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An Intelligent Scheme Switching for Multiple Input and Output System Using Fuzzy Logic Technique

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Abstract: Link adaptation is an important approach to achieve robust, QoS-based wireless multimedia communications. Scheme switching in multiple-input multiple-output (MIMO) systems is an aspect of connection adaptation and involves selecting different MIMO transmission schemes or modes in order to adapt to the different conditions of the radio channel in order to achieve QoS delivery. Finding the most suitable switching method in MIMO links, however, remains a challenge since existing methods are either computationally complex or not always accurate. This paper presents a smart MIMO system switching method consisting of two schemes-transmit diversity (TD) and spatial multiplexing (SM)-using fuzzy logic technique. In this technique, two channel quality indicators (CQI), such as the average received signal - to - noise ratio (RSNR) and the received signal strength indicator (RSSI), are measured and passed to the fuzzy logic system as inputs, which then provides a decision – an inference. To switch between the TD and SM schemes, the switching decision of the fuzzy logic system is fed back to the transmitter. Computation results indicate that the proposed fuzzy logic-based switching technique outperforms standard static switching techniques in terms of bit error rate and spectral efficiency.

Keywords: Fuzzy logic, link adaptation, MIMO, spatial multiplexing, transmit diversity

1. INTRODUCTION

The wireless transmission research community has revealed numerous benefits of using multi antenna and multi - carrier techniques for improved broadband multimedia applications, one of which is MIMO systems [1]. MIMO systems improve spectral efficiency, network throughput, data rate and reliability of connections [2]. MIMO technology has found applications in mobile terminals, access point stations, wireless local area networks (WLANs) and mobile communications standards such as High-Speed Downlink Packet Access (HSDPA), IEEE 802.11n and Long-Term Evolution (LTE) networks [3]. TD and SM are the two widely used MIMO channel communications schemes [4]. The TD scheme, like the orthogonal space - time block code (OSTBC), involves conveying a space - time coded stream of data through several transmitting antennas [5], [6]. This helps to improve diversity and reliability of the system invariably. The SM scheme, on the other hand, involves dividing the information stream into sub-streams and transferring each sub-stream through various individual antennas. As a result of the increased number of information symbols transferable by MIMO symbol [4], [7], this improves the data transmission rate. However, there is a trade - off between the increased data rate that can be achieved by SM and the reliability of the link that can be achieved by TD, particularly under very different channel conditions.

Multiple strategies were proposed to adapt these MIMO schemes to modifying channel requirements by switching between schemes in order to achieve high data rates, maximize spectral efficiency and ensure reliability of links [8]. Most of the current practical switching criteria are based on channel state information (CSI) or CQI calculation with selection rules, algorithms or search tables. CSI / CQI metrics include signal to noise ratio (SNR) or signal to interference ratio (SIR), packet error rate (PER), bit error rate (BER) and several gained SNR statistics [9]. In [7], the average spatial correlation matrix SNR and condition number were the indicators of link-quality used and are mapped to a look-up table. The results obtained showed substantial gain in spectral efficiency but at a fixed rate. A link adaptation algorithm based on the SIR estimate CQI average was proposed [3]. The approach showed performance improvements in throughput, but only works for low-to-medium vehicle speeds. The objective of the link adaptation presented by [2] is to maximize the average spectral efficiency while meeting a specific BER limit using

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the MIMO channel's Instant Spectral Efficiency (ISE) as the switching criterion. It has been proposed a low - complex approach but can only be effective in flat fading channels. Some other approaches include the use of the matrix channel's Demmel condition number [4] and the discrete spectral efficiency - based statistical CSI [10]. Application of Fuzzy Logic System (FLS) or Fuzzy Inference System (FIS) has been suggested in certain interaction systems [11], [12].

Since a single CQI metric cannot perfectly represent the quality of the channel [10], this paper suggests the use of two CQI metrics, RSNR and RSSI, as inputs to an FLS. The RSNR refers to the recipient's average SNR [2], [10]. The RSSI is a measure of the power strength of radio frequency (RF) in a wireless environment and is easy to calculate [13], [14]. The FLS - based approach proposed is to ensure that the MIMO system makes a more accurate switching decision as it does not rely solely on a single CQI and switching criterion.

2. MIMO SYSTEM MODEL

The discrete time baseband signal model can be represented as: Assuming a N_R X N_T MIMO transmission over multipath Rayleigh fading channels.

$$y[t] = \sqrt{\rho} H[t] x[t] + n[t], \qquad (1)$$

where y[t] is the N_R X 1 received signal at time t, H[t] is the N_R X N_T MIMO channel matrix, x[t] is the N_T X 1 transmitted signal, n[t] is the additive white Gaussian noise (AWGN) with zero mean and unity variance; $\rho = P/N_T$ is the effective SNR where P is equally divided between all transmitting antennas, N_T is the number of transmitting antenna elements and N^R is the number of receiving antenna elements. It is assumed that the MIMO channel is quasi - static, i.e. the channel differs randomly between frame to frame but is fixed within a single time interval and is indicated by

$$H = \begin{pmatrix} h_{1,1} & h_{1,2} & \cdots & h_{1,N_T} \\ h_{2,1} & h_{2,2} & \cdots & h_{2,N_T} \\ \vdots & \vdots & \ddots & \vdots \\ h_{N_R,1} & h_{N_R,2} & \cdots & h_{N_R,N_T} \end{pmatrix} \qquad (2)$$

The attenuation and phase shift between the j^{th} transmitter and the i^{th} receiver where each entry in $h_{i,j}$ denotes. It is assumed that H entries are i.i.d Gaussian random variables complex. The full diversity gain of the MIMO system is equal to $N_R N_T$.

3. MATERIALS AND METHODS

This investigation uses a 2x2 MIMO configuration. The zero-forcing (ZF) receiver is used for the SM scheme, while the TD scheme uses a full-rate OSTBC with Alamouti coding. The RSNR - measured in decibel (dB) and RSSI - measured in decibel - milliwatts (dBm) is combined with the Scheme Selection Fuzzy - logic rules. It is assumed that there is no error and no delay feedback path.

A. RSNR

The average channel gain received by SNR is given by

$$\bar{\gamma}_o = \frac{E_s}{N_o} = \frac{PT_s}{N_o} = \frac{P}{B_s N_o} \qquad (3)$$

Where E_S is the transmitted symbol energy, N_0 is the AWGN's noise power spectral density, B_S is the bandwidth of the signal, and T_S is the symbol period.

B. RSSI

The RSS is the mean total power in dBm observed within the specified bandwidth in the signals received by the MIMO antennas. A combination of useful signal, interference, and noise is the total power received.

C. Fuzzy Logic System

The block diagram for the fuzzy logic-based MIMO mode switching is presented in Fig. 1. Mamdani FLS model is used in this work because it provides intuitiveness of expert knowledge. The FLS system consists of two input variables: RSNR value and RSSI value of the MIMO signal. These input variables are supplied to the fuzzifier, which uses membership functions to transform the input variables into linguistic variables or fuzzy (crisp). The fuzzy set is passed to the fuzzy inference engine that uses the rule base's fuzzy rules. From the knowledge base, the rules are formulated. Data on typical values of input variables from field tests or experiments is transformed into the base of knowledge. For example, the RSSI is in the range of -50 to -120 dBm for HSPA or 3 G networks [15]. The inference engine output is passed to the defuzzifier which transforms it into a crisp value used by the system to decide whether or not to change the MIMO scheme. Table I presents the fuzzy or linguistic variables and range of values inputs used to develop the fuzzy rules.

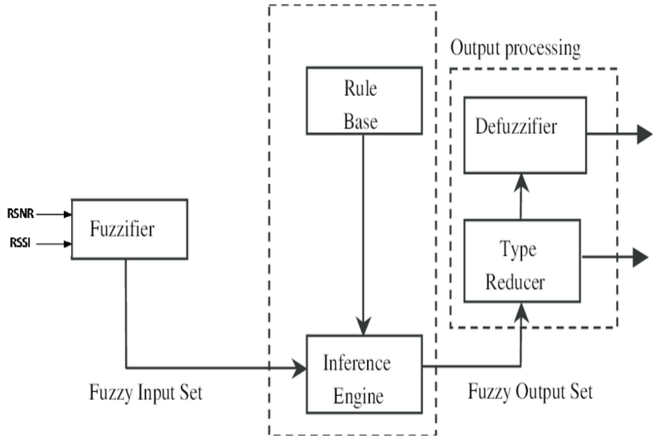

Figure 1. Fuzzy logic system model for MIMO scheme switching

D. Link Adaptation

i) Static Switching Method
ii) Fuzzy-Logic Switching Method

i) Static Switching Method

The conventional static switching rule is: the system switches to the TD scheme if the average received SNR is below the specified SNR threshold; otherwise the system switches to the SM scheme. Using the Lagrange multiplier method [2], the SNR thresholds can be obtained based on a specific target BER or I- BER limit and modulation scheme. Based on the [5] method, the SNR threshold used in this study is 17 dB.

Table 1. Classification of Fuzzy Logic Parameters

Input Parameter	Fuzzy Input Range	Membership Functions	Signal Conditions
RSNR value	>= 17.0 dB 12.0 to 16.9 dB <= 11.9 dB	High Medium Low	Excellent Good Poor
RSSI value	>= -79 dBm -80 to -89 dBm <= -90 dBm	High Medium Low	Excellent Good Poor

ii) Fuzzy-Logic Switching Method

The MIMO system's decision to switch between the two schemes, TD and SM, is based on the inference engine rules. The rules are as follows:

- ✓ IF (RSNR is High) AND (RSSI is High) THEN (switch to SM)
- ✓ IF (RSNR is High) AND (RSSI is Medium) THEN (switch to SM)
- ✓ IF (RSNR is High) AND (RSSI is Low) THEN (switch to SM)
- ✓ IF (RSNR is Medium) AND (RSSI is Low) THEN (switch to TD)
- ✓ IF (RSNR is Medium) AND (RSSI is Medium) THEN (switch to SM)
- ✓ IF (RSNR is Medium) AND (RSSI is High) THEN (switch to SM)
- ✓ IF (RSNR is Low) AND (RSSI is Low) THEN (switch to TD)
- ✓ IF (RSNR is Low) AND (RSSI is Medium) THEN (switch to TD)
- ✓ IF (RSNR is Low) AND (RSSI is High) THEN (switch to TD)

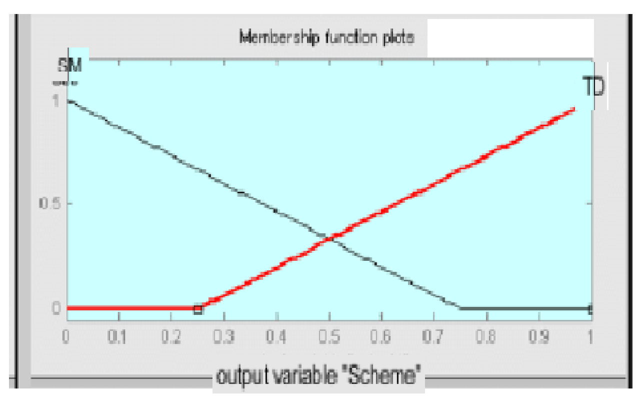

Figure 2. The FLS output variable and membership

The output variable of the FLS is called Scheme, which consists of two membership functions, namely SM and TD, as shown in Fig. 2. If Scheme's output value exceeds 0.5,

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then MIMO system selects the transmission TD scheme but selects SM for transmission if the output is equal to or less than 0.5. The input variable surface plot versus output variable is shown in Fig. 3. This illustrates how the FLS output variable value relates to each input variable value. If the value of RSSI increases and the value of RSNR decreases, then the value of Scheme increases towards TD.

4. RESULT AND DISCUSSION

Computer simulations in the MATLAB environment evaluate the performance of the proposed FLS - based MIMO scheme switching method. In the Rayleigh fading channel with 10,000 channel realizations, a 2x2 MIMO antenna configuration is simulated for both the TD scheme (OSTBC) and the SM scheme (ZF). It is assumed that the MIMO channel varies randomly from frame to frame but is fixed at a one-time interval. Signaling scheme 16-QAM (16-quadrature amplitude modulation) generates and modulates the information bits randomly. The MIMO system adapts the SM and TD schemes to the different channel conditions during the simulation. For the static method, if the average RSNR falls below the threshold, i.e. 17 dB, the MIMO system selects the TD scheme; otherwise the SM scheme is selected. The MIMO system selects either of the transmission schemes based on inferences generated from multiple rules, however, for the FLS switching method.

Fig. 4 Shows the BER with the proposed FLS switching method and static (or fixed) switching method as a function of the SNR for TD and SM MIMO transmission schemes.

The results show that the SM scheme provides lower BER than the TD scheme in the low SNR region but higher BER in the high SNR region. The schemes of SM and TD intersect at about 15 dB. It is therefore expected that the MIMO system will transmit SNR < 15 dB with the SM scheme while the TD scheme is preferred for SNR ≥ 15 dB. The static switching method, however, selects SNR < 10 dB TD scheme and selects SM for SNR ≥ 15 dB. On the other hand, appropriate selections are made by the proposed FLS switching method as it selects SM scheme for SNR < 15 dB and TD scheme for SNR ≥ 15 dB as well. The method of static and FLS switching gives mean BER of about 0.28 and 0.24 respectively. The FLS switching method has SNR gaining an advantage of approximately 5 dB over the static switching method because due to the use of a single switching criterion the later could not accurately select appropriate MIMO scheme.

The spectral efficiency comparison between the static and FLS switching methods is shown in Fig. 5. The MIMO scheme that gives the higher spectral efficiency is preferred while keeping the BER below the target level of 0.001. The results of spectral efficiency show that the SM scheme has relatively lower spectral efficiency comparison to the TD scheme for SNR < 10 dB; therefore, the TD scheme is preferred and the FLS technique selects the TD scheme accurately. However, the SM scheme is preferred for SNR average 20 dB and the FLS method selects the SM scheme accurately while the static method fails to select the scheme that provides higher spectral efficiency for SNR average 10 to 15 dB. This shows that the FLS switching method provides approximately 1 bps / Hz of spectral efficiency gain. This is due to the use of more than one CQI metrics in combination with multiple rules to make smart switching decisions.

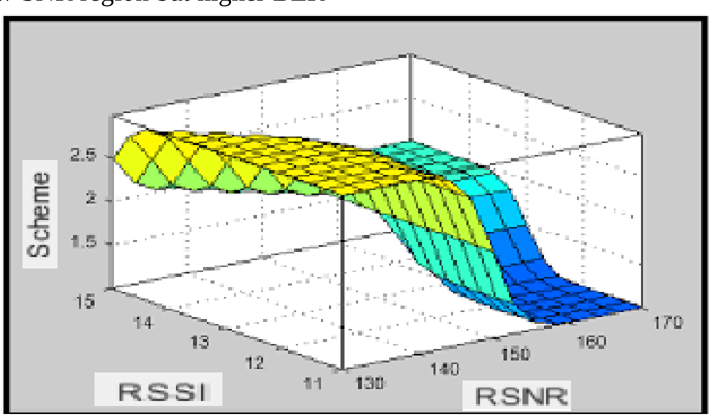

Figure 3. Surface plot of the FLS variables

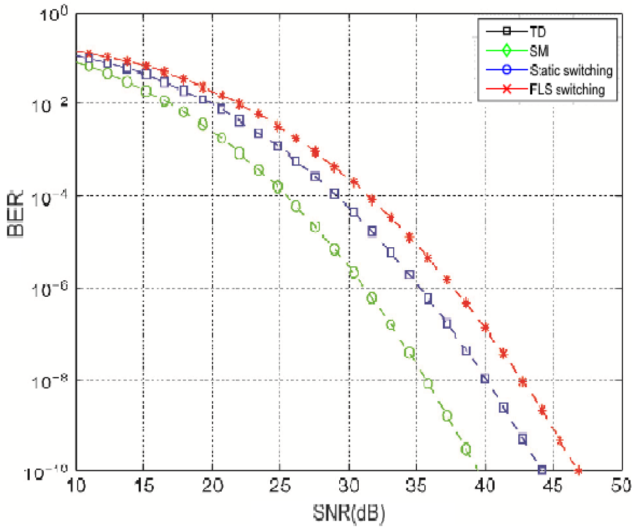

Figure 4. Bit error rate performance of the adaptive MIMO scheme switching by fuzzy logic system

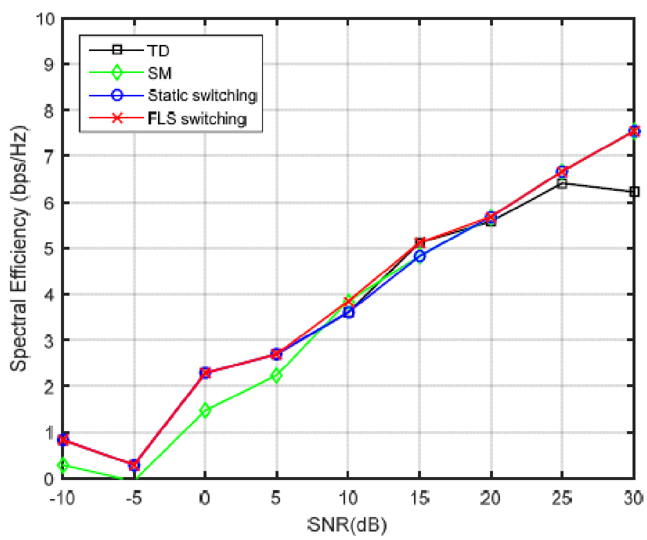

Figure 5. Spectral efficiency performance of the adaptive MIMO scheme switching by fuzzy logic system

5. CONCLUSION

This paper presents an adaptive technique based on a fuzzy-logic MIMO transmission scheme. In response to varying channel conditions, the technique uses two CQI metrics and a set of rules to form a fuzzy inference system that makes a smart switching decision between TD and SM MIMO systems. In terms of BER and spectral efficiency, the proposed method outperforms the static switching method; and is capable of providing QoS requirements under highly varying channel conditions.

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