World Academy of Science, Engineering and Technology
International Journal of Electronics and Communication Engineering
Vol:12, No:12, 2018

An Intelligent Scheme Switching for MIMO Systems Using Fuzzy Logic Technique

Robert O. Abolade, Olumide O. Ajayi, Zacheaus K. Adeyemo, Solomon A. Adeniran

***Abstract*—**Link adaptation is an important strategy for achieving robust wireless multimedia communications based on quality of service (QoS) demand. Scheme switching in multiple-input multiple-output (MIMO) systems is an aspect of link adaptation, and it involves selecting among different MIMO transmission schemes or modes so as to adapt to the varying radio channel conditions for the purpose of achieving QoS delivery. However, finding the most appropriate switching method in MIMO links is still a challenge as existing methods are either computationally complex or not always accurate. This paper presents an intelligent switching method for the MIMO system consisting of two schemes - transmit diversity (TD) and spatial multiplexing (SM) - using fuzzy logic technique. In this method, two channel quality indicators (CQI) namely average received signal-to-noise ratio (RSNR) and received signal strength indicator (RSSI) are measured and are passed as inputs to the fuzzy logic system which then gives a decision – an inference. The switching decision of the fuzzy logic system is fed back to the transmitter to switch between the TD and SM schemes. Simulation results show that the proposed fuzzy logic – based switching technique outperforms conventional static switching technique in terms of bit error rate and spectral efficiency

***Keywords*—**Channel quality indicator, fuzzy logic, link adaptation, MIMO, spatial multiplexing, transmit diversity.

I. Introduction

THE wireless communication research community has revealed numerous advantages of utilizing multiantenna and multicarrier techniques for improved broadband multimedia applications, and one of such techniques is the MIMO systems [1]. MIMO systems provide enhancements in spectral efficiency, network throughput, data rate and link reliability [2]. MIMO technology has found applications in mobile terminals, access point stations, wireless local area networks (WLANs) and mobile communication 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 commonly used MIMO schemes for communicating over the MIMO channel [4]. The TD scheme, such as the orthogonal space-time block code (OSTBC), involves transmitting a space-time coded information stream through multiple transmit antennas [5], [6]. This helps to improve diversity and invariably system reliability. On the other hand, the SM scheme involves splitting the information stream into sub-streams and transferring each sub-stream through different individual antennas. This improves the transmission data rate as a result of increased number of information symbols transferable per MIMO symbol [4], [7]. There is however a trade-off between increased data rate achievable by SM and link reliability achievable by TD especially under highly varying channel conditions.

Different strategies have been proposed for adapting these MIMO schemes to the changing channel conditions by switching between the schemes with the aim of achieving high data rate, maximizing spectral efficiency and ensuring link reliability [8]. Most of the existing practical switching criteria are based on the computation of channel state information (CSI) or CQI with selection rules, algorithms or look-up tables. The CSI/CQI metrics include signal-to-noise ratio (SNR) or signal-to-interference ratio (SIR), packet error rate (PER), bit-error rate (BER) and multiple statistics of received SNR [9]. In [7], average SNR and condition number of the spatial correlation matrix were the link-quality indicators employed and are mapped to a look-up table. Results obtained showed significant gain in spectral efficiency but for a fixed rate. An algorithm for link adaptation based on CQI averaging of SIR estimate was proposed by [3]. The approach showed performance improvement in throughput but works for only low-to-medium vehicular speeds. The goal of the link-adaptation presented by [2] is to maximize the average spectral efficiency while satisfying a given BER constraint using the instantaneous spectral efficiency (ISE) of the MIMO channel as the switching criterion. Low-complexity approach was proposed but can only be effective in flat fading channels. Some other approaches include the use of Demmel condition number of the matrix channel [4] and statistical CSI based on discrete rate spectral efficiency [10]. Application of fuzzy logic system (FLS) or fuzzy inference system (FIS) has been proposed in some communication systems [11], [12].

Because a single CQI metric cannot perfectly represent channel quality [10], this paper is thereby proposing the use of two CQI metrics, RSNR and RSSI, as inputs to an FLS. The RSNR refers to the average SNR at the receiver [2], [10]. The RSSI is a measure of radio frequency (RF) power strength in a wireless environment, and is simple to compute [13], [14]. The proposed FLS–based approach is to ensure that a more accurate switching decision is made by the MIMO system as it

R. O. Abolade is with the department of Electronic and Electrical Engineering Ladoke Akintola University of Technology PMB 4000, Ogbomoso, Nigeria (corresponding author, phone: +234(0)8035394269; e-mail: roabolade@lautech.edu.ng).

O. O. Ajayi is with department of Electrical and Electronics Engineering Adeleke University, P.O. Box 250, Ede, Nigeria (e-mail: ajayi.olumide@adelekeuniversity.edu.ng).

Z. K. Adeyemo is with the department of Electronic and Electrical Engineering Ladoke Akintola University of Technology PMB 4000, Ogbomoso, Nigeria (e-mail: zkadeyemo@lautech.edu.ng).

S. A. Adeniran is with the department of Electronic and Electrical Engineering Obafemi Awolowo University, Ile-Ife, Nigeria (e-mail: sadenira@oauife.edu.ng).

does not rely only on a single CQI and switching criterion.

II. MIMO System Model

Assuming a $N_R \times N_T$ MIMO transmission over multipath Rayleigh fading channels, the discrete-time baseband signal model can be represented as:

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

where $y[t]$ is the $N_R \times 1$ received signal at time t, $H[t]$ is the $N_R \times N_T$ MIMO channel matrix, $x[t]$ is the $N_T \times 1$ 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 total transmit power equally divided among all transmit antennas, N_T is the number of transmit antenna elements and N_R is the number of receive antenna elements. The MIMO channel is assumed to be quasi-static, i.e. the channel varies randomly between frame to frame but fixed within one time interval, and is denoted by

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

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

III. Materials and Methods

A 2x2 MIMO configuration is used in this investigation. The zero-forcing (ZF) receiver is used for the SM scheme, while a full-rate OSTBC with Alamouti coding is used with maximum likelihood (ML) receiver for the TD scheme. The RSNR - measured in decibel (dB) and RSSI - measured in decibel-milliwatts (dBm), are combined with fuzzy-logic rules for the scheme selection. Error free and no delay feedback path are assumed.

A. RSNR

The average received SNR under unity channel gain is given by

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

where E_s is the energy of the transmitted symbols, N_0 is the noise power spectral density of the AWGN, B_s is the signal bandwidth, and T_s is symbol period.

B. RSSI

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

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 into the fuzzifier which transforms the input variables into linguistic variables or fuzzy (crisp) set using membership functions. The fuzzy set is passed to the fuzzy inference engine, which utilizes fuzzy rules from the rule base. The rules are formulated from the knowledge base. Information about typical values of input parameters obtained from field tests or experiments are transformed into the knowledge base. For example, the RSSI for HSPA or 3G networks is in the range -50 to -120 dBm [15]. The output of the inference engine is passed to the defuzzifier which transforms it into crisp value that the system uses to decide whether to change MIMO scheme or not. The fuzzy or linguistic variables and inputs range of values used to develop the fuzzy rules are presented in Table I.

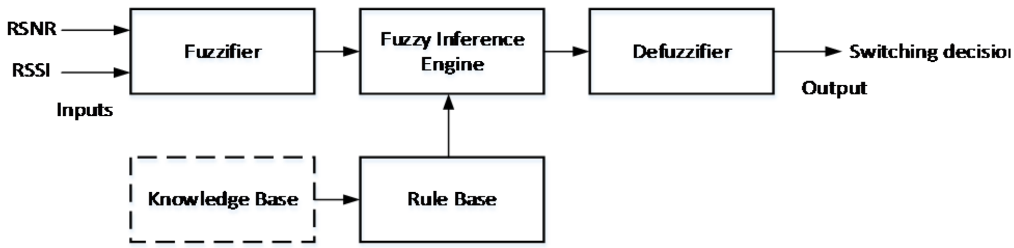

Fig. 1 Fuzzy logic system model for MIMO scheme switching

D.Link Adaptation

Static Switching Method

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

TABLE I
CLASSIFICATION OF FUZZY LOGIC PARAMETERS

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

Fuzzy-Logic Switching Method

The decision of the MIMO system to switch between the two schemes, TD and SM, is based on the rules supplied to the inference engine. The rules are stated 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)

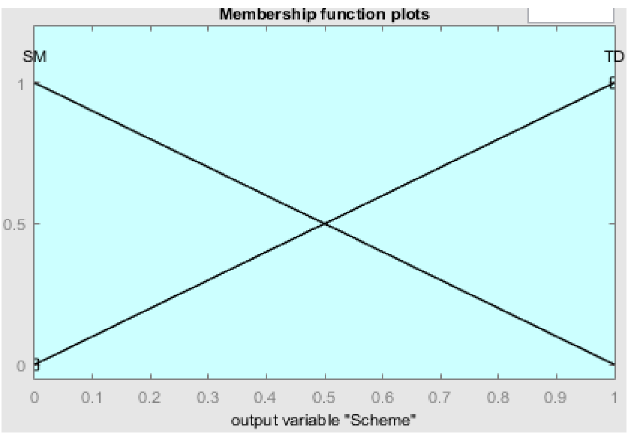

Fig. 2 The FLS output variable and membership

The FLS output variable is named Scheme, and it consists of two membership functions namely SM and TD as shown in Fig. 2. If the output value of Scheme is greater than 0.5, then MIMO system selects the TD scheme for transmission but selects SM for transmission if the output is equal to or less than 0.5. The surface plot of the input variables versus output variable is presented in Fig. 3. This illustrates how the value of the FLS output variable relates to every value of each of the input variables. If the RSSI value is increasing and RSNR value is decreasing, then Scheme value is increasing tending towards TD.

IV. RESULTS AND DISCUSSION

The performance of the proposed FLS–based MIMO scheme switching method is evaluated by computer simulations in MATLAB environment. A 2x2 MIMO antenna configuration is simulated for both the TD scheme (OSTBC) and SM scheme (ZF) in Rayleigh fading channel with 10,000 channel realizations. The MIMO channel is assumed to vary randomly between frame to frame but fixed within one-time interval. The information bits are randomly generated and modulated with 16-QAM (16-quadrature amplitude modulation) signaling scheme. During the simulation, the MIMO system adapts the SM and TD schemes to the varying channel conditions. For the static method, the MIMO system selects the TD scheme when the average RSNR falls below the threshold, i.e. 17 dB, otherwise the SM scheme is selected. However, for the FLS switching method, the MIMO system selects either of the transmission schemes based on inference generated from multiple rules.

Fig. 4 shows the BER as a function of the SNR for the TD and SM MIMO transmission schemes with the proposed FLS switching method and static (or fixed) switching method. The results reveal that the SM scheme gives lower BER compared to the TD scheme at low SNR region but higher BER at high SNR region. The SM and TD schemes intersect each other at about 15 dB. Hence, the MIMO system is expected to transmit with the SM scheme for SNR < 15 dB while TD scheme is preferred for SNR ≥ 15 dB. However, the static switching method selects TD scheme for SNR < 10 dB and selects SM for SNR ≥ 15 dB. On the other hand, the proposed FLS switching method appropriately makes right selections as it selects SM scheme for SNR < 15 dB and TD scheme for SNR ≥ 15 dB. The static and FLS switching method give mean BER of approximately 0.28 and 0.24, respectively. The FLS switching method has SNR gain advantage of about 5 dB over the static switching method because the later could not accurately select appropriate MIMO scheme due to the use of only a single switching criterion.

The comparison between the static and FLS switching methods in terms of spectral efficiency is shown in Fig. 5. While keeping the BER below the target level of 0.001, the MIMO scheme that gives the higher spectral efficiency is preferred. The spectral efficiency results reveal that for SNR < 10 dB, SM scheme has relatively lower spectral efficiency compared to the TD scheme; hence, the TD scheme is preferred and the FLS method accurately selects the TD scheme. However, for SNR ≥ 20 dB, the SM scheme is preferred and the FLS method accurately selects the SM scheme while for SNR of 10 to 15 dB, the static method fails to select the scheme that provides higher spectral efficiency. This shows that the FLS switching method gives spectral efficiency gain of about 1 bps/Hz. This is as a result of the use of more than one CQI metrics combined with multiple rules to produce intelligent switching decision.

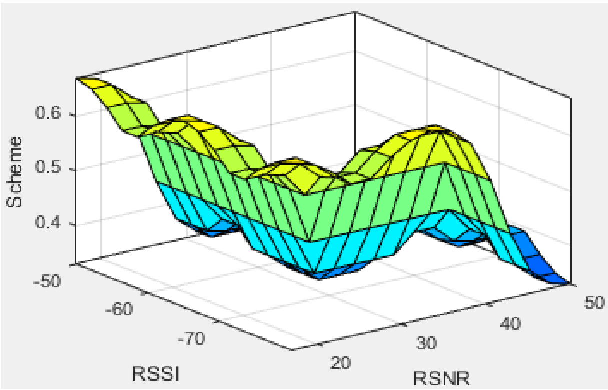

Fig. 3 Surface plot of the FLS variables

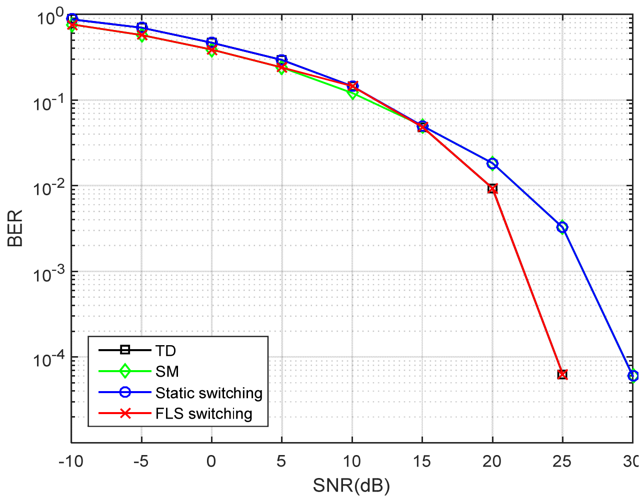

Fig. 4 Bit error rate performance of the adaptive MIMO scheme switching by fuzzy logic system

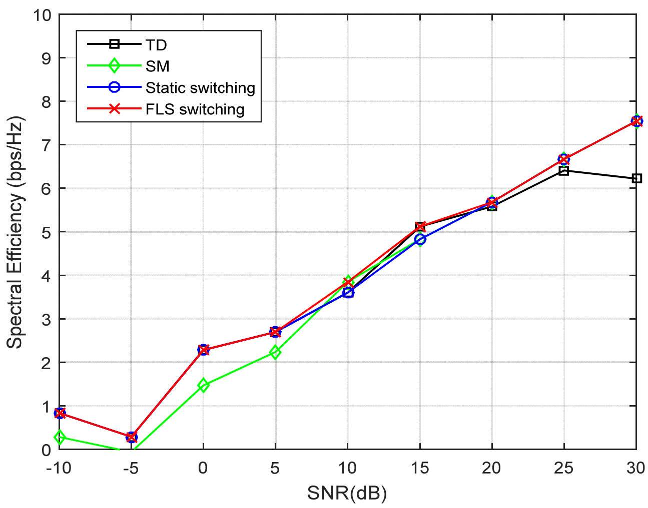

Fig. 5 Spectral efficiency performance of the adaptive MIMO scheme switching by fuzzy logic system

V. Conclusion

In this paper, a fuzzy-logic based MIMO transmission scheme adaptive technique is presented. The technique utilizes two CQI metrics and a set of rules to form a fuzzy inference system that makes an intelligent switching decision between TD and SM MIMO schemes in response to varying channel conditions. The proposed method outperforms the static switching method in terms of BER and spectral efficiency; and it is capable of providing QoS requirement in highly-varying channel conditions.

References

[1] R. O. Abolade and O. O. Ajayi, "Reduction of outage probability in fast rayleigh fading MIMO channels using OFDM," International Journal of Engineering Research and Applications, vol. 4, Issue 9, pp. 06-10, 2014.
[2] C. Kim and J. Lee, "Dynamic rate-adaptive MIMO mode switching between spatial multiplexing and diversity," *EURASIP Journal on Wireless Communications and Networking*, 2012:238., August 2012.
[3] H. Touheed, A. U. Quddus, R. Tafazolli, "An Improved Link Adaptation Scheme for High Speed Downlink Packet Access", *IEEE 68th Vehicular Technology Conference (VTC)*, Spring, pp. 2051 – 2055, September 2008.
[4] R. W. Heath Jr., A. J. Paulraj, "Switching between diversity and multiplexing in MIMO systems". IEEE Trans. Commun., vol. 53, no. 6, pp. 962–968, June 2005.
[5] J. H. Winters, "The diversity gain of transmit diversity in wireless systems with Rayleigh fading," IEEE Trans. Veh. Technol., vol. 47, no. 1, pp. 119–123, Feb. 1998
[6] G. Ganesan and P. Stoica, "Space-time block codes: A maximum SNR approach," IEEE Trans. Inf. Theory, vol. 47, no. 4, pp. 1650–1656, May 2001.
[7] A. Forenza, A. Pandharipande, H. Kim and R.W. Heath Jr, "Adaptive MIMO Transmission Scheme: Exploiting the Spatial Selectivity of Wireless Channels", IEEE 2005.
[8] L. C. Png, L. Xiaoy, K. S. Yeoz, T. S. W. and Y. L. Guan, "MIMO-diversity switching techniques for digital transmission in visible light communication," 18th IEEE Symposium on Computers and Communications (ISCC'13) (Split, Croatia, 2013), pp. 576–582. Jul. 2013.
[9] S. Catreux, V. Erceg, D. Gesbert, R.W. Heath Jr., "Adaptive modulation and MIMO coding for broadband wireless data networks," IEEE Commun. Mag., vol. 40, no. 6, pp. 108–115, June 2002.
[10] J. Huang and S. Signell, "Discrete rate spectral efficiency improvement by scheme switching for MIMO systems." in Proc. IEEE Int. Conf. Commun. (ICC'08), (Beijing, China, 2008), pp. 3998–4002, 2008.
[11] C. G. Patil and M. T. Kolte, "An approach for optimization of handoff algorithm using fuzzy logic system", International Journal of Computer Science and Communication, vol. 2, no. 1, pp. 113-118. 2011.
[12] A. M. Orimogunje, O. O. Ajayi, O. A. Fakolujo and J. O. Abolade (2017), "Adaptive Network Based Fuzzy Inference System Model for Minimizing Handover Failure in Mobile Networks," International Journal of Innovative Science and Research Technology, Vol. 2, Issue 9, pp. 332-342.
[13] Oka, A. and Lampe, L. (2010), "Distributed Target Tracking Using Signal Strength Measurements by a Wireless Sensor Network," International Journal of Computer Science and Communication, vol. 28, no. 7, pp. 1006-1015. 2010.
[14] Y. Chapre, P. Mohapatra, S. Jha and A. Seneviratne (2013), "Received Signal Strength Indicator and Its Analysis in a Typical WLAN System," 38th Annual IEEE Conference on Local Computer Networks.
[15] A. Fourie, (2015), "Received signal strength indicator," Poynting Group. Retrieved from http://LinkedIn/ on 31/05/18.