 감소되어 STS의 성능과 거의 일치하였다. 뿐만 아니라, 송신신호의 PAR(peak-to-average power ratio)가 STS보다 적으므로, 기지국 전력증폭기와 같은 RF 회로의 복잡도를 감소시킬 수 있는 장점이 있다.

ABSTRACT

This paper proposes a novel transmit diversity technique, namely symbol split orthogonal transmit diversity (SS-OTD). In this technique, full path diversity and temporal diversity are achieved by combining the orthogonal transmit diversity technique (OTD) technique with the symbol splitting method proposed by Meyer[1]. Its performance is simulated for fundamental channels associated with the forward link of the IS-2000 system, and then compared with those of OTD and space-time spreading (STS). Our proposed method offers a 0.5-7.7dB performance improvement over OTD under various simulation environments and its performance is similar to STS. Moreover, compared with that of STS, the peak-to-average power ratio (PAR) of transmitted signals in SS-OTD is reduced by a maximal 1.35dB, which decreases the complexity of base station RF devices, such as power amplifiers. Thus, SS-OTD is comparable to STS in performance and superior to STS in the cost and efficiency of base station RF devices.

I. Introduction

The fundamental phenomenon that makes reliable wireless transmission difficult is time-varying multipath fading. Increasing the capacity or reducing the effective error rate in multipath fading channels is very difficult. In the third generation code division multiple access (CDMA) systems, the reverse link capacity can be enhanced by various techniques, including multiple antenna reception and multi-user detection. However, techniques that increase the forward link capacity have not been developed in recent years with the same intensity. It is understood that the capacity imposed by the projected data services places a heavy burden on the forward link channel. Hence, it is important to find techniques that improve the capacity of the forward link.

* 연세대학교 전기전자공학과 전파통신연구실(hgyoon@yonsei.ac.kr)
논문번호 : 010045-0328, 접수일자 : 2001년 3월 28일

Typically, receive diversity techniques utilizing multiple antennas are exploited at the receiver to alleviate the effect of multipath fading characteristics of the mobile radio channel. In the forward link, however, receive diversity is not employed due to the cost and size of the mobile unit and performance degradation coming from closely-spaced antennas. In these cases, transmit diversity (TD) can be used to provide diversity gain at a receiver by using multiple transmit antennas.

Many of the transmit diversity schemes that have been previously proposed can be divided into two categories: closed loop methods and open loop methods. The closed loop methods require a feedback channel from the mobile station to aid in the multiplexing of the transmitted signal onto the transmit antennas. Selection transmit diversity (STD) and transmit antenna array (TxAA) are two examples of closed loop methods. In STD[2], the base station antenna is dynamically selected, based on a fast transmit antenna selection control signal transmitted by the mobile station. In TxAA[3], the mobile station determines array weights based on measurements of the forward link and sends this information back to the base station. For closed loop methods, the forward link performance is tightly coupled with the reverse link feedback channel performance. This leads to degraded links, especially for mobiles near cell boundaries. However, the open loop methods require no feedback from the mobile. The multiplexing of the transmitted signal onto the transmit antennas is predetermined. The open loop TD is particularly appealing when the mobile speed is high enough to make channel estimation and tracking too difficult. Time switched transmit diversity (TSTD), OTD, and STS have been proposed on an open loop transmit diversity [4][5][6][7]. Both OTD and STS have been adopted by IS-2000 CDMA systems[8], because TSTD has the power-balancing problem that increases system complexity even though TSTD and OTD have similar performances. OTD utilizes code division transmission diversity, i.e. different orthogonal codes are used for each antenna for spreading. It splits the information and its power equally between multiple transmit antennas. Thus, it provides a natural balancing of the transmission power between the transmitters. In OTD, however, the path diversity inherent in the channel is not fully exploited. On the other hand, full path diversity can be achieved via STS without extra resources. As a result, STS outperforms OTD in various

Therefore, we propose a novel transmit diversity scheme, namely SS-OTD, which uses the symbol splitting method proposed by Meyer[1]. SS-OTD is equal to OTD in PAR distribution, because its signal generation scheme is the same as OTDs. SS-OTD is also comparable to STS in performance, since full path diversity can be achieved by symbol splitting.

The paper is organized as follows. In Section II, a brief description of the symbol splitting scheme are shown. Section III describes the three open loop transmit diversity techniques, i.e. OTD, STS, and SS-OTD. Major simulation parameters and simulation results are presented in Section IV. Finally, conclusions are drawn in Section V.

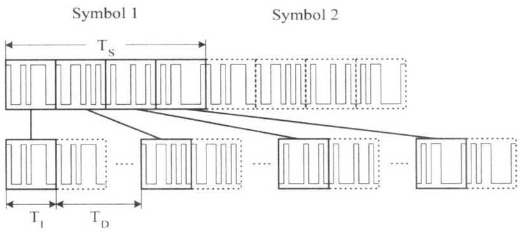


Fig. 1 Principle of symbol splitting (r=4)[1]

Ⅱ. Symbol Splitting Scheme

In the direct sequence CDMA (DS-CDMA) system, an information symbol consists of G chips, where G denotes processing gain. These G chips are transmitted consecutively, which results in approximately the same fading influence for the chips belonging to one symbol in the slow fading channel. This channel may significantly disturb a complete symbol. However, if a symbol is split into r sub-symbols and transmitted by multiple transmit antennas with randomly distributed time intervals, then it is less probable that a complete symbol is disturbed. The principle of the symbol splitting scheme is specifically depicted in Fig.1[1], where the splitting rate is $r=4$ and T_D denotes the time interval between the sub-symbols. The first sub-symbol of symbol 1 is transmitted, and then the second sub-symbol of symbol 1 is transmitted after T_D. If the value T_D1) is chosen to be greater than channel coherence time $t_c = 1/(2f_{d,\max})$, then the channel states for the different sub-symbols are statistically independent, where $f_{d,\max}$ is the maximum Doppler frequency.

Symbol splitting is realized as follows. A symbol is divided into r sub-symbols with time duration $T_I = T_S/r$, where T_S is the symbol time duration. These sub-symbols are interleaved in order to randomize burst error. The even interleaved sub-symbol stream is spread, QPSK-modulated, and transmitted on antenna 1. The same procedure is applied to the odd sub-symbol stream but being transmitted on antenna 2. Half of the sub-symbols of a symbol are in the even sub-symbol stream, and the other half are in the odd sub-symbol stream. As a result, the interleaved sub-symbols belonging to one symbol are transmitted on both antennas with the time interval denoted by T_D. Therefore, full path diversity and temporal diversity can be obtained by symbol splitting.

Ⅲ. Transmit Diversity Techniques

We consider TD systems using two transmit antennas at the base station and one antenna at the mobile. It is assumed that the multipath fading channel can be adequately modeled as a tapped delay line with L time-varying, complex-valued Gaussian distributed tap coefficients. Furthermore, we assume that the channels between each transmit and receive antenna are independent with identical power-delay profiles, and that the fading is constant over at least two consecutive symbol intervals. The receiver uses a RAKE detector with L fingers to capture as much of the energy of the multipath signal as possible, and perfect despreading is assumed.

1. Orthogonal transmit diversity

OTD has been already adopted by the IS-2000 standard[8]. It utilizes code division transmission diversity. Let the four consecutive data bits of the kth user be $Y_{I1}(k)$, $Y_{I2}(k)$, $Y_{Q1}(k)$, and $Y_{Q2}(k)$. In OTD[5], odd order bits are transmitted on antenna 1 and even order bits are transmitted on antenna 2. If QPSK-modulation is used, the two QPSK symbols can be expressed as

$$s_1 = Y_{I1}(k) + jY_{Q1}(k) \qquad (1a)$$

$$s_2 = Y_{I2}(k) + jY_{Q2}(k) \qquad (1b)$$

where s_1 and s_2 each consist of $2M$ chips after spreading. Both symbols are spread with the two orthogonal spreading codes $W_{1,k}^{2M} = [\,W_k^M \;\; W_k^M\,]$ and $W_{2,k}^{2M} = [\,W_k^M \;\; -W_k^M\,]$, respectively, where W_k^M presents the Walsh function of length M that is serially constructed from the kth row of a $M\times M$ Hadamard matrix2). For notational convenience, we will drop the length of the Walsh function and the user index k. The resulting complex envelope of the transmitted signal on the mth antenna for two consecutive symbols can be expressed as

$$\tilde{x}_m(t) = \sqrt{E_c}\sum_{n=1}^{2M} s_m w_m(n)\, p(t-nT_c) \quad (m=1,2) \qquad (2)$$

where E_c is the chip energy, $w_m(n)$ is the nth

1) The time interval between sub-symbols belonging to one symbol is randomly distributed, because the sub-symbols are interleaved. So its average value has been used in this paper for mathematical simplification.

2) Since each symbol is repeated twice, the Walsh code length used on each antenna is $2M$. Thus, the available number of Walsh codes is the same that in a non-TD system

chip of W_m^{2M}, T_c is the chip duration, and $p(t)$ is the transmission pulse shape. In a channel with L paths, the received signal in two consecutive symbol intervals can be expressed as

$$r(t) = \sqrt{E_c}\sum_{n=1}^{2M}\sum_{l=1}^{L}[s_1 w_1(n) h_{1,l} + s_2 w_2(n) h_{2,l}]p(t-nT_c-\tau_l) + z(t) \quad (3)$$

where $h_{m,l} = \alpha_{m,l}\exp(j\theta_{m,l})$ are the complex-valued channel coefficients on the mth transmit antenna, $\alpha_{m,l}$ is its envelope, $\theta_{m,l}$ is its random phase, τ_l is the lth path delay, and $z(t)$ is an additive white Gaussian nose (AWGN) process with variance of σ_z^2. The outputs of the lth RAKE finger are given by

$$\begin{aligned} r_l(n) &= \int_0^{T_c} r(t)p^*(t-nT_c-\tau_l)\,dt \\ &= \sqrt{E_c}[s_1 h_{1,l}w_1(n) + s_2 h_{2,l}w_2(n)] \\ &\quad + z(n) \end{aligned} \quad (4)$$

where $(\cdot)^*$ denotes the complex conjugate operation and $z(n)$ is a sample of AWGN process. With perfect knowledge of the channel coefficients, this output can be combined to form the following maximum likelihood estimates of the transmitted symbol

$$\begin{aligned} \hat{s}_m &= \sum_{l=1}^{L}\sum_{n=1}^{2M} r_l(n) w_m(n) h_{m,l}^* \\ &= 2M\sqrt{E_c}\Big[\sum_{l=1}^{L}\alpha_{m,l}^2\Big]s_m + \Big[\sum_{l=1}^{L}\alpha_{m,l}\Big]z' \end{aligned} \quad (5)$$

where $\sigma_{z'}^2 = 2M\sigma_z^2$. The instantaneous SNR for s_m is then

$$\gamma_{OTD}(s_m) = \frac{2\Big[\sum_{l=1}^{L}\alpha_{m,l}^2\Big]^2 ME_c}{\Big[\sum_{l=1}^{L}\alpha_{m,l}\Big]^2\sigma_z^2} \quad (6)$$

From (6), it can be seen that OTD has an effective path diversity of order L.

2. Space-time spreading

In [6], the complex envelopes of the transmitted signals for the first M chips are

$$\tilde{x}_1(t) = \sqrt{\frac{E_c}{2}}\sum_{n=1}^{M}[s_1 - s_2^*]w_1(n)p(t-nT_c) \quad (7a)$$

$$\tilde{x}_2(t) = \sqrt{\frac{E_c}{2}}\sum_{n=1}^{M}[s_1^* + s_2]w_2(n)p(t-nT_c) \quad (7b)$$

and for the second M chips are

$$\tilde{x}_1(t) = \sqrt{\frac{E_c}{2}}\sum_{n=M+1}^{2M}[s_1 + s_2^*]w_1(n)p(t-nT_c) \quad (8a)$$

$$\tilde{x}_2(t) = \sqrt{\frac{E_c}{2}}\sum_{n=M+1}^{2M}[s_2 - s_1^*]w_2(n)p(t-nT_c) \quad (8b)$$

where the factor $1/\sqrt{2}$ normalizes the total transmitted power equal that of one transmit antenna. The received signal in the first M chips is

$$r_1(t) = \sqrt{\frac{E_c}{2}}\sum_{n=1}^{M}\sum_{l=1}^{L}\begin{bmatrix}(s_1 - s_2^*)w_1(n)h_{1,l} \\ +(s_1^* + s_2)w_2(n)h_{2,l}\end{bmatrix} \times p(t-nT_c-\tau_l) + z_1(t) \quad (9)$$

and for the second M chips is

$$r_2(t) = \sqrt{\frac{E_c}{2}}\sum_{n=1}^{M}\sum_{l=1}^{L}\begin{bmatrix}(s_1 + s_2^*)w_1(n)h_{1,l} \\ +(s_2 - s_1^*)w_2(n)h_{2,l}\end{bmatrix} \times p(t-nT_c-\tau_l) + z_2(t) \quad (10)$$

The outputs of the lth RAKE finger are given by

$$\begin{aligned} r_{1,l}(n) &= \int_0^{T_c} r_1(t)p^*(t-nT_c-\tau_l)\,dt \\ &= \sqrt{\frac{E_c}{2}}\begin{bmatrix}(s_1 - s_2^*)w_1(n)h_{1,l} \\ +(s_1^* + s_2)w_2(n)h_{2,l}\end{bmatrix} + z_1(n) \end{aligned} \quad (11a)$$

$$\begin{aligned} r_{2,l}(n) &= \int_0^{T_c} r_2(t)p^*(t-nT_c-\tau_l)\,dt \\ &= \sqrt{\frac{E_c}{2}}\begin{bmatrix}(s_1 + s_2^*)w_1(n)h_{1,l} \\ +(s_2 - s_1^*)w_2(n)h_{2,l}\end{bmatrix} + z_2(n) \end{aligned} \quad (11b)$$

Then the estimated symbols are given by

$$\hat{s}_1 = \sum_{l=1}^{L}\Big[\sum_{n=1}^{M}\{r_{1,l}(n)w_1(n)h_{1,l}^{*} + r_{1,l}^{*}(n)w_2(n)h_{2,l}\} + \sum_{n=M+1}^{2M}\{r_{2,l}(n)w_1(n)h_{1,l}^{*} - r_{2,l}^{*}(n)w_2(n)h_{2,l}\}\Big] = 2M\sqrt{\frac{E_c}{2}}\sum_{l=1}^{L}(\alpha_{1,l}^2 + \alpha_{2,l}^2)s_1 + \Big(\sum_{l=1}^{L}\alpha_{1,l}\Big)z_1 + \Big(\sum_{l=1}^{L}\alpha_{2,l}\Big)z_2 \quad (12a)$$

$$\hat{s}_2 = \sum_{l=1}^{L}\Big[\sum_{n=1}^{M}\{r_{1,l}(n)w_2(n)h_{2,l} - r_{1,l}^{*}(n)w_1(n)h_{1,l}^{*}\} + \sum_{n=M+1}^{2M}\{r_{2,l}^{*}(n)w_1(n)h_{1,l} + r_{2,l}(n)w_2(n)h_{2,l}^{*}\}\Big] = 2M\sqrt{\frac{E_c}{2}}\sum_{l=1}^{L}(\alpha_{1,l}^2 + \alpha_{2,l}^2)s_2 + \Big(\sum_{l=1}^{L}\alpha_{1,l}\Big)z_1 + \Big(\sum_{l=1}^{L}\alpha_{2,l}\Big)z_2 \quad (12b)$$

where $\sigma_{z_m}^2 = 2M\sigma_z^2$. The instantaneous SNR for s_m is then

$$\gamma_{STS}(s_m) = \frac{\Big[\sum_{l=1}^{L}(\alpha_{1,l}^2 + \alpha_{2,l}^2)\Big]^2 ME_c}{\Big[\Big(\sum_{l=1}^{L}\alpha_{1,l}\Big)^2 + \Big(\sum_{l=1}^{L}\alpha_{2,l}\Big)^2\Big]\sigma_z^2} \quad (13)$$

As shown in the above equation, STS has an effective path diversity of order $2L$.

3. Symbol split orthogonal transmit diversity

In SS-OTD with the symbol splitting rate r, each of the two consecutive symbols s_1 and s_2 is split into r sub-symbols, where r is assumed to be the power of 2 for mathematical convenience. The relationship between an original symbol and its sub-symbols can be expressed as follows

$$s_m = \sum_{i=1}^{r} s_m(i) \quad (14)$$

where $s_m(i)$ denotes the ith split sub-symbol of the mth symbol, which consists of $M_r = 2M/r$ chips after spreading. The resulting complex envelopes of the transmitted signals for the odd order sub-symbols are

$$\tilde{x}_1(t) = \sqrt{E_c}\sum_{odd\ i}\sum_{n=(i-1)M_r+1}^{iM_r} s_1(i)w_1(n) \times p(t-nT_c) \quad (15a)$$

$$\tilde{x}_2(t) = \sqrt{E_c}\sum_{odd\ i}\sum_{n=(i-1)M_r+1}^{iM_r} s_2(i)w_2(n) \times p(t-nT_c) \quad (15b)$$

and those for the even sub-symbols are

$$\tilde{x}_1(t) = \sqrt{E_c}\sum_{even\ i}\sum_{n=(i-1)M_r+1}^{iM_r} s_2(i)w_1(n) \times p(t-nT_c) \quad (16a)$$

$$\tilde{x}_2(t) = \sqrt{E_c}\sum_{even\ i}\sum_{n=(i-1)M_r+1}^{iM_r} s_1(i)w_2(n) \times p(t-nT_c) \quad (16b)$$

It is important to note that the following two Walsh codes should be used instead of $W_1^{2M} = [\,W^M\ \ W^M\,]$ and $W_2^{2M} = [\,W^M\ \ -W^M\,]$:

$$W_1^{2M} = [\,W^{M/r}\ \ W^{M/r}\ \cdots\ W^{M/r}\ \ W^{M/r}\,] \quad (17a)$$

$$W_2^{2M} = [\,W^{M/r}\ \ -W^{M/r}\ \cdots\ W^{M/r}\ \ -W^{M/r}\,] \quad (17b)$$

The received signal for the odd order sub-symbol is given by

$$r_o(t) = \sqrt{E_c}\sum_{l=1}^{L}\sum_{odd\ i}\sum_{n=(i-1)M_r+1}^{iM_r}[s_1(i)w_1(n)h_{1,l} + s_2(i)w_2(n)h_{2,l}] \times p(t-nT_c-\tau_l) + z(t) \quad (18)$$

and for the even order sub-symbols by

$$r_e(t) = \sqrt{E_c}\sum_{l=1}^{L}\sum_{even\ i}\sum_{n=(i-1)M_r+1}^{iM_r}[s_2(i)w_1(n)h_{1,l} + s_1(i)w_2(n)h_{2,l}] \times p(t-nT_c-\tau_l) + z(t) \quad (19)$$

The output of the lth RAKE finger for the odd order sub-symbols is given by

$$r_{o,l}(n) = \int_0^{T_c} r_o(t)p^{*}(t-nT_c-\tau_l)dt = \sqrt{E_c}[s_1(i)w_1(n)h_{1,l} + s_2(i)w_2(i)h_{2,l}] + z(n) \quad ((i-1)M_r \le n \le iM_r) \quad (20)$$

and for the even order sub-symbols by

$$r_{e,l}(n) = \int_0^{T_c} r_e(t)p^*(t-nT_c-\tau_l)dt = \sqrt{E_c}[s_2(i)w_1(n)h_{1,l} + s_1(i)w_2(i)h_{2,l}] + z(n) \quad ((i-1)M_r \le n \le iM_r) \tag{21}$$

With perfect knowledge of the channel coefficients, these outputs can be combined to form the following maximum likelihood estimates of the transmitted symbols

$$\hat{s}_1 = \sum_{l=1}^{L}\left[\sum_{odd\ i}\sum_{n=(i-1)M_r+1}^{iM_r} r_{o,l}(n)w_1(n)h^*_{1,l} + \sum_{even\ i}\sum_{n=(i-1)M_r+1}^{iM_r} r_{e,l}(n)w_2(n)h^*_{2,l}\right] = M\sqrt{E_c}\sum_{l=1}^{L}(\alpha^2_{1,l}+\alpha^2_{2,l})s_1 + \left(\sum_{l=1}^{L}\alpha_{1,l}\right)z_1 + \left(\sum_{l=1}^{L}\alpha_{2,l}\right)z_2 \tag{22a}$$

$$\hat{s}_2 = \sum_{l=1}^{L}\left[\sum_{odd\ i}\sum_{n=(i-1)M_r+1}^{iM_r} r_{o,l}(n)w_2(n)h^*_{1,l} + \sum_{even\ i}\sum_{n=(i-1)M_r+1}^{iM_r} r_{e,l}(n)w_1(n)h^*_{2,l}\right] = M\sqrt{E_c}\sum_{l=1}^{L}(\alpha^2_{1,l}+\alpha^2_{2,l})s_2 + \left(\sum_{l=1}^{L}\alpha_{1,l}\right)z_1 + \left(\sum_{l=1}^{L}\alpha_{2,l}\right)z_2 \tag{22b}$$

where $\sigma^2_{z_m} = M\sigma^2_z$. The instantaneous SNR for s_m is then

$$\gamma_{SS-OTD}(s_m) = \frac{\left[\sum_{l=1}^{L}(\alpha^2_{1,l}+\alpha^2_{2,l})\right]^2 ME_c}{\left[\left(\sum_{l=1}^{L}\alpha_{1,l}\right)^2 + \left(\sum_{l=1}^{L}\alpha_{2,l}\right)^2\right]\sigma^2_z} \tag{23}$$

Hence, OTD has an effective path diversity of order $2L$. Compared with (13) for STS, the SNR of SS-OTD is identical to that of STS.

Ⅳ. Simulation parameters and results

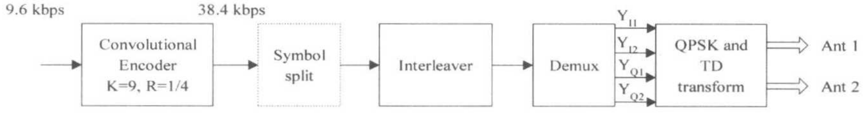
According to the IS-2000 standard, a set of forward traffic channel and reverse traffic channel transmission formats is characterized by physical layer parameters, such as data rates, modulation characteristics, and spreading rates. This is called a radio configuration (RC)[7]. RC3 and RC4 are considered in this paper. The difference between RC3 and RC4 is that RC3 uses 1/4 rate convolutional code and 64 Walsh codes, while RC4 uses 1/2 convolutional code and 128 Walsh codes.

Table Ⅰ. Simulation parameters

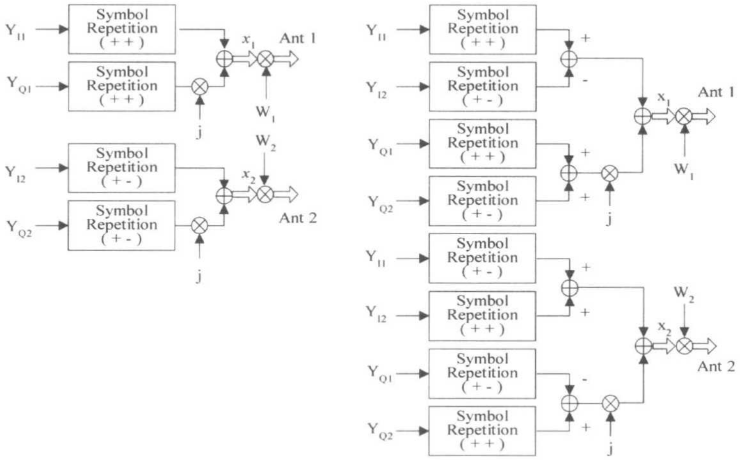
BS antennas	2
Bit rate	9.6kbps
Chip rate	1.2288Mcps
Frame duration	20ms
Mobile geometry	0 or 6dB
Min/Max power	-40dB/-3dB
Inner-loop PC rate	800Hz
Inner-loop PC step	±0.5dB
Outer-loop PC	1% FER target
PC error rate	4%
Channel	Flat fading(1 and 2 path)
]Channel estimation	perfect

A block diagram of a base station transmitter with TD is depicted in Fig.2, and the corresponding block diagram of a mobile station receiver is shown in Fig.3. The splitting and combining blocks with dotted lines are necessary only in SS-OTD. Note that the size of the interleaver in SS-OTD should be r-times larger than those in OTD and STS in order to maintain the same total interleaving delays. The demultiplexer function distributes input symbols sequentially from the top to the bottom output paths. These symbols are grouped in the even data stream or the odd data stream, and each stream is associated with one of the two extended Walsh codes.

The performance of SS-OTD was simulated for the fundamental channel associated with the forward link of IS-2000 systems, and those simulation parameters are summarized in Table I. The transmit power fractions, E_c/I_{or}, required to achieve 1% FER were simulated, where E_c represents the energy per chip, and I_{or} denotes the total transmit power spectral density. The



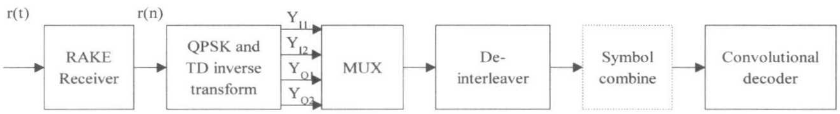
(a) Entire block diagram of base station transmittter



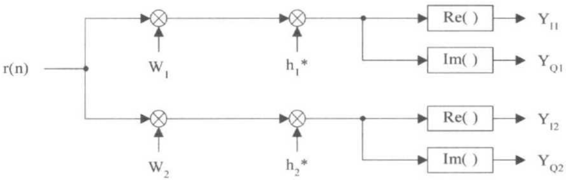
(b) QPSK and TD transform (OTD and SS-OTD)

(c) QPSK and TD transform (STS)

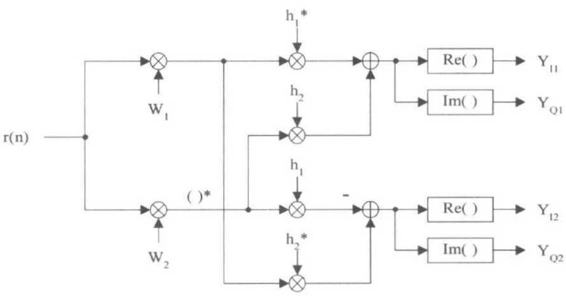
Fig. 2 Block diagram of base station transmitter



(a) Entire block diagram of mobile station receiver



(b) TD Inverse transform (OTD and SS-OTD)



(c) TD Inverse transform (STS)

Fig. 3 Block diagram of mobile station receiver quantity, I_{or}/I_{oc}, is commonly referred to as mobile geometry; for low values mobiles are located close to the edge of the cell and for high values mobiles close to the base station, where I_{oc} denotes other cell interference power spectral density which is modeled as AWGN.

First, we investigate the effect of the symbol splitting rate on system performance. If the value T_D is chosen to be larger than the channel coherence time, channel states for the different sub-symbols are statistically independent. However, as the splitting rate is increased, T_D may be decreased, which may result in performance degradation. In order to show this quantitatively, we shall define the transmit power enhancement factor of SS-OTD over OTD as η.

$$\eta = \frac{E_c/I_{or}(SS-OTD)}{E_c/I_{or}(OTD)} \qquad (23)$$

The calculation of η according to the splitting rate under various simulation environment is shown in Fig.4, where R is denoted by the code rate. In all cases, η does not increase by more than $r \geq 2$, while the size of the interleaver increases linearly. Thus, $r=2$ is used in all of the following simulations.

Fig.5 shows the average E_c/I_{or} required to achieve 1% FER as a function of mobile velocity in RC3. For the one-path case, SS-OTD shows performance improvement over OTD 3.8dB at low speeds, and 0.5dB at high speeds. In Fig.5(b), SS-OTD outperform OTD by about 1dB at all mobile speeds. Simulation results for RC4 are depicted in Fig.6. In Fig.6(a), SS-OTD offers up to 7.7dB performance improvement over OTD at low speeds, and a minimum of 0.8dB at high speeds. From both Fig.5 and Fig.6, the performance improvement of SS-OTD and STS over OTD is reduced at high mobile speed, because the spatial diversity not fully exploited in OTD is compensated through temporal fluctuations in the

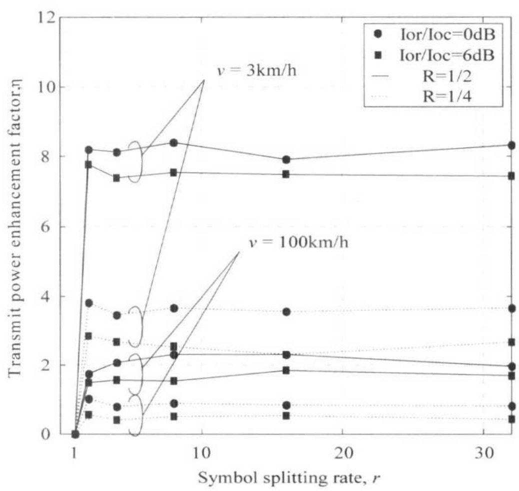
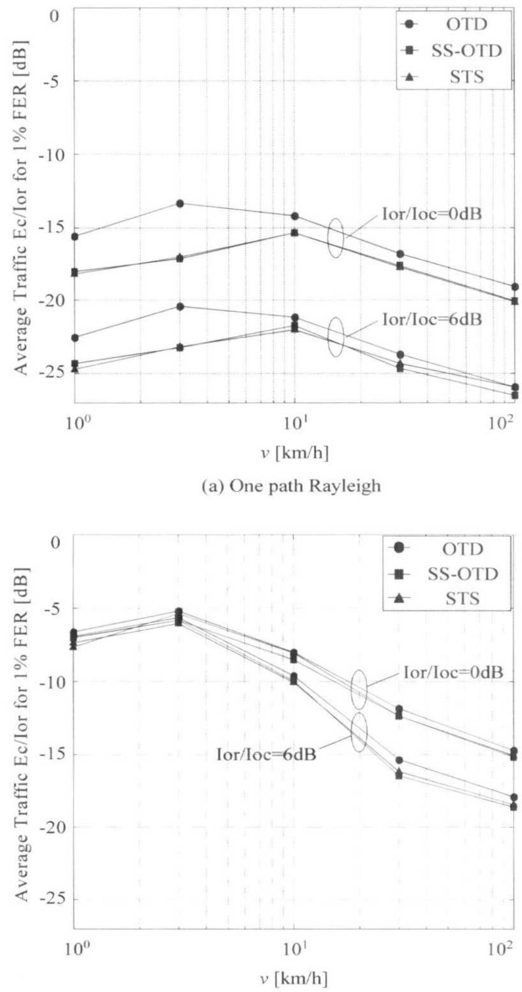


Fig. 4 Transmit power enhancement factor

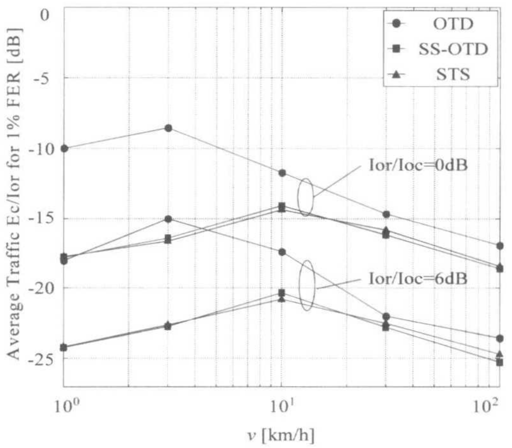


(a) One path Rayleigh

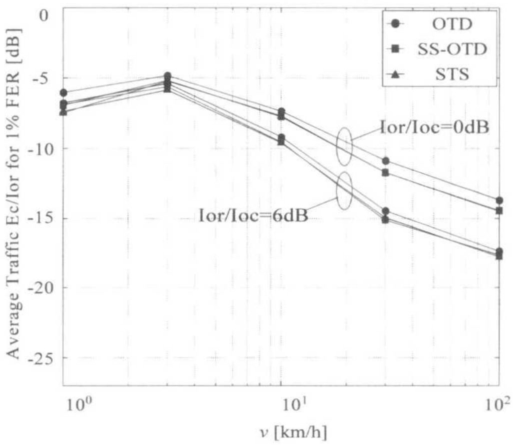
(b) Two path Rayleigh

Fig. 5 Average traffic E_c/I_{or} for 1% FER(RC3) channel.

As shown in (7) and (8), the two QPSK symbols are added or subtracted, which may result in increasing the peak value of the transmitted signals. However, since SS-OTD and OTD have an identical TD transformation, the PAR values of them are same. The calculated 99% PAR values for OTD, SS-OTD, and STS are shown in Fig.7. The PAR increases quickly as the number of users increases to 10 for all transmit diversity schemes. STS requires at least a 1.35dB higher power handling capacity than OTD and SS-OTD for 4 users. It is well known that PAR is a significant factor in the linearity of RF devices. Thus, SS-OTD is comparable to STS in performance and superior to STS in the cost and efficiency of base station RF devices.



(a) One path Rayleigh



(b) Two path Rayleigh

Fig. 6 Average traffic E_c/I_{or} for 1% FER(RC4)

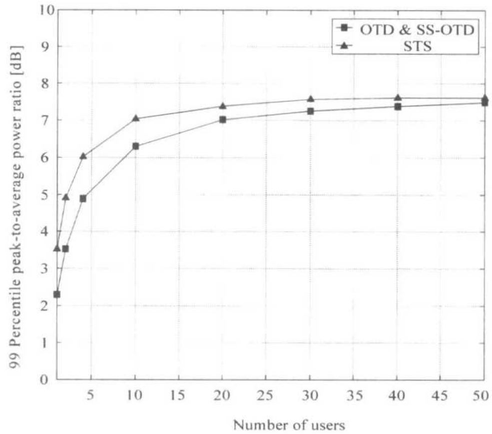


Fig. 7 Simulated PAR

V. Conclusion

In this paper, we proposed a modified OTD technique, namely SS-OTD. The average transmit power fractions, E_c/I_{or}, required to achieve 1% FER were simulated for the fundamental channel associated with the forward link of IS-2000 system. SS-OTD offers significant improvement of up to 7.7dB over OTD for RC4, and 3.8dB for RC3, and a minimum of 0.5-0.8dB improvement in the worst case. From PAR simulation results, approximately 1.35dB of the PA design overhead will be required for STS. Thus, we can conclude that SS-OTD is comparable to STS in performance and superior to STS in the cost and efficiency of base station RF devices.

참고문헌

[1] M.Meyer, "Improvement of DS-CDMA mobile communication systems by symbol splitting", in Proc. *IEEE 45th VTC*, pp.689-693, 1995

[2] Motorola, "A comparison of forward link transmit diversity schemes", ETSI SMG2 L1, Italy, June 15-17, 1998.

[3] Nokia, "Downlink transmit diversity", ETSI

SMG2 L1, Bocholt, Germany, May 18-20, 1998.

[4] S.M.Alamouti, "A simple transmit diversity technique for wireless communicaitons", *IEEE J-SAC*, vol.16, no.8, pp.1451-1458, Aug. 1998.

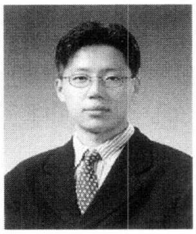
[5] L.Jalloul et al, "Perfomance analysis of CDMA transmit diversity methods", in Proc. *IEEE 50th VTC*, pp.1326-1330, 1999.

[6] Lucent technologies, "Performance of space-time spreading techniques for IS-2000 systems", 3GPP2-C30-19990914-014, 1999.

[7] R.A.Soni et al., "Open-loop transmit diversity in IS-2000 systems", in Proc. *IEEE Signals, Systems, and Computers Conf.*, pp.654-658, 1999.

[8] TIA/EIA/IS-2000.2, *Physical layer standard for CDMA2000 spread spectrum systems*

윤 현 구(Hyun-goo Yoon) 정회원



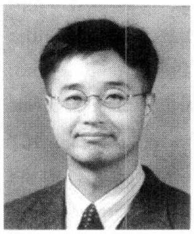
1995년 2월 : 연세대학교 전자공학과 졸업

1997년 2월 : 연세대학교 전자공학과 석사

1997년 3월~현재 : 연세대학교 전기전자공학과 박사과정

<주관심 분야> Mobile communication, Diversity technique

육 종 관(Jong-gwan Yook) 정회원



1987년 2월 : 연세대학교 전자공학과 졸업

1989년 2월 : 연세대학교 전자공학과 석사

1998년 12월 : University of Michigan 전기전자공학과 박사

1997년 1월~1998년 10월 : Univ. of Michigan Research Fellow

1998년 11월~1999년 2월 : Qualcomm Inc. Senior Engineer

1999년 3월~2000년 2월 : 광주과학기술원 조교수

2000년 3월~현재 : 연세대학교 전기전자공학과 조교수

<주관심 분야> 마이크로파 구조 해석 및 설계, RF MEMS, 박막공진구조

박 한 규(Han-kyu Park) 정회원

통신학회논문지 제25권 4호(2000) 참조