# PERFORMANCE ANALYSIS OF PN CODE ACQUISITION OF A SMART ANTENNA SYSTEM IN A DS/CDMA SIGNAL ENVIRONMENT

Yusuk Yun (School of Electrical and Computer Engineering, Hanyang University, Seoul,
133-791, Korea, yusukyun@dsplab.hanyang.ac.kr); Soojin Kim
(soojin7978@dsplab.hanyang.ac.kr); Taeyoul Oh (tyoh@dsplab.hanyang.ac.kr);
Seungwon Choi (choi@ieee.org)

## ABSTRACT

This paper presents a performance analysis of a novel searcher designed for array antenna in terms of average acquisition time as well as detection and false alarm probability. It has been shown that proposed searcher significantly reduces the acquisition time compared to the conventional searcher, which does not exploit the merit of array antenna structure. Due to the shortened acquisition time, which is provided by the phase diversity, the smart antenna system utilizing the phase diversity can enhance the demodulation performance, which consequently improves the system capacity, service area, and entire throughput.

## 1. INTRODUCTION

As mobile communication services are developed, the needs of service for Internet access and convergence service of broadcasting and communication are rapidly increased. One of the properties of these services is a capability of transmission of higher rate data service to more subscribers than voice-oriented services. The techniques for wireless communication systems which can support higher data rate services to more number of mobile stations under limited resource-frequency bandwidth, transmit power, etc. have been researched intensively[1, 2]. Smart antenna is a spot-lighted technique that improves the capacity, service area and throughput of the communication system. The benefits of smart antenna system are based on the optimal beam-forming that increases the gain along the direction of desired signal using array antennas and can decrease the gain to the other direction's.

For proper demodulation and detection of received signals in CDMA system the synchronization of the propagation delay of received signal and the local PN code's offset must be guaranteed. The procedure of finding the local PN code which is coincident with the delay of received signal is known as PN code acquisition and the searcher of CDMA system performs the PN code acquisition. The performance enhancement of the PN code acquisition is provided by the smart antenna system in terms of average acquisition time and detection and false alarm probability of searcher utilizing the phase diversity[1] of received signals at array antenna.

Section 2 describes a received signal and channel modeling for a DS/CDMA smart antenna system. Section 3 presents a technique for PN code acquisition. Section 4 provides performance analysis in terms of acquisition time as well as detection and false alarm probability with AWGN and Rayleigh fading channel.

## 2. RECEIVED SIGNAL

For simplicity but without loss of generality, let's assume that the transmitted signal consists of the pilot signal only, i.e. all 1's. Note that the CDMA signal in general consists of pilot and traffic signals. Then, the received signal at the $n^{th}$ antenna element can be written as [2]

$$r_n(t) = \sqrt{P} \sum_{l=1}^{L} \alpha_n(t,\phi_l;l)\ c(t-\tau_l) + m_n(t) + w_n(t) \tag{1}$$

where $P$ is the received power, $\alpha_n(t,\phi_l;l)$ denotes the channel response of the $l^{th}$ path components for the propagation channel, $\phi_l$ is the arrival direction of the $l^{th}$ path, $c(t)$ denotes the PN code, $\tau_l$ is the propagation delay of the $l^{th}$ path, $L$ is the number of scattered components, $m_n(t)$ is the MAI (Multiple Access Interference), and $w_n(t)$ is the background white noise. Note that it has been assumed that the propagation delays between the transmitting subscriber and each of the antenna elements through the $l^{th}$ path are identical to each other.

## 3. PN CODE ACQUISITION

To achieve the synchronization of the local PN-code to the received signal in CDMA systems, the received signal shown in (1) is correlated with the locally generated PN code for which the time lag should be exhaustively tested within a preset interval. In this paper the correlation value, which is often referred to as the “decision value”, is obtained from each of the antenna channels and summed for each time lag of the local PN code. Then, PN code acquisition performance can be significantly enhanced according to [1].

The intermediate decision variable at the $n^{th}$ antenna element $Z_n$ can be written as

$$Z_n = \left| \frac{1}{\sqrt{KT_c}} \int_0^{KT_c} r_n(t)c(t-\xi)dt \right|^2 \qquad (2)$$

where $T_c$ is the chip period, $K$ is the correlation length, and $\xi$ is the time lag of the local PN code in the receiver.

The final decision variable, $Z$, obtained by summing up the intermediate decision variables at each of the antenna channels can be written as

$$Z = \sum_{n=1}^{N} Z_n \, . \qquad (3)$$

## 4. SIMULATIONS AND PERFORMACES

In this section, we present the performances of the PN code acquisition obtained through extensive computer simulations. The performance analysis presented in this paper has been focused on PN code acquisition time together with detection and false alarm probability. The detection and false alarm probability can be generalized as [3]

$$\begin{aligned} P_d &= \Pr\{ Z > \beta_T \mid \xi = \tau_l \} \\ P_{fa} &= \Pr\{ Z > \beta_T \mid \xi \neq \tau_l \} \end{aligned} \qquad (4)$$

where $P_d$ and $P_{fa}$ is the detection and false alarm probability, respectively and $\beta_T$ denotes the optimum threshold which should be preset to maximize the performance in terms of the mean acquisition time and the detection and false alarm probabilities.

Mean acquisition time is the average time required for testing all the time lag candidates in a preset interval with an assumption that only a single time lag candidate of the local PN code is matched to the propagation delay of the received signal. The mean acquisition time is a function of the detection and false alarm probability, which can be written as [3]

$$T_{acq} = \frac{2 + (2 - P_d)(W-1)(1 + T_p P_{fa})}{2P_{fa}} \times T_{acc} \qquad (5)$$

where $W$ is the number of time lag candidates in the local PN code, $T_p$ is a penalty time for a false alarm and $T_{acc}$ is the time required to test a single candidate of the local PN code time lag.

In our computer simulations, the correlation length $K$ has been set to 384chips, the number of the candidates of PN code time lag $W$ becomes 128chips, and the penalty time $T_p$ for a false alarm is 100 chips.

Figure 1 shows that the detection and false alarm probability of the searcher as a function of the number of antenna elements with AWGN propagation channel. As shown in Figure 1, the performance in terms of detection of false alarm probability improves as the number of antenna increases.

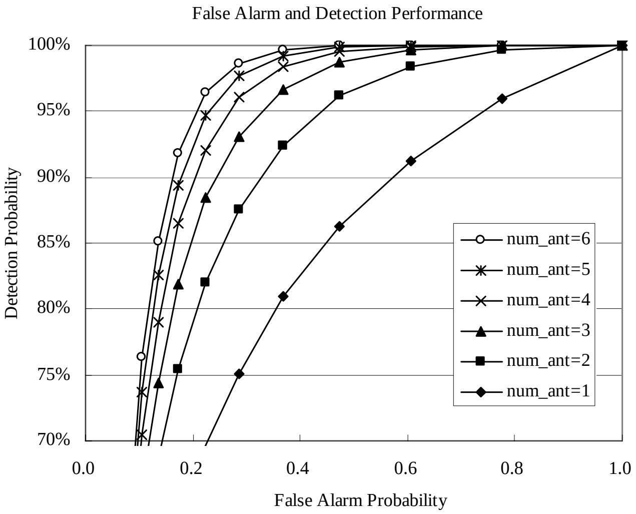

Figure 1. Detection and false alarm probability with AWGN ($P/\sigma_w^2$=-20dB) showing that the performance improves as the number of antenna increases

Figure 2 illustrates that the detection and false alarm probability of the searcher as a function of the number of antenna elements with Rayleigh fading propagation channel. As shown in Figure 2, the performance in terms of detection of false alarm probability improves as the number of antenna increases.

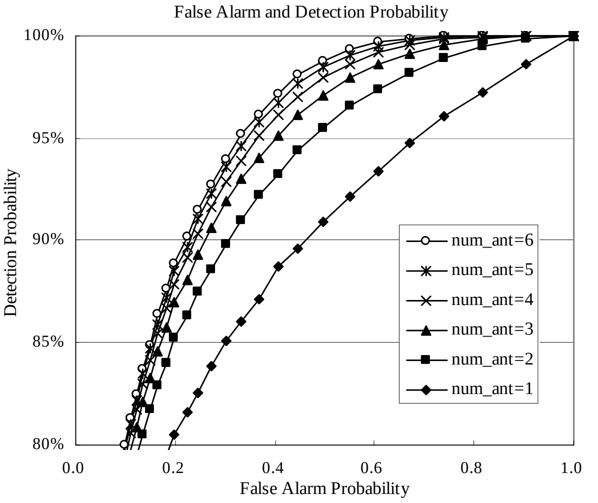

Figure 2. Detection and false alarm probability with Rayleigh fading ( $P/\sigma_w^2$ =-15dB) showing that the performance improves as the number of antenna increases

Figure 3 and Figure 4 show that the mean acquisition time as the function of the number of antenna elements when false alarm probability is set to be less than 0.2 and 0.1, respectively. It can be observed from figures that the mean acquisition time decreases as the number of antenna elements increases.

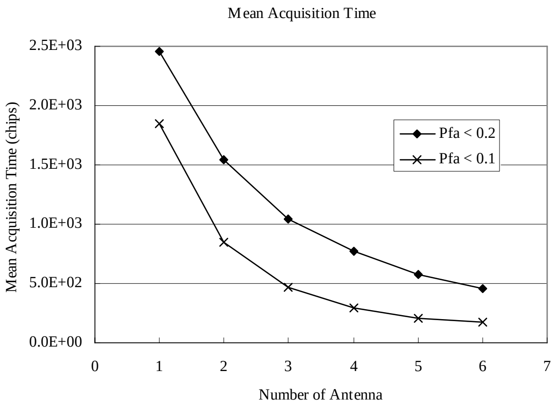

Figure 3. Mean acquisition time as the function of the number of antenna with AWGN ( $P/\sigma_w^2$ =-20dB) showing that the mean acquisition time decreases as the number of antenna increases

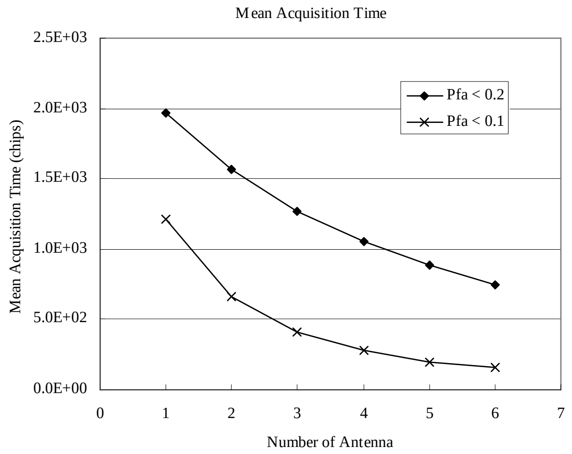

Figure 4. Mean acquisition time as the function of the number of antenna with Rayleigh fading ( $P/\sigma_w^2$ =-15dB) showing that the mean acquisition time decreases as the number of antenna increases

## 5. CONCLUSIONS

This paper has shown the performances of PN code acquisition for a DS/CDMA smart antenna system in terms of the acquisition time as well as the detection and false alarm probability. The key part of the proposed technique is to compute the correlation values at each of the antenna channels and to sum up the intermediate results at each of the time lags in the local PN code. As the statistical properties of the received signal at each antenna element become nearly independent of each other in most practical CDMA signal environments, we can exploit a diversity gain when the correlation values obtained at each of the antenna channels are summed. The diversity gain provides a significant improvement in PN code acquisition in practical DS/CDMA signal environments. The performance analysis has shown that the acquisition time as well as detection and false alarm probability are tremendously enhanced as the number of antenna elements in a smart antenna system increases.

## ACKNOWLEDGEMENT

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# Performance Analysis of PN code Acquisition of a Smart Antenna System in a DS/CDMA Signal Environment

Taeyoul Oh
HY-SDR Research Center, Hanyang University, Seoul, Korea
tyoh@dsplab.hanyang.ac.kr

# Contents

# 1. Introduction

- For proper demodulation and detection of received signals in CDMA system the synchronization of the propagation delay of received signal and the local PN code's offset must be guaranteed.

- The performance enhancement of the PN code acquisition is provided by the smart antenna system in terms of average acquisition time and detection and false alarm probability of searcher utilizing the phase diversity of received signals at array antenna.

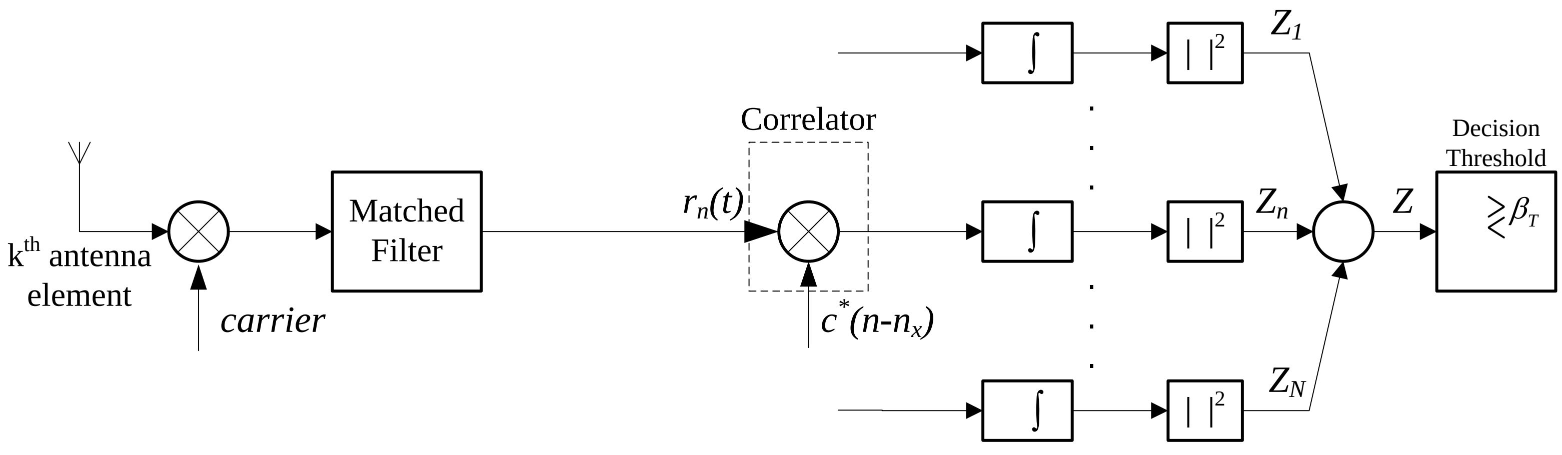
# 2. Received Signal

## ❖ Received Signal

$$r_n(t) = \sqrt{P}\sum_{l=1}^{L} \alpha_n(t,\phi_l;l)\; c(t-\tau_l) + m_n(t) + w_n(t) \qquad (1)$$

- $P$ : received power.
- $\alpha_n(t,\phi_l;l)$ : channel response of the $l^{th}$ path components for the channel propagation channel.
- $\phi_l$ : arrival direction of the $l^{th}$ path.
- $c(t)$ : PN code.
- $\tau_l$ : propagation delay of the $l^{th}$ path.
- $m_n(t)$ : MAI (Multiple Access Interference).
- $w_n(t)$ : background white noise.

# 3. PN code Acquisition



# 3. PN code Acquisition

- $Z_n$ : Intermediate decision variable of at the $n^{th}$ antenna element.

$$Z_n = \left| \frac{1}{\sqrt{KT_c}} \int_0^{KT_c} r_n(t)\, c(t-\xi)\, dt \right|^2$$

  - $T_c$ : chip period.
  - $K$ : correlation length.
  - $\xi$ : time lag of the local PN code in the receiver.

- $Z$ : Final decision variable.

$$Z = \sum_{n=1}^{N} Z_n$$

# 4. Simulation and Performance

- Detection Probability

$$P_d = \Pr\{Z > \beta_T \mid \xi = \tau_l\}$$

- False Alarm Probability

$$P_{fa} = \Pr\{Z > \beta_T \mid \xi \neq \tau_l\}$$

  - Where, $\beta_T$ : optimum threshold.

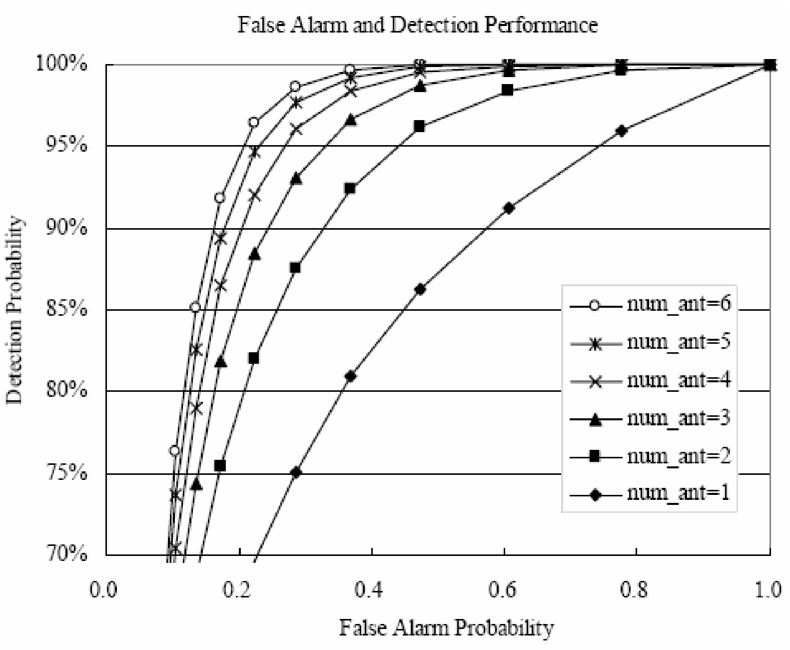
- Mean Acquisition Time( $T_{acq}$ )

$$T_{acq} = \frac{2 + (2 - P_d)(W-1)(1 + T_p P_{fa})}{2P_{fa}} \times T_{acc}$$

  - $W$: number of time lag candidates in the local PN code.
  - $T_p$: penalty time for a false alarm.
  - $T_{acc}$: time required to test a single candidate of the local PN code time lag

# 4. Simulation and Performance

- Simulation assumption
  - $K$ : 384 chips.
  - $W$ : 128 chips.
  - $T_p$ : 100 chips.
- False Alarm and Detection Probability



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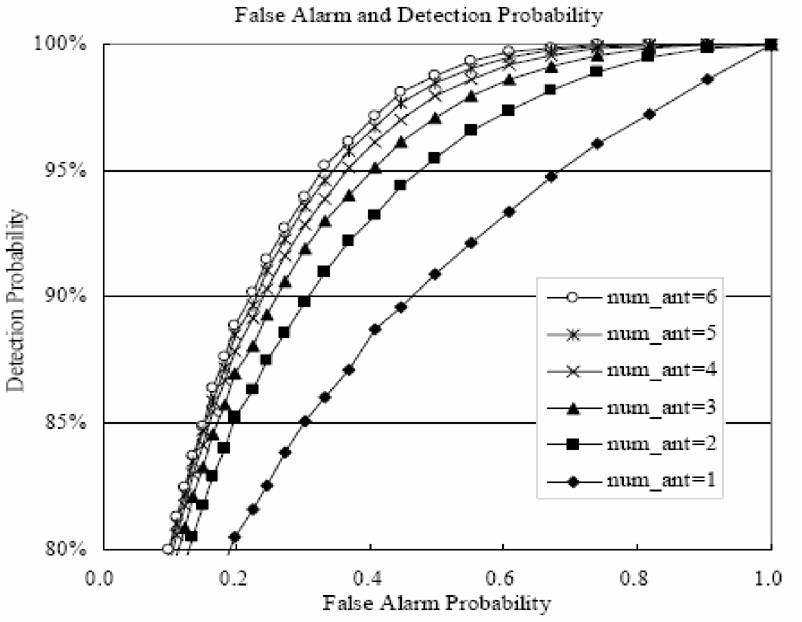
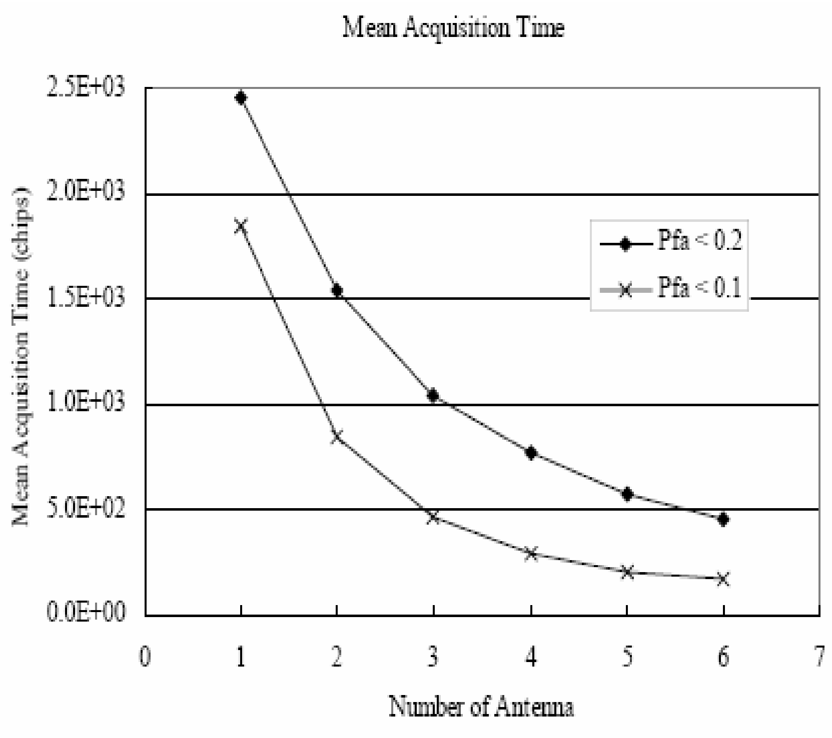


<Rayleigh fading(SNR:-15dB)>

# 4. Simulation and Performance

- Mean Acquisition Time



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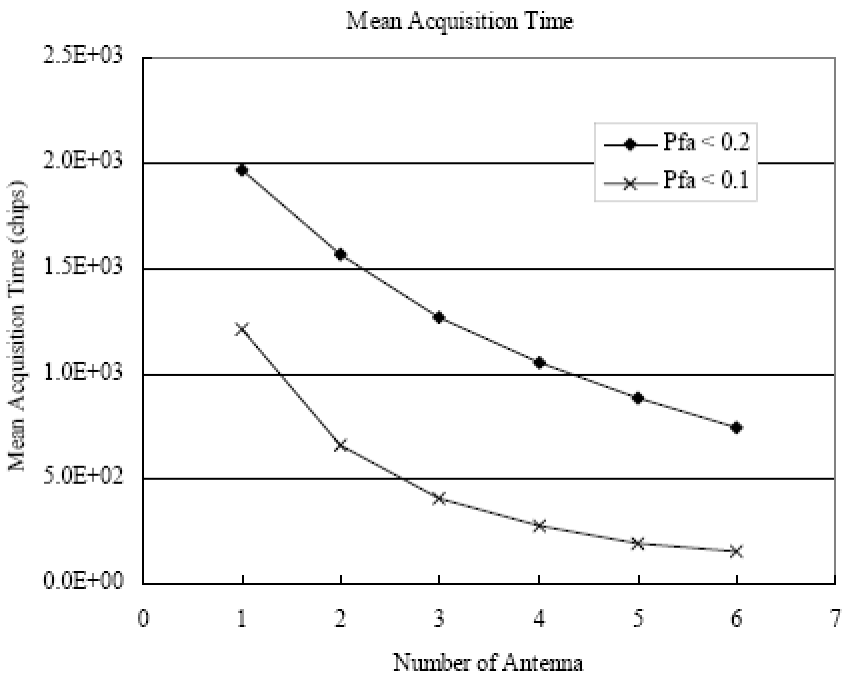

<Rayleigh fading(SNR:-15dB)>

# 5. Conclusions

- This paper has shown the performances of PN code acquisition for a DS/CDMA smart antenna system in terms of the acquisition time as well as the detection and false alarm probability.

- The key part of the proposed technique is to compute the correlation values at each of the antenna channels and to sum up the intermediate results at each of the time lags in the local PN code.

- The performance analysis has shown that the acquisition time as well as detection and false alarm probability are tremendously enhanced as the number of antenna elements in a smart antenna system increases.