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불균일 경로 전력 이득을 가진 레일리 페이딩 환경에서 STD 기법의 성능 향상 기법

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Performance enhancement of a simple transmit diversity at Rayleigh fading channel with the unequal average branch power ratio

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요 약

본 논문에서는 불균일 전력 이득을 가진 레일리 페이딩 채널환경하에서 간단한 전송 다이버시티 (STD: simple transmit diversity) 기법의 성능 향상 방안을 제시한다. 제안된 STD 시스템에서, 각 다이버시티 가지상의 수신된 신호의 신호대잡음비(SNR)를 추정하여 특정 문턱값 이상을 가지는 추정 SNR 값을 갖는 신호들만을 결합하게 된다. 먼저, 다양한 불균일 전력비를 가진 환경에서 주어진 SNR값에 대해 최적의 성능을 나타낸는 특정 SNR 문턱값에 대해서 알아본다. 다음으로 기존의 STD 기법과 제안된 STD 기법의 비트오류율(BER)이 분석되어지고 불균일 전력비와 SNR의 함수로써 비교되어진다. 수치적 결과를 통하여 제안된 STD 시스템은 불균일 전력 비가 증가함에 따라 기존의 STD 기법보다 성능이 향상됨을 보여준다.

ABSTRACT

This paper proposes the performance enhancement scheme of a simple transmit diversity (STD) at Rayleigh fading channel with the unequal average powers on diversity branches. In the proposed STD system, the signal-to-noise ratio (SNR) of received signals on each diversity branch is estimated and then the signals, whose estimated SNR is larger than the specific SNR threshold value, are only selected for STD combining. First, the specific SNR threshold values, which give the best performance at the given SNR for the various unequal average branch power ratios, are investigated. Second, the average bit error rate (BER) of the conventional and the proposed STD system is analyzed numerically and compared in terms of the unequal average branch power ratio and the SNR. Numerical results show that the performance of the proposed STD system is better than that of the conventional as the unequal average branch power ratio increases.

Ⅰ. Introductio

The antenna diversity is the effective technique to mitigate the effects of fading in a mobile radio channel [1]. In the third generation cellular communication systems, the better quality, coverage and the small and lightweight mobile handsets are required. These requirements can be satisfied by introducing the multiple transmit antennas to base stations. This scheme is called the transmit diversity (TD). Many TD schemes, such as Space-Time Spreading (STS) and Orthogonal Transmit Diversity (OTD) for synchronous IS-2000 wideband system and Space-Time Transmit Diversity (STTD) for asynchronous WCDMA system, have been

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proposed [2-3]. Also a simple transmit diversity (STD) scheme, which is similar to STTD/STS scheme, using two transmit antennas and one or two receive antenna was proposed by Siavash M. Alomouti in [4] and shown that the average bit error rate (BER) with two transmit antennas and one receive antenna is identical to that of one transmit antenna and two receive antennas. MRC scheme was considered in the receiver. But the BER performance of the above diversity systems has been analyzed on condition that the diversity branches have the equal average power gain. This condition gives the lower bound of the performance. However, the received fading signals from different transmit diversity antennas are partially correlated and furthermore, their average powers are not equal.

So, this paper presents the performance analysis of the conventional STD system when the received faded signals have the unequal average branch power gain. The conventional STD system shows the degradation of the performance as the unequal average power ratio increases. In addition, this paper proposes the new STD system to mitigate the performance degradation by the large unequal average power ratio. Very low received power signals seem to be noise and combinations of those signals degrade the performance. In our proposed system the proposed selection block rejects these signals. To design the selection block, the optimal specific SNR threshold values are investigated at given SNR for various conditions through the simulation. Performance simulation results show that the performance of the proposed STD system having the optimal specific SNR threshold at given SNR is better than that of the conventional STD system in the case of a large unequal average branch power ratio.

The rest of this paper is organized as follows. In Section II and III, the performance of the conventional and the proposed STD system are analyzed respectively. In Section IV, the simulation results are presented. Section V contains conclusions.

Ⅱ. Average BER analysis of the conventional STD system

In this section, the numerical performance analysis of the conventional STD system is presented in terms of the unequal average branch power ratio (R) at Rayleigh fading environments. Conventional STD system is depicted in Fig. 1. Following [4], a complex baseband representation of the systems is used. The two channels are referred to as channels 0 and 1 with complex gains $h_i = \alpha_i \exp(j\theta_i), i \in \{0,1\}$, respectively, where α_0 and α_1 are Rayleigh random variables (RVs) and θ_0 and θ_1 are uniform RVs in the interval $[0, 2\pi]$. The data bits to be transmitted are independent, each taking on one of two equiprobable values. Coherent BPSK modulation is assumed so that the transmitted signal amplitude is either $\sqrt{E_s}$ or $-\sqrt{E_s}$. Also the perfect channel estimation is considered and the sum of the two branches' average power is normalized to 1, namely $\overline{\alpha_0}^2 + \overline{\alpha_1}^2 = 1$, where $\overline{\alpha_0}^2$ and $\overline{\alpha_1}^2$ represent the average power of channels 0 and 1, respectively. Define the parameter R as the average power ratio of the two diversity branches, $R = \overline{\alpha_1}^2 / \overline{\alpha_0}^2$. Then the $\overline{\alpha_0}^2$ and $\overline{\alpha_1}^2$ are rewritten as $\overline{\alpha_0}^2 = 1/(1+R)$ and $\overline{\alpha_1}^2 = R/(1+R)$.

Very slow, independent rayleigh fading signals, where the fading gain is constant during the two consecutive symbol periods, are assumed. The received signals r_0 and r_1 can be written as $r_0 = (s_0 h_0 + s_1 h_1) + n_0$ and $r_1 = (-s_1^* h_0 + s_0^* h_1) + n_1$, where the pairs s_0 and s_1 in r_0 are the BPSK symbols which sent from antenna 1 and antenna 2 in first bit time ($t = t$) and the pairs $-s_1^*$ and s_0^* in r_1 being in second bit time ($t = t + T$), respectively. And $n_i = n_{i,I} + jn_{i,Q}$ are the samples of independent complex gaussian random variables, with each power spectral density $\sigma_n^2 = N_0/2$ in the real and imaginary part.

After the perfect channel compensation and STD combining, resulting signals relative to the

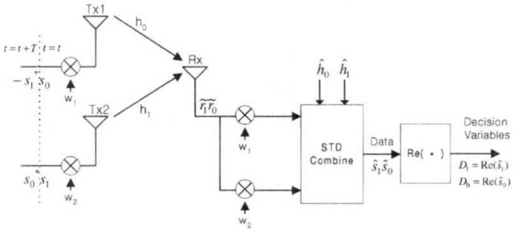

Fig. 1 Conventional STD system

decoding of s_0 and s_1 are $\widehat{s_0}=r_0\widehat{h_0^*}+r_1^*\widehat{h_1}$ and $\widehat{s_1}=r_0\widehat{h_1^*}-r_1^*\widehat{h_0}$. The decision random variables are denoted by D_0 for the first symbol $\widehat{s_0}$ and D_1 for the second symbol $\widehat{s_1}$ and expressed as

$$\begin{aligned} D_0 = Re(\widehat{s_0}) &= s_0\alpha_0^2+s_0\alpha_1^2+\alpha_0(n_{0I}\cos\theta_0+n_{0Q}\sin\theta_0) \\ &\quad +\alpha_1(n_{1I}\cos\theta_1+n_{1Q}\sin\theta_1) \\ D_1 = Re(\widehat{s_1}) &= s_1\alpha_1^2+s_1\alpha_0^2+\alpha_1(n_{0I}\cos\theta_1+n_{0Q}\sin\theta_1) \\ &\quad -\alpha_0(n_{1I}\cos\theta_0+n_{1Q}\sin\theta_0) \end{aligned} \tag{1}$$

In slow fading environments, α_0 and α_1 can be considered to be constants instantaneously and then D_0 and D_1 follow the normal density. After simplification, the mean and variance of the decision RVs can be written as

$$E[D_0]=s_0(\alpha_0^2+\alpha_1^2),\quad E[D_1]=s_1(\alpha_0^2+\alpha_1^2) \tag{2}$$

$$Var[D_0]=Var[D_1]=\alpha_1^2\sigma_n^2+\alpha_0^2\sigma_n^2=(\alpha_0^2+\alpha_1^2)\frac{N_0}{2} \tag{3}$$

The instantaneous BER for the conventional STD system is given by

$$\begin{aligned} P_e &= \frac{1}{4}\left\{\sum_{i=0}^{1}p(e|s_i=\sqrt{E_s})+\sum_{i=0}^{1}p(e|s_i=-\sqrt{E_s})\right\} \\ &= Q\left(\sqrt{\alpha_0^2+\alpha_1^2}\sqrt{\frac{2E_s}{N_0}}\right)=Q(\sqrt{\gamma_0+\gamma_1}) \end{aligned} \tag{4}$$

where

$$Q(x)=\{1/\sqrt{2\pi}\}\int_x^{\infty}e^{-y^2/2}dy=\int_0^{\pi/2}e^{-x^2/(2\sin^2\theta)}d\theta$$

[5], the terms $p(e|s_i=\sqrt{E_s})$ and $p(e|s_i=-\sqrt{E_s})$ represent the probability of error at the transmission of symbol $s_i=\sqrt{E_s}$ and $s_i=-\sqrt{E_s}$ and γ_i is defined as the instantaneous signal-to-noise power ratio (SNR) per symbol by $\gamma_i=2\alpha_i^2E_s/N_0$. The probability density function (PDF) of γ_i follows the exponential density as in [5].

Therefore the average BER can be calculated by

$$\begin{aligned} \overline{P_e} = &\frac{2\overline{\gamma_0}}{\overline{\gamma_0}-\overline{\gamma_1}}\left(1-\frac{\overline{\gamma_0}}{\sqrt{\overline{\gamma_0}(\overline{\gamma_0}+2)}}\right) \\ &-\frac{2\overline{\gamma_1}}{\overline{\gamma_0}-\overline{\gamma_1}}\left(1-\frac{\overline{\gamma_1}}{\sqrt{\overline{\gamma_1}(\overline{\gamma_1}+2)}}\right) \end{aligned} \tag{5}$$

where $\overline{\gamma_i}$ represents the average SNR per symbol by $\gamma_i= 2\overline{\alpha_i}^2E_s/N_0$.

Consequently, the average BER considering the average branch power ratio R can be written as

$$\overline{P_e}(R,SNR)=\frac{2}{1-R}(b-a) \tag{6}$$

where SNR represents the signal-to-noise power ratio by $SNR=\frac{E_s}{N_0}$ and $a=\sqrt{\frac{SNR}{1+R+SNR}}$, $b=\sqrt{\frac{R\cdot SNR}{1+R+R\cdot SNR}}$.

Ⅲ. Average BER analysis of the proposed STD system

The proposed STD system is shown in Fig. 1. The key idea is the rejection of noise-like very low received power signals. To do this work, the SNRs of received signals on each diversity branch are estimated and the signals over the specific threshold SNR are only selected for postprocessing (e.g. STD combine and decision).

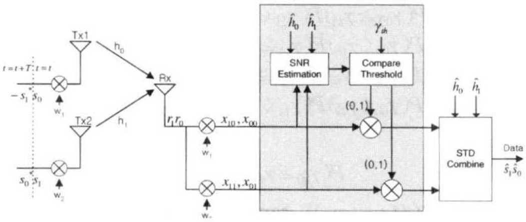

Fig. 2 Proposed STD system

The received signal $r_0(r_1)$ can be divided into the sub-signals $x_{00}(x_{01})$ at time t and $x_{10}(x_{11})$ at time t+T, respectively and written as $x_{00}=s_0 h_0+n_0(x_{01}=s_1 h_1+n_0)$ and $x_{10}=-s_1^* h_0+n_1(x_{11}=s_0^* h_1+n_1)$.

The perfect channel estimation is assumed. The resulting signal relative to the decoding of $s_0(s_1)$ are $\widehat{s_0}(\widehat{s_1})$ and these signals can be expressed as $\widehat{s_0}=\hat{x}_{00}+\hat{x}_{11}(\widehat{s_1}=\hat{x}_{01}+\hat{x}_{10})$, where the sub-signals through the channel compensation and the selection block are written as

$$\begin{aligned}\hat{x}_{00}&=x_{00}\ \hat{h}_0{}^*I_{00}=\{s_0h_0\ \ \hat{h}_0{}^*+n_0\ \ \hat{h}_0{}^*\}I_{00}\\ \hat{x}_{01}&=x_{01}\ \hat{h}_1{}^*I_{01}=\{s_1h_1\ \ \hat{h}_1{}^*+n_0\ \ \hat{h}_1{}^*\}I_{01}\\ \hat{x}_{10}&=-x_{10}^*\ \hat{h}_0I_{10}=\{s_1h_0^*\ \hat{h}_0-n_1^*\ \ \hat{h}_0\}I_{10}\\ \hat{x}_{11}&=x_{11}^*\ \hat{h}_1I_{11}=\{s_0h_1^*\ \ \hat{h}_1+n_1^*\ \ \hat{h}_1\}I_{11}\end{aligned}\tag{7}$$

The selection variable I_{ij} can be represented by

$$I_{ij}=\begin{cases}1, & \gamma_{ij}\geq\gamma_{th}\\ 0, & \gamma_{ij}<\gamma_{th}\end{cases}\tag{8}$$

where γ_{th} represents the average SNR threshold value for the selection of valuable branches and γ_{ij} the instantaneous estimated SNR by

$$\gamma_{ij}=SNR_{x_{ij}}=2\,\alpha_j^2\frac{E_s}{N_0},\ i,j\in\{0,1\}\tag{9}$$

The probability density function (PDF) of γ_{ij} follows the exponential density as in [5]. The important point is to acquire the optimal γ_{th} at given SNR.

In the proposed STD system, the instantaneous BER for transmitted symbol s_0 can be calculated by

$$\begin{aligned}P_{e,s_0}=&P(\gamma_{00}\geq\gamma_{th})P(\gamma_{11}<\gamma_{th})P_{e,\ \widehat{s_0}=\ \widehat{x_{00}}|s_0}\\ &+P(\gamma_{00}<\gamma_{th})P(\gamma_{11}\geq\gamma_{th})P_{e,\ \widehat{s_0}=\ \widehat{x_{11}}|s_0}\\ &+P(\gamma_{00}\geq\gamma_{th})P(\gamma_{11}\geq\gamma_{th})P_{e,\ \widehat{s_0}=(\ \widehat{x_{00}}+\ \widehat{x_{11}})|s_0}\\ &+P(\gamma_{00}<\gamma_{th})P(\gamma_{11}<\gamma_{th})P_{e,\ \widehat{s_0}=0|s_0}\end{aligned}\tag{10}$$

where $P(\gamma_{00}\geq\gamma_{th})(P(\gamma_{11}\geq\gamma_{th}))$ and $P(\gamma_{00}<\gamma_{th})(P(\gamma_{11}<\gamma_{th}))$ represent the probability of selection and non-selection of the sub-signal $\hat{x}_{00}(\hat{x}_{11})$, respectively.

The instantaneous BER for each case in Eqn. 10 can be represented by

$$\begin{aligned}P_{e,\ \widehat{s_0}=\ \widehat{x_{00}}|s_0}&=Q(\sqrt{2\alpha_0^2E_s/N_0})=Q(\sqrt{\gamma_{00}})\\ P_{e,\ \widehat{s_0}=\ \widehat{x_{11}}|s_0}&=Q(\sqrt{2\alpha_1^2E_s/N_0})=Q(\sqrt{\gamma_{11}})\\ P_{e,\ \widehat{s_0}=(\ \widehat{x_{00}}+\ \widehat{x_{11}})|s_0}&=Q(\sqrt{2(\alpha_0^2+\alpha_1^2)E_s/N_0})\\ &=Q(\sqrt{\gamma_{00}+\gamma_{11}})\\ P_{e,\ \widehat{s_0}=0|s_0}&=0.5\end{aligned}\tag{11}$$

Let the specific SNR γ_{th} be $\gamma_{th}=AE_s/N_0$. We call A the threshold parameter. The selection probability in eqn. 10 can be written in terms of the threshold parameter A and the unequal average branch power ratio R as

$$\begin{aligned}&P(\gamma_{00}\geq\gamma_{th})=\exp\left(-\frac{\gamma_{th}}{\bar{\gamma}_{00}}\right)=c,\quad P(\gamma_{00}<\gamma_{th})=1-c\\ &P(\gamma_{11}\geq\gamma_{th})=\exp\left(-\frac{\gamma_{th}}{\bar{\gamma}_{11}}\right)=d,\quad P(\gamma_{11}<\gamma_{th})=1-d\end{aligned}\tag{12}$$

where $c=\exp(-A(1+R)), d=\exp(-A(1+R)/R)$.

The average BER for Eqn. 11 can be calculated by

$$\begin{aligned}\overline{P}_{e,\ \widehat{s_0}=\ \widehat{x_{00}}|s_0}&=\frac{1}{2}\left(1-\sqrt{\frac{\bar{\gamma}_{00}}{2+\bar{\gamma}_{00}}}\right)=\frac{1}{2}(1-a)\\ \overline{P}_{e,\ \widehat{s_0}=\ \widehat{x_{11}}|s_0}&=\frac{1}{2}\left(1-\sqrt{\frac{\bar{\gamma}_{11}}{2+\bar{\gamma}_{11}}}\right)=\frac{1}{2}(1-b)\\ \overline{P}_{e,\ \widehat{s_0}=(\ \widehat{x_{00}}+\ \widehat{x_{11}})|s_0}&=\frac{2}{1-R}(b-a)\end{aligned}\tag{13}$$

where a and b are given in Eqn. (6).

Consequently, the average BER for the symbol s_0 can be expressed by

$$\begin{aligned}\overline{P}_{e,s_0}(A,R,SNR)=&\frac{1}{2}c(1-d)(1-a)\\ &+\frac{1}{2}(1-c)d(1-b)\\ &+cd\frac{2}{1-R}(b-a)\\ &+\frac{1}{2}(1-c)(1-d)\end{aligned}\tag{14}$$

The average BER for the symbol s_1, $\overline{P}_{e,s_1}(A,R,SNR)$, can be also shown to be the same as the average BER for the symbol s_0. Eventually, the total average BER of proposed STD system, which is calculated by $\overline{P}_e(A,R,SNR)=\{\overline{P}_{e,s_0}(A,R,SNR)+\overline{P}_{e,s_1}(A,R,SNR)\}/2$, can be the same as Eqn. (14).

Ⅳ. Numerical Results

At first, we have carried out the computer simulations to find the optimal A having the best performance at the given SNR and the various R, 0.1, 1, 5, 10, 20 and 30dB. Fig. 3 and 4 show the effects of the threshold parameter A on the average BER at SNR=10dB and SNR=20dB, respectively. In both cases, it is noticed that the conventional STD system has the performance degradation, as the R is increase. However the performance enhancement of the proposed STD system is shown in the fixed period of A if the R is larger than the given SNR. For example, in Fig. 3, the given SNR is 10dB and the performance enhancement arises in the duration (0, 0.12] at R>10dB. Table 1 represents the optimal A values, give the best performance for all the R at the given SNR, 5, 10, 20 and 30dB. Note that the proposed scheme is not useful in the case of the smaller R than the given SNR.

Using the optimal A values (Refer to Table 1) given from the above results, the average BER performance curves for the conventional and the proposed STD system as functions of the SNR and the R are shown in the Fig. 5. Note that, in the proposed STD scheme, the A given in Table 1 is applied adaptively to achieve the better performance through the overall SNR. The performance of the conventional system becomes worse as the R increase from 1dB to 30dB. The reason is that the conventional STD system affect the combining loss of very noisy (low SNR) branch. Whereas, as decreasing the effects of this combining loss by the rejection of very noisy signals, the proposed STD system has better performance than that of the conventional in the finite relatively low SNR duration at Rayleigh fading channel with the unequal average branch power gain.

Table 1. Optimal A values for the different SNR

SNR(dB)	5	10	20	30
A	0.06	0.01	0.002	0.0005

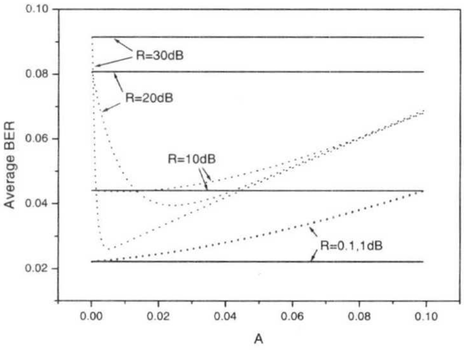

Fig. 3 Effects of the threshold parameter A on the average BER at SNR = 10dB Rayleigh fading, R=0.1,1,5,10,20,30dB
——— Conventional STD system
-------- Proposed STD system

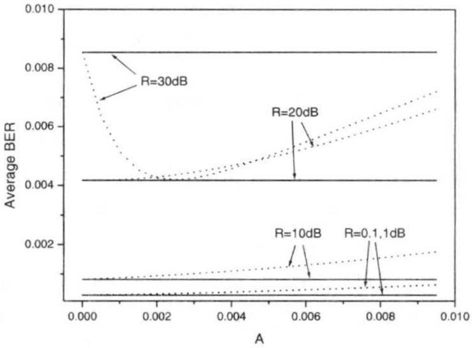

Fig. 4 Effects of the threshold parameter A on the average BER at SNR = 20dB Rayleigh fading, R=0.1,1,5,10,20,30dB
——— Conventional STD system
-------- Proposed STD system

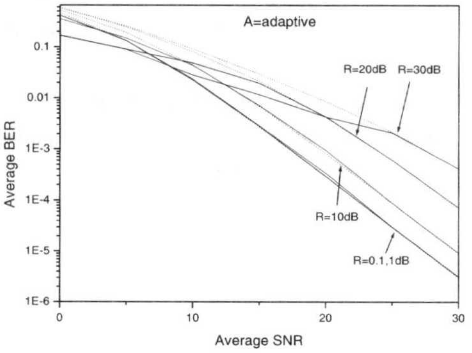

Fig. 5 Average BER performance when A is adaptive Rayleigh fading, R=0.1, 1, 5, 10, 20, 30dB
——— Conventional STD system
-------- Proposed STD system

V. Conclusions

We proposed the performance enhancement scheme of a simple transmit diversity(STD) at Rayleigh fading channel with the unequal average powers on diversity branches. To enhance the average BER performance at this environments, our new STD system rejects the received very low power signals using the proposed selection block. Through the computer simulations the optimal threshold parameter A was acquired and the BER performances of both STD systems are analyzed and compared. It is shown that the performance of the proposed STD system is better than that of the conventional for the large unequal average branch power ratio R if the A can be used adaptively at the given SNR.

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