A New Acquisition Scheme of a DS/SS Signal with Transmit and Receive Antenna Diversity

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Abstract— **In this paper, we propose the introduction of space diversity techniques to the code acquisition of a direct-sequence spread-spectrum signal. In this scheme, both a transmitter and a receiver have multiple antennas and the signals corresponding to all the combinations of the transmitter/receiver antennas are combined at the acquisition circuit of the receiver. The performance is evaluated for indoor packet radio communication systems from the viewpoints of average time for acquisition, probability of success of acquisition, and necessary preamble length. As the result, we show great performance improvements by the proposed scheme under slow and flat Rayleigh fading environment.**

I. Introduction

For indoor wireless communication systems, direct-sequence spread-spectrum (DS/SS) is widely used for its advantageous features such as anti-interference and anti-artificial noise capabilities together with the low impact (interference) to other systems. In indoor environment, the radio waves reflected by walls and furniture in a room are relatively strong and they may cause multi-path fading, which is one of the most important factors of performance degradation. Since the delay spread of indoor environment is often very small, the fading tend to be flat which may cause the drop of total received power. Furthermore, the fading speed is often very slow, so the error correcting codes based on time diversity does not improve the performance.

Under this flat and slow fading environment, the space diversity technique is known to be effective[3], and considerable number of studies have been performed. However, most of them only aim to improve BER provided that the synchronization of PN sequence has been already established. In indoor systems where the fading environment is severe, however, it may be difficult to achieve the synchronization of PN sequence itself. Although this difficulty, the space diversity techniques have not been considered well for the acquisition of PN sequence of a spread spectrum signal.

Recently, there appear the proposals of the employment of space diversity technique for the acquisition of a DS/SS signal [5][7], however, they use only the receive antenna diversity, and do not use the transmit antenna diversity which uses multiple antennas at a transmitter[6].

In this paper, we introduce the transmit antenna diversity to the code acquisition of a DS/SS signal in addition to the receive antenna diversity. We assume a indoor packet radio communication system, and the performance is evaluated from the viewpoints of average time of acquisition, probability of success or failure of acquisition, and necessary preamble length. As the results, we show great performance improvement by the proposed scheme under slow and flat Rayleigh fading environment.

II. System Model

The transmitter and the receiver proposed in this paper are shown in Figs.1 and 2. The transmitter and the receiver have M and K antennas, respectively. It is assumed that each transmitter antenna is spatially separated from others by several wavelengths of the carrier, and this assumption is also applied to the receiver antennas. Under this assumption, the statistics of the fading between each pair of transmitter and receiver antennas can be considered to be independent.

At the m-th transmitter antenna, the time delay d_m is intentionally introduced before the transmission. In this paper, we assume that d_m/T_c is an integer, $2T_c < d_m - d_{m-1}$, and $d_M < T_b$, where T_c is a chip duration and T_b is a bit duration. The transmitted signal from the m-th transmitter antenna is given by

$$s_m(t) = \sqrt{2S/M}c(t - d_m)\cos\omega_0 t \quad (1)$$

where S is the total transmit power, $c(\cdot)$ is the PN sequence, and ω_0 is the angular carrier frequency. We assume that the length of the PN sequence is L and $T_b = LT_c$. The transmit power at each transmitter antenna is normalized by $1/M$ to keep the total transmit power unity.

The received signal at the k-th receiver antenna is given by

$$r_k(t) = \sum_{m=1}^{M} \sqrt{2S/M}\beta_{mk}c(t-d_m-\zeta T_c)\cos(\omega_0 t-\theta_{mk})+n(t), \quad (2)$$

where β_{mk} is fading attenuation between m-th transmitter antenna and k-th receiver antenna. The initial phase offsets of the PN sequence and the carrier at the receiver are denoted as ζT_c and θ_{mk}, respectively. Additive white gaussian noise(AWGN) is denoted as $n(t)$, which has zero mean and one-sided spectral density of N_0. Since the distances between each pair of

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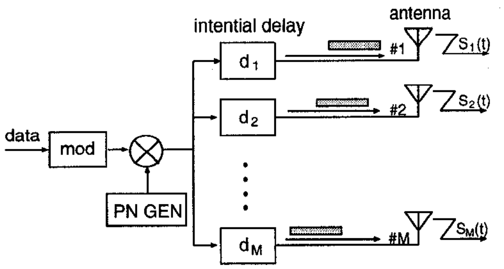

Fig. 1. Transmitter model

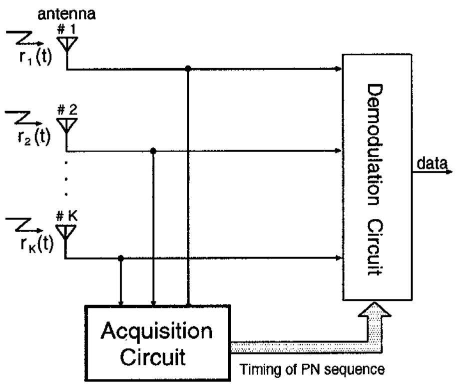

Fig. 2. Receiver model

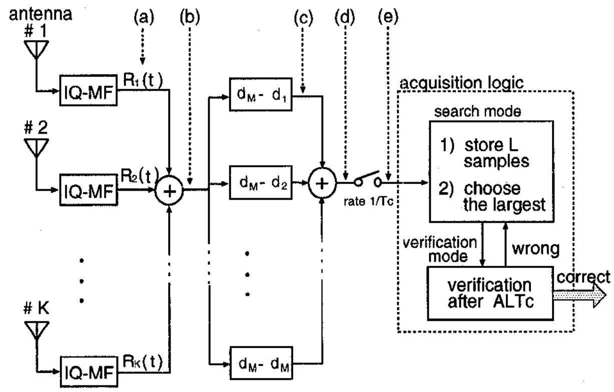

Fig. 3. Acquisition circuit

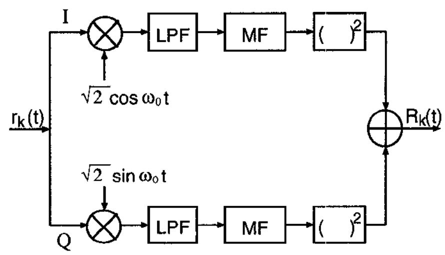

Fig. 4. IQ-MF

transmitter antenna and receiver antenna are approximately the same all over m and k, it can be assumed that all the signals arrive at K receiver antennas simultaneously, in other words, the difference of the arrival timings of the signals between different receiver antennas are negligibly small. Hence, the phase offset of PN code ζ is common for all over the M and K antennas. Since the fading characteristics of different pairs of transmitter and receiver antennas are assumed to be mutually independent, for each m and k, β_{mk} is an independently and identically distributed (i.i.d.) Rayleigh random variable with the probability density function (pdf)

$$p(\beta_{mk}) = 2\beta_{mk}\exp\left(-\beta_{mk}^2\right) \quad \text{for } \beta_{mk} \geq 0, \qquad (3)$$

where the mean square value of β_{mk} is normalized to be unity.

III. Acquisition Circuit

The proposed acquisition circuit is shown in Fig.3, and the IQ-MF in the figure is shown in Fig.4. Since we assume a packet radio communication scheme, the acquisition process is expected to be completed during the preamble of a packet which has no data modulation.

A. Signals at each stage of Acquisition Circuit

In this section, we show the signal waveforms at each stage of the acquisition circuit with the help of Fig.5, which shows the case that the number of transmitter antenna is two. In this figure, influences of fading and noise are omitted.

The output of the IQ-MF of the k-th receiver antenna, (a) of Fig.3 and 5, is represented as

$$R_k(t) = \Big(\sum_{m=1}^{M} \sqrt{S/M}\beta_{mk}\Lambda(t - d_m - \zeta T_c)\cos\theta_{mk} + n_I(t)\Big)^2$$
$$+\Big(\sum_{m=1}^{M} \sqrt{S/M}\beta_{mk}\Lambda(t - d_m - \zeta T_c)\sin\theta_{mk} + n_Q(t)\Big)^2, \qquad (4)$$

where $n_I(t)$ and $n_Q(t)$ is the noise components at I and Q branches of IQ-MF respectively, and $\Lambda(\cdot)$ is the auto-correlation function of PN sequence. For simplicity of analysis, we approximate the auto-correlation function with a simple triangle function which is represented as

$$\Lambda(\tau) = \int_0^{LT_c} c(\delta)c(\delta - \tau)d\delta$$
$$= \begin{cases} L(T_c - |\tau|) & |\tau| \leq T_c \\ 0 & T_c < |\tau|, \end{cases} \qquad (5)$$

where τ is the phase offset of PN sequence. In this paper, we use the term "sync-timing" of the signal from m-th transmitter antenna to refer the timing that $t = d_m + \zeta T_c$. The outputs corresponding to two different receiver antennas, $R_k(t)$ and $R_l(t)$, are shown in Fig.5(a). This figure assumes two transmitter antennas sending an identical signal in different timings

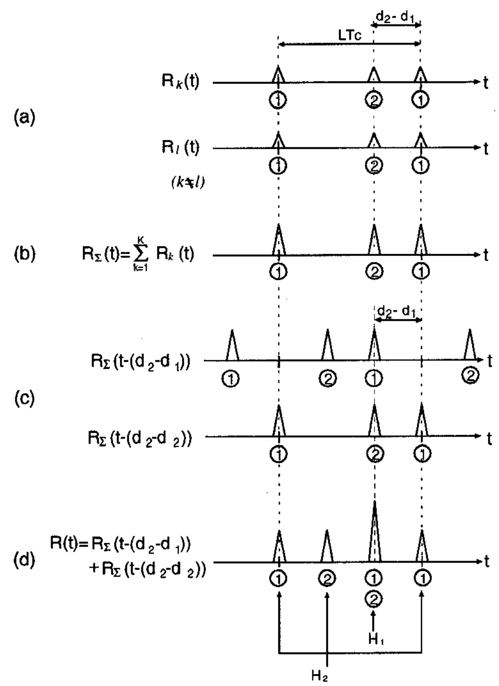

Fig. 5. Signal waveforms at each stage

: the peaks labeled ① and ② correspond to the sync-timings of the signals from the first and second transmitter antenna, respectively.

Next, we consider the summation of the IQ-MF's outputs all over the receiver antennas—(b) in the figures. Signal waveform after the summation, $R_\Sigma(t) = \sum_{k=1}^{K} R_k(t)$, appears as Fig.5(b).

Then, to compensate the delays introduced at transmitter antennas, the delays $d_M - d_m$ $(m = 1, 2, \cdots M)$ are introduced at the receiver. The waveforms of the signals at the branches in Fig.3(c), $R_\Sigma(t - (d_M - d_m))$, are shown in Fig.5(c).

The summation of these signals (Fig.3(d)), $R(t) = \sum_{m=1}^{M} R_\Sigma(t - (d_M - d_m))$, is then illustrated in Fig.5(d). We may notice that there is a peak which includes all the peaks of the signals from M transmitter antennas. If the receiver detect this peak properly, the receiver can acquire sync-timings of all the signals from M transmitter antennas, in other words, the receiver can despread all the signals. In this paper, we use the term "full-peak" to refer to this peak. In addition to this peak, there exist several small peaks which include only one peak of a signal from a transmitter antenna. If the receiver takes one of these small peaks, the receiver can despread only one signal from a transmitter antenna. In this paper, we use the term "partial-peak" to refer to these small peaks.

Finally, the signal at (d) is sampled at every chips — Fig.3(e). In this process, we assume that the chip synchronization is perfect. The acquisition logic uses these samples to find the timing of PN sequence, as is described in the followings.

B. Acquisition Process

The acquisition process in the acquisition logic of Fig.3 has two modes, i.e., the search mode and the verification mode. Acquisition is performed based on the following algorithm.

1) The search mode employs the parallel search strategy. The L samples for LT_c seconds are stored in a memory.
2) The largest one among the L samples is selected, and this is considered, tentatively, to be full-peak, then the acquisition system is turned to the verification mode to test this hypothesis.
3) In the verification mode, the above hypothesis is examined in A-bit duration (ALT_c second). If the sample is verified to be of full-peak, acquisition is declared and despreading is performed based on the timing of this sample, otherwise, the system goes back to 1). In this paper,we assume that the verification mode works ideally.

C. Probability density of the signals

In this subsection, we discuss the probability density function (pdf) of the samples used in the acquisition logic.

The pdf of the IQ-MF output of each receiver antenna at the sampling timings $R_k(nT_c)$ is given by (6) and (7)[4], where $\mathrm{H}_{01}(m)$ represents the case that the sampling timing corresponds to the sync-timing of the signal from m-th transmitter antenna, and H_{00} is the case that the sampling timing corresponds to none of the sync-timings of every signals from M transmitter antennas.

$$P_{R_k}(x|\mathrm{H}_{01}(m)) = f_{NC_{\chi^2}}(x, {\sigma_n}^2, {a_{mk}}^2, 1) \quad (6)$$

$$P_{R_k}(x|\mathrm{H}_{00}) = f_{C_{\chi^2}}(x, {\sigma_n}^2, 1), \quad (7)$$

where

$${a_{mk}}^2 = \frac{{\beta_{mk}}^2 L^2 {T_c}^2 S}{M} \quad {\sigma_n}^2 = \frac{N_0 L T_c}{2}. \quad (8)$$

In the above equations, $f_{NC_{\chi^2}}(x, \cdot, \cdot, n)$ and $f_{C_{\chi^2}}(x, \cdot, n)$ are the probability distribution function (pdf) of noncentral and central chi-square distribution with $2n$ degrees of freedom respectively, and they are expressed as [1].

$$f_{NC_{\chi^2}}(x, \sigma^2, s^2, n) = \frac{1}{2\sigma^2}\left(\frac{x}{s^2}\right)^{\frac{n-1}{2}} \exp\left(-\frac{x+s^2}{2\sigma^2}\right) \cdot I_{n-1}\left(\sqrt{x}\frac{s}{\sigma^2}\right) \quad (9)$$

$$f_{C_{\chi^2}}(x, \sigma^2, n) = \frac{1}{(2\sigma^2)^n (n-1)!} x^{n-1} \exp\left(-\frac{x}{2\sigma^2}\right), \quad (10)$$

where, $I_\alpha(x)$ is the αth-order modified Bessel function of the first kind represented by the infinite series

$$I_\alpha(x) = \sum_{k=0}^{\infty} \frac{(x/2)^{\alpha+2k}}{k!\Gamma(\alpha+k+1)}, \quad (11)$$

where $\Gamma(\cdot)$ is the gamma function, defined as

$$\Gamma(p) = \int_0^\infty t^{p-1}e^{-t}dt \qquad p > 0$$
$$\Gamma(p) = (p-1)! \qquad p : integer, p > 0. \quad (12)$$

Next, we consider the probability density function of the signal at Fig.5(b). The signal is the sum of K i.i.d. chi-square random variables, each with 2 degrees of freedom. Thus the signal, $R_\Sigma(nT_c)$, follows chi-square distribution with $2K$ degrees of freedom, given by

$$P_{R_\Sigma}(x|\mathrm{H}_{01}(m)) = f_{NC_{\chi^2}}(x, {\sigma_n}^2, {a_m}^2, K) \qquad (13)$$

$$P_{R_\Sigma}(x|\mathrm{H}_{00}) = f_{C_{\chi^2}}(x, {\sigma_n}^2, K), \qquad (14)$$

where

$$\begin{aligned} {a_m}^2 &= \sum_{k=1}^{K} \frac{{\beta_{mk}}^2 L^2 {T_c}^2 S}{M} \\ &= \sum_{k=1}^{K} {a_{mk}}^2. \end{aligned} \qquad (15)$$

Finally, let us consider the pdf of the samples used in the acquisition logic, i.e. $R(nT_c)$. The samples are classified in the following three classes: the sample corresponding to full-peak(H_1), samples corresponding to partial peaks for the m-th transmitter antenna($\mathrm{H}_2(m)$), and samples corresponding to none of these peaks (H_0). Since the samples at Fig.5(e) is the sum of M i.i.d. chi-square random variables, each with $2K$ degrees of freedom, the samples $R(nT_c)$ follow chi-square distribution with $2MK$ degrees of freedom as follows.

$$P_R(x|\mathrm{H}_1) = f_{NC_{\chi^2}}(x, {\sigma_n}^2, a^2, MK) \qquad (16)$$

$$P_R(x|\mathrm{H}_2(m)) = f_{NC_{\chi^2}}(x, {\sigma_n}^2, {a_m}^2, MK) \qquad (17)$$

$$P_R(x|\mathrm{H}_0) = f_{C_{\chi^2}}(x, {\sigma_n}^2, MK), \qquad (18)$$

where

$$\begin{aligned} a^2 &= \sum_{m=1}^{M}\sum_{k=1}^{K} \frac{{\beta_{mk}}^2 L^2 {T_c}^2 S}{M} \\ &= \sum_{m=1}^{M} {a_m}^2. \end{aligned} \qquad (19)$$

IV. Performance Analysis

A. Measures of Performance

In this paper, we evaluate the performance of the proposed scheme by the following three measures.

1) *Mean Acquisition Time*
Mean acquisition time has been most widely used for the measure of performance of the acquisition scheme. This is the expectation of the time needed to acquire the timing of PN sequence. To find this value, we assume that the preamble length is infinite.

2) *Miss-Acquisition Probability :* p_{macq}
In packet radio communications, the acquisition must be completed within a preamble of a packet, or the packet would be lost. Thus the probability that the acquisition circuit cannot acquire the timing of PN sequence within a certain time period is calculated. For this calculation, we assume that the preamble length is NLT_c.

3) *Required Preamble Length :* N_{req}
From the viewpoint of the efficiency of the channel capacity, the preamble length should be as short as possible. Thus, we employ the preamble length required for the acquisition circuit to acquire the timing of PN sequence with the probability more than p_{acq} as another performance measure.

B. Mean Acquisition Time

In this subsection, we derive the mean acquisition time of the proposed scheme in a similar way to [4]. The state transition diagram is shown in Fig.6. The state "S" represents the condition that the acquisition circuit has been detecting the timing corresponding to full-peak, and the state "Acq", which is the sole absorbing state, represents the condition that the acquisition is completed. In this figure, $G_1(z)$ denotes the generating function of the correct decision through the search mode and the verification mode, and $G_2(z)$ denotes that the candidate of the search mode is rejected in the verification mode. $G_1(z)$ and $G_2(z)$ is given by

$$G_1(z) = P_D z^{(A+1)LT_c} \qquad (20)$$
$$G_2(z) = (1-P_D) z^{(A+1)LT_c}, \qquad (21)$$

where P_D denotes the probability that the selected sample in the search mode corresponds to the full-peak.

Using $G_1(z)$ and $G_2(z)$, the generating function of the acquisition time is obtained as

$$\begin{aligned} G(z) &= G_1(z) + G_2(z)G_1(z) + {G_2}^2(z)G_1(z) + \cdots \\ &= \frac{G_1(z)}{1 - G_2(z)}. \end{aligned} \qquad (22)$$

We can see that the acquisition probability $G(1) = 1$ when the length of the preamble is infinite. The acquisition time is a

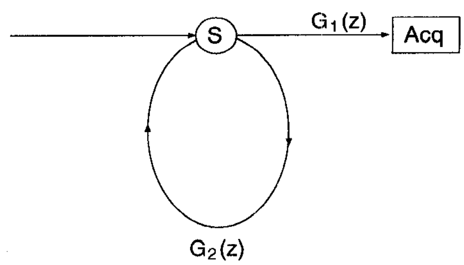

Fig. 6. Transition state diagram

random variable due to noise, and the average of this is given by

$$\overline{T_{acq}} = \frac{d}{dz}\ln G(z)|_{z=1}, \quad (23)$$

where $\overline{x}$ means ensemble average over the noise. With (20)-(22), (23) becomes

$$\overline{T_{acq}} = \frac{1+A}{P_D}LT_c. \quad (24)$$

Since, P_D is the function of the fading coefficient β_{mk}, so (24) can be expressed as

$$\overline{T_{acq}}(\beta_{11},\beta_{12},\cdots,\beta_{MK}) = \frac{(1+A)LT_c}{P_D(\beta_{11},\beta_{12},\cdots,\beta_{MK})}. \quad (25)$$

In this paper, we assume that β_{mk} keeps a constant value over the acquisition process, and for each m and k, β_{mk} is independently and identically distributed. Thus, the mean acquisition time is expressed as

$$\mathrm{E}[\overline{T_{acq}}] = (1+A)LT_c \int\!\cdots\!\int \left[\prod_{k=1}^{k=K}\prod_{m=1}^{m=M} p(\beta_{mk})\right] P_D(\beta_{11},\beta_{12},\cdots,\beta_{MK})^{-1} d\beta_{11}d\beta_{12}\cdots d\beta_{MK}, \quad (26)$$

where E$[x]$ denotes the average over the attenuation due to fading.

From (26), the remained problem to find the mean acquisition time is the derivation of the function $P_D(\beta_{11},\beta_{12},\cdots,\beta_{MK})$.

1) $M = 1$

When the number of transmitter antenna is one, it is not necessary to introduce the delays to distinguish transmitter antennas, and thus $R(t) = \sum_{k=0}^{K} R_k(t)$. In this case, the samples can be classified only into two classes. The first one is with the sync-timing of the signals, and the second is involving none of the peaks.

The detection probability in the search mode $P_D(\beta_{11},\beta_{12},\cdots,\beta_{MK})$ is the probability that the largest sample is corresponding to the peak. Since all L samples are independent when $M = 1$, using (16) and (18), we can express the detection probability as

$$P_D(\beta_{11},\beta_{12},\cdots,\beta_{1K}) = \int_0^\infty f_{NC_{\chi^2}}(y,{\sigma_n}^2,a^2,K) \left[\int_0^y f_{C_{\chi^2}}(x,{\sigma_n}^2,K)dx\right]^{L-1} dy. \quad (27)$$

2) $M \geq 2$

When multiple transmitter antennas are in use, the L samples are not independent each other. This is because the sum of IQ-MF outputs, $R_\Sigma(nT_c)$, at each sampling timings affects M samples, i.e. at $t = nT_c - (d_M - d_1), nT_c - (d_M - d_2), \cdots, nT_c - (d_M - d_M)$.

Thus, the detection probability $P_D(\beta_{11},\beta_{12},\cdots,\beta_{MK})$ can not be expressed easily with (16)-(18), not like with $M = 1$. In this paper, we derive the detection probability $P_D(\beta_{11},\beta_{12},\cdots,\beta_{MK})$ by simulation and we use monte-carlo integration in (26).

C. *Miss-Acquisition Probability and Required Preamble Length*

The miss-acquisition probability is represented as

$$p_{macq} = \int\!\cdots\!\int \left[\prod_{m=1}^{m=M}\prod_{k=1}^{k=K} p(\beta_{1k})\right] (1 - P_D(\beta_{11},\beta_{12},\cdots,\beta_{MK}))^{\frac{N}{1+A}} d\beta_{11}d\beta_{12}\cdots d\beta_{MK} \quad (28)$$

When $M = 1$, we derive the detection probability $P_D(\beta_{11},\beta_{12},\cdots,\beta_{MK})$ using (27).

When $M \geq 2$, detection probability $P_D(\beta_{11},\beta_{12},\cdots,\beta_{MK})$ can not be derived easily. Thus, in this paper, we derive the detection probability $P_D(\beta_{11},\beta_{12},\cdots,\beta_{MK})$ by simulation and we use monte-carlo integration in (28).

We derive the required preamble length N_{req} by increasing N until $(1 - p_{macq}) > p_{acq}$ is fulfilled.

V. Numerical Examples

We calculate the mean acquisition time, miss-acquisition probability, and required preamble length of the proposed scheme under the following conditions.

- The length of PN sequence : $L = 63$.
- Time required in the verification mode : $ALT_c = 4LT_c$.

In the following discussions, the bit energy E_b is defined as ST_b, and noise power is normalized to be $2\sigma_n^2 = 1$.

The mean acquisition time of the proposed scheme is shown in Fig.7. From this figure, it can be seen that the receive antenna diversity offers a substantial performance improvement. Figure.7 also shows that the transmit antenna diversity improves the performance when the number of the receiver antenna is one and E_b/N_0 is larger than about 3dB. This is the result of the tradeoff between the prevention of the drop of the total received power by antenna diversity and the noncoherent combining loss due to the dispersion of the transmitted power. When E_b/N_0 is larger than about 3dB, the former factor influences larger, though the latter dominates if E_b/N_0 is smaller. If the receiver uses plural antennas, however, the transmit antenna diversity less improves the performance even when E_b/N_0 is large. The reason of this is that when the receive antenna diversity is in use, we can mitigate fading to some extent even when $M = 1$, and performance improvement by transmit antenna diversity does not influences much.

Next, we show the miss-acquisition probability of the proposed scheme in Fig.8. We assume that the length of the preamble is 40bits. This figure shows again that the receive antenna diversity improves the performance substantially. Not as in Fig.7, however, the transmit antenna diversity improves the performance in large E_b/N_0, even when the number of the receiver antenna is more than one. This fact implies that the transmit antenna diversity mitigates the effect of fading especially when the received power drops largely and the acquisition circuit tends to fail the synchronization of PN sequence. This situation dominates miss-acquisition probability, and thus the performance improvement is considerably large, while the average at time is less improved.

In Fig.9, the required preamble length of the proposed scheme is showed. We assume that the required acquisition probability p_{acq} is 99.9%. In this figure, it can be found again that the receive antenna diversity improves the performance. The interesting result from this figure is that the transmit antenna diversity improves the performance in almost all E_b/N_0, and that the improvement itself is remarkably large, especially when the number of the transmitter antenna increases from one to two. The reason of this performance improvement is the same as for Fig.8, i.e. transmit antenna diversity improves performance of acquisition especially when the fading is deep, which dominates the required preamble length.

VI. Conclusion

In this paper, we considered the introduction of space diversity techniques for the acquisition of PN sequence of a direct-sequence spread-spectrum signal and proposed a new acquisition scheme with the transmit and the receive antenna diversity.

From the numerical examples, we have shown that the receive antenna diversity is very effective in acquisition of PN sequence of a DS/SS signal in flat and slow Rayleigh fading channels. Though the transmit antenna diversity is not as effective as the receive antenna diversity in the sense of the mean acquisition time, it achieves substantial performance improvements in the sense of miss-acquisition probability and required preamble length, which are important performance measures of packet radio communication systems.

Acknowledgment

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References

[1] J.G.Proakis, "Digital Communications, 3rd edition", New York: McGrawHill,1995.

[2] B.Sklar, "Rayleigh Fading Channels in Mobile Digital Communication Systems Part I: Characterization", IEEE Communications Magazine, pp90-100, July 1997.

[3] S. Aikawa, A. Sato, Y.Nakayama, S.Kurosaki, T.yoshida, "Transmission Performance and Diversity Technique of 100 Mbps Indoor Radio on 37GHz",IEICE Trans. Commun, vol.E81-B, NO.4, pp798-805, April 1998.

[4] E.A.Sourour, S.C.Gupta, "Direct-Sequence Spread-Spectrum Parallel Acquisition in a Fading Mobile Channel", IEEE Trans.Commun., vol.38, NO.7, pp992-998, July 1990.

[5] R.R.Rick, L.B.Milstein, "Parallel Acquisition of Spread-Spectrum Signals with Antenna Diversity", IEEE Trans. Commun., vol.45, NO.8, pp903-905, August 1997.

[6] K.Ban, M.Katayama, T.Yamazato, A.Ogawa, "A Simple Transmit/Receive Antenna Diversity for Indoor DS/CDMA Communication Systems",IEICE Trans. Commun, vol.E80-B, NO.12, pp1790-1796, Descember 1997.

[7] Y.Ikai, M.Katayama, T.Yamazato, A.Ogawa, "A New Acquisition Scheme of a DS/SS Signal with Antenna Diversity in Rayleigh Fading Channel", Tokai-Section Joint Conference of the Seven Institutes of Electrical and Related Engineers, pp254, September 1997.

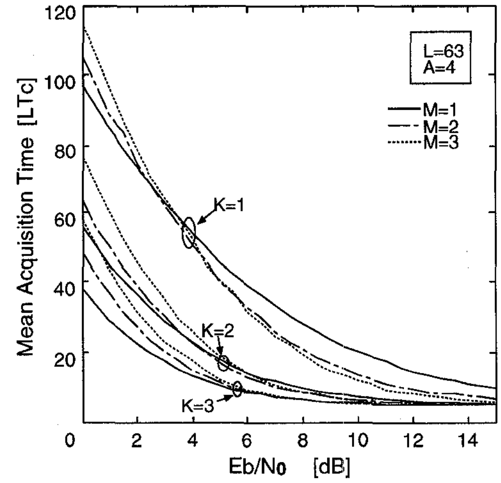

Fig. 7. Mean acquisition time

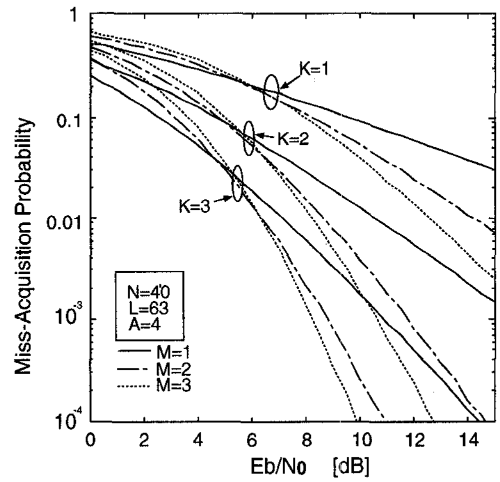

Fig. 8. Miss-acquisition probability

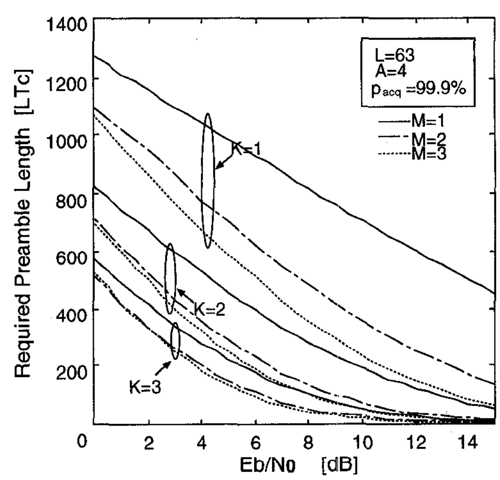

Fig. 9. Required preamble length