CHAPTER 5

PERFORMANCE ANALYSIS OF SWITCHED DIVERSITY IN CDMA

5.1 Introduction 116

5.2 System Model of Switched Diversity 117

5.3 Bit Error Rate Performance of Switched Diversity with Threshold 119

5.4 The Switched Diversity Combining with Fuzzy Threshold Control 119

5.5 Results & Discussion 123
CHAPTER 5

PERFORMANCE ANALYSIS OF SWITCHED DIVERSITY IN CDMA

5.1 Introduction

It is well known that multipath fading is one of the main causes of performance degradation in a CDMA mobile radio system [88]. A widely recognized technique for combating fading effects in CDMA, is the use of a diversity combiner [88,89,90,91,92]. The two or more radio links of a diversity channel are presumed to be statistically independent. There are basically four diversity combining methods, maximal-ratio combining, equal gain combining, selective combining and switched combining. The maximal-ratio combining and equal-gain combining require very complicated analog circuitry, thus, having hardly been used in practice. The maximum ratio and equal gain combining have excellent performance. Selective combining and switched combining are two potential techniques in practice due to their simplicity in implementation with moderate performance. Typically, selective combining requires multiple receivers, one for each branch. When the channel variation is very slow, selective combining may be achieved with a reduced number of receivers [91,92]. A.Arasteh [91] described the received signal measurement and selection has been performed with the aid of a pre-amble. Thus, even one receiver could offer an approximate realization of selective combining. However, very often pre-amble [91] and/or post-amble [92] aided combining techniques are only effective in a very slow fading environment. Similarly, switched diversity combining is less costly since it needs only one receiver. However, switched diversity has better performance if the threshold is adapted dynamically in real time based on the present varying channel conditions [89].

Consider a switched diversity combining with adaptive threshold. The adaptive threshold is the dynamic threshold value based on the channel state. In particular, this adaptive threshold is achieved by the use of fuzzy logic control techniques. The technique of fuzzy
logic control has made rapid progress in recent years in the field of communication [93]. The fuzzy application in wireless communication has been reported for equalization in non-linear channel [94]. K.Y.Lee [95] has given a new approach to the equalization of non-linear channels using fuzzy adaptive filters [96]. Similarly, P.Y.Chang et al [97] successfully introduced a fuzzy logic control technique for adaptive power control in a direct-sequence code-division multiple-access (DS/CDMA) cellular system. To achieve an effective fuzzy switched threshold control, both statistical analysis of mobile channels and simulations are used to refine the fuzzy IF-THEN rules. It is shown that the FLTC (fuzzy Logic Threshold Control) achieves significant improvement in the combining performance of the switched diversity while maintaining reasonable simplicity in implementation. In this system, the fuzzy logic control is used to provide an algorithm, which converts the linguistic control strategy, which is based on the characteristics of mobile radio channels, into the threshold-level control strategy for the switched diversity. This fuzzy control strategy is then converted with defuzzification into a crisp threshold control command to adjust the threshold level.

5.2 System Model of switched Diversity

Consider a two-branch switched diversity receiver given by the author Hui HUANG [67] for switched diversity combining. Let \( r_1(t) \) and \( r_2(t) \) be the envelopes of the signals received by the two antenna. It is assumed that the switching is done at discrete instants of time \( t = nT \), where \( n \) is an integer, and \( T \) is the interval between switching instants. Let \( r_1 = r(nT) \) and \( r_2 = r(nT) \) denote the samples of the two signal envelopes at \( t = nT \). The switched diversity combining is considered in this study. Figure 4.1 shows the overall schematics of two branch \( (r_1, r_2) \) switched diversity where “\( Rx \)” represents a receiver. In this scheme, the received signals are scanned in a sequential order, and the first signal with a power level above a certain threshold is selected. While above the threshold, the selected signal remains at the combiner’s output; otherwise, a scanning process is switched to another branch. For the sake of a simple implementation, we further consider the case of switch-and-stay threshold selection. This switching process is further illustrated by assuming two independent fading signals, \( r_1 \) and \( r_2 \) coming from two antennas. Suppose the receiver is initially a state of “receiving \( r_1 \)”. It will “stay” at this
state until $r_1$ goes below the threshold. When $r_1$ is detected to be below the threshold, the receiver switches to receiving $r_2$, no matter what the current signal level of $r_2$ is.

Figure 5.1 Switched Diversity with Threshold Detection
After $r_2$ drops below the threshold, the receiver switches to $r_1$, and so on. As a result, the received signal is obtained. It is noted that the threshold may be either fixed or variable. Setting its level is a task involving the knowledge of the mean signal strength in the geographical area. The performance of the switched diversity is greatly affected by the threshold level. In the proposed work, the bit error rate performance of switched diversity is evaluated by applying the fuzzy logic to the threshold level.

### 5.3 Bit Error Rate Performance of Switched Diversity with Threshold

The average BER of Non Coherent Frequency Shift Keying with switched diversity on two independent Rayleigh-fading channels is given by [99].

$$P_e = \frac{1}{2 + \beta} \left(1 - e^{-\frac{\xi}{\beta}} + e^{-\frac{1}{2} \left(\frac{1}{\beta} + \frac{1}{\beta}\right)}\right)$$

(5.1)

It is seen that $P_e$ is a function of the fading parameter $m$, the average SNR on each branch $\beta$, and the switching threshold $\xi$.

### 5.4 The Switched Diversity Combining with Fuzzy Logic Threshold Control

It is well known, the choice of the fuzzy control rules has a substantial effect on the performance of a Fuzzy Logic Threshold Control (FLTC). Basically, the FLTC comprises four principal components: a fuzzification interface, a fuzzy rule base, an inference engine, and a defuzzification interface [93]. The fuzzification interface intends to convert the input values, such as the current channel state (signal strength), the channel state variation, and the current threshold, into some linguistic values, i.e., fuzzy sets. The fuzzy rule base, which comprises knowledge of the specific application and the attendant control goals, is used to define linguistic control rules and fuzzy number manipulation in an FLTC. Likewise, the inference engine is a decision-making logic mechanism of an FLTC. This concept has been applied to simulate mobile radio channel based on fuzzy
concepts and of inferring fuzzy control actions employing fuzzy implications and the rules of inference in fuzzy logic. Finally, the defuzzification interface converts fuzzy control decisions into crisp value. Which are applied to adjust the threshold level of the switched diversity.

A close observation of mobile channel indicate that, if the threshold level is high, most likely the output signal of the switched diversity will be in the lower value for long time, which in turn implies that the overall system performance will be poor. In such case, the threshold level should be decreased. Similarly, if the threshold level is very low, it becomes more difficult to catch up a high level signal. Thereby, it achieves very little gain especially in the region with high signal strength. Based on these observations, consider four linguistic variables, $S$, $\Delta S$, $Th$ and $\Delta Th$, which denote the present channel state (signal power), the variation of channel state (received signal level), the previous threshold level and the change of threshold level, respectively. The output control linguistic variable is $\Delta Th$, while the other three variables are used as inputs. The schematic of the switched diversity is given in Figure 5.2, which always work with normalized signal power.
Figure 5.2 Fuzzy Threshold Switched Diversity
In this analysis, we shall determine the Fuzzy Rule Base, Inference Engine, and Defuzzification Interface elements.

5.4.1 Fuzzification

The universes of discourse for $S$, $\Delta S$, $Th$ and $\Delta Th$ are assumed to be [11]

\[
U_s = \{ S \mid -30 \text{ dB} \leq S \leq 10 \text{ dB}\}, \tag{5.2}
\]

\[
U_{\Delta S} = \{ S \mid -10 \text{ dB} \leq \Delta S \leq 10 \text{ dB}\}, \tag{5.3}
\]

\[
U_{Th} = \{ Th \mid -30 \text{ dB} \leq Th \leq 10 \text{ dB}\}, \tag{5.4}
\]

\[
U_{\Delta Th} = \{ Th \mid -10 \text{ dB} \leq \Delta Th \leq 10 \text{ dB}\}, \tag{5.5}
\]

Where the bounds of the universes of discourse are determined in terms of the fading statistics of typical wireless channels. The associated fuzzy term sets are \{L (Large), M (Medium), S (Small)} for $S$ and $Th$, and \{PL (Positive Large), PM (Positive Medium), PS (Positive Small), NL (Negative Large), NM (Negative Medium), NS (Negative Small)} for $\Delta S$ and $\Delta Th$.

5.4.2 Fuzzy Inference

It is noted that there are 324 possible combinations of the above fuzzy terms, which generate 324 fuzzy IF-THEN rules. If all the rules are used in constructing the fuzzy system, fuzzy logic design will be very complicated, which in turn contradicts the goal of the present analysis. The experiments show that there are very few IF-THEN rules, which indeed dominate the performance of FLTC. However, an incomplete set of fuzzy IF-THEN rules may cause an ill-defined and unstable fuzzy system, which is not desirable [100]. To overcome this problem, we have chosen the Gaussian membership functions, which cover the whole universes of discourse for each linguistic variable. The following Gaussian membership functions are used [98].

The Analysis for selecting the most significant IF-THEN rules and determining the parameters of the above membership functions is very hard. This is because the wireless channel is always varying, which implies that it is difficult to obtain some input-output pairs such that we can use standard methods such as Gradient Descent Training or
Recursive Least Squares [93] to derive the required membership functions. Eventually, the following six IF-THEN rules, along with the attendant membership functions defined in [102], are shown to be dominant to the overall system performance of the FLTC. The five rules are:

- If $S$ is small, $Th$ is large, $ΔS$ is negative large, then $ΔTh$ is negative large
- If $S$ is small, $Th$ is medium, $ΔS$ is negative medium, then $ΔTh$ is negative medium
- If $S$ is medium, $Th$ is large, $ΔS$ is negative medium, then $ΔTh$ is negative medium
- If $S$ is medium, $Th$ is small, then $ΔTh$ is positive small
- If $S$ is large, $Th$ is small, then $ΔTh$ is positive medium.

If $S$ is large, $Th$ is medium, $ΔS$ is positive medium, then $ΔTh$ is negative small

5.4.3. Defuzzification

The defuzzification is implemented using the product inference engine and the center average defuzzifier [96], and a very simple fuzzy adaptive threshold control $ΔTh_{fuzz}$, is given by:

\[
ΔTh_{fuzz} = \frac{-8Y_1 - 4Y_2 - 4Y_3 + 4Y_4 + Y_5 + Y_6}{Y_1 + Y_2 + Y_3 + Y_4 + Y_5 + Y_6} \tag{5.6}
\]

Where $Y_1 = \mu_S(S) \cdot \mu_L(ΔTh) \cdot \mu_{NL}(ΔS)$, $Y_2 = \mu_S(S) \cdot \mu_M(ΔTh) \cdot \mu_{NM}(ΔS)$, $Y_3 = \mu_M(S) \cdot \mu_L(ΔTh) \cdot \mu_{NM}(ΔS)$, $Y_4 = \mu_L(S) \cdot \mu_S(ΔTh)$, $Y_5 = \mu_M(S) \cdot \mu_S(Th)$, and $Y_6 = \mu_L(S) \cdot \mu_M(Th) \cdot \mu_{NS}(ΔS)$. The threshold control in above equation is implemented in the defuzzification Interface in Figure 5.2.

5.5 Results & Discussion

In this chapter, the probability of bit error rate has been investigated and the probability of bit error rate have been analyzed without diversity and with diversity for different value of the threshold. The Figure 5.3 shows the probability of bit error rate versus signal to noise ratio without the diversity. These result shows that the probability of bit error rate decreases as the signal to noise ratio increases. The probability of error is high in this case because of single receiving path and no diversity is used. The Figure 5.4 shows
the probability of bit error rate for lower threshold value i.e. Th = -4. The Probability of bit error rate decreases with increase in signal to noise ratio but this value is less than the case of without diversity. This value is less because of the two branch diversity and the switching take place at the threshold value. The two branch diversity give good results because of any one of them may have good signal strength. Further, figure 5.5 shows the probability of bit error rate with signal to noise ratio for increased value of the threshold. The probability of bit error rate improved due to higher value of signal to noise ratio at higher threshold value. Next is the figure 5.6 which shows the probability of error with signal to noise ratio by applying fuzzy logic at the threshold value. The probability of bit error rate improves further because of adaptive nature of threshold value. Thus fuzzy logic application has improved bit error rate substantially.

In this work, we have analyzed an effective fuzzy logic control switched diversity (FLTC) scheme, which can be considered to be used in mobile units. To achieve a simplified design of FLTC, which is a key element of the FLTC, the efforts have been made in selecting the most significant fuzzy IF-THEN rules and determining the parameters of the associated membership functions. Eventually, we find that there are in fact only six IF-THEN rules are considered for analysis and the resulted fuzzy threshold control has a very simple form. Results show that the proposed FLTC can achieve a significant improvement in system performance in terms of both the diversity gain and BER over various channel conditions.
Figure 5.3 Probability of Error Rate (No Diversity)
Figure 5.4 Probability of Error Rate (Th=-4)
Figure 5.5 Probability of Error Rate (Th=-8)
Figure 5.6 Probability of Error Rate (fuzzy logic)