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Reliable Best-Relay Selection for Secondary Transmission in Co-operation Based Cognitive Radio Systems: A Multi-Criteria Approach

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Abstract

Selection of Relay for unlicensed transmission in cooperation based cognitive radio systems is an essential area of research which ensures the transmission performance of the secondary system & at the same time maintains the transmission behavior of the licensed network with respect to the quality-of-service (QoS).So far we have studied Signal-to-Interference-plus-Noise Ratio (SINR) of a relay node as the sole parameter to judge the BEST relay in the existing research works. This time we have proposed few other important parameters like Reliability and Relative Link Quality (RLQ) of a relay node as seen from the receiver, in order to select the Reliable BEST relay in a more accurate manner from the rest of the lot as the authors believe that for a faithful transmission, the selected best relay should be reliable along with other parameters. We have carried out ample simulation study to find out the reliable best relay applying our proposed fuzzy logic-based scheme. The implementation of the suggested system is verified with the earlier proposed schemes, i.e., fuzzy logic-based, SINR based and without relay have been studied holistically through the Secondary Outage Probability & Bit Error Rate (BER) simulation results.

Keywords : Best Relay selection, Relay node, Cognitive radio Systems, Decision making, Fuzzy logic.

I. Introduction

Cognitive Radio (CR) [I, II], the most key enabling paradigm of modern era and one of the new long term investments in the research of Mobile communication is powerful enough to come up with modern strategies to alleviate the problem [VII] of spectrum insufficiency [IV] by adopting dynamically spectrum accessing (DSA) policy that permits secondary users (SUs) to avail the authorized spectrum simultaneously with primary user (PU) satisfying interference temperature [VIII, XII, XIII, XVIII].

In cooperative communication, cooperative diversity [X, XI] and relay selection considering cooperative diversity [XIII] has been investigated for both of the systems, i.e. non-cognitive [III] and cognitive networks, where transmission occurs in two channels. Between these two, one is direct link and another is best-relay link which gets selected only by the best relay to forward the received & decoded signal. In this publication the authors have particularly attempted to formulate the benchmark of selecting the best relay in cooperative CRNs [VI].

Author's prominent contributions can be outlined like, firstly, the proposal of a unique way to select relay node [V,XIV, XV] based on fuzzy logic where not only the maximum value SINR obtained relay is considered, but reliability and RLQ are also counted. Secondly, a definite form of reliability of the relay node in terms of probability for secondary transmissions has been derived.

The letter is arranged as: firstly, system model and data transmission process, next illustration of the proposed FLBRS scheme, then simulation results and discussions. Finally, we talked about the future scope of fuzzy logic based best Relay selection [XVI, XVII] technique and have put some concluding remarks.

System Model

Underlay cognitive relay (IX, XIX, XX) approach has been assumed in this study that allows simultaneous transmission of both primary and secondary transmitters to their respective destinations via the frequency channel. Authors consider a secondary transmission system (Shown in fig 1) which comprises a Secondary Transmitter (ST) and a Secondary Destination (SD) with K nodes (of Decode and Forward type) for relaying ($\Re = \{SR_i \mid i = 1, 2, 3 \ldots K\}$). The authors have restricted these relay nodes (SRs) only for the assistance of the secondary transmission. The impulse response of the channel connecting nodes i and j is represented as:

$$h_{i,j} = \left\{ \sqrt{d_{i,j}^{-\alpha}} \times g_{i,j} \right\} \mid i \in (P, R, S) \text{ and } j \in (P, R, S, D) \quad (1)$$

Here α denotes the path loss coefficient, $d_{i,j}$ is the distance in between nodes i and j and $g_{i,j}$ denotes the fading coefficient. The instantaneous channel gain between nodes i and j thus becomes:

$$H_{i,j} = \left| h_{i,j} \right|^2 = \left\{ d_{i,j}^{-\alpha} \times \left| g_{i,j} \right|^2 \right\} \mid i \in (P,R,S) \text{ and } j \in (P,R,S,D) \tag{2}$$

In this very paper, time is supposed to consist of number of slots $\left(t_f \mid \text{f is any integer} > 0 \right)$ and each slot is again subdivided into two portions $\langle t_f(\iota) \mid \iota \in (1,2) \rangle$ viz. *relaying interval* and *observation interval*.For the CR users, observation time is to listen to the signal transferred by the PU and the consequent relaying time is to act as a relay.

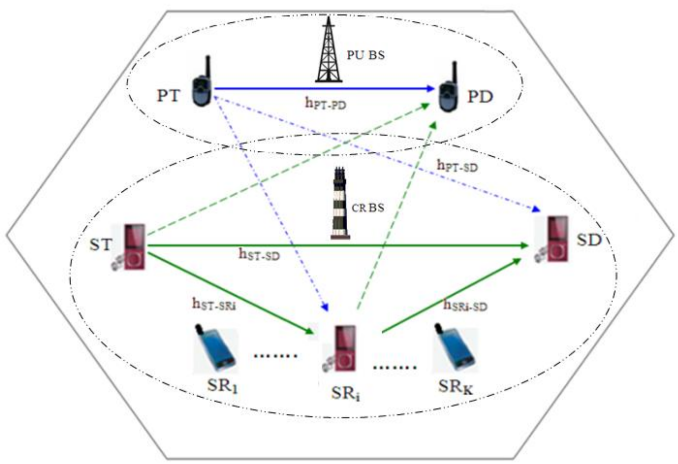


Figure1: Relay Model of cooperative CRNs

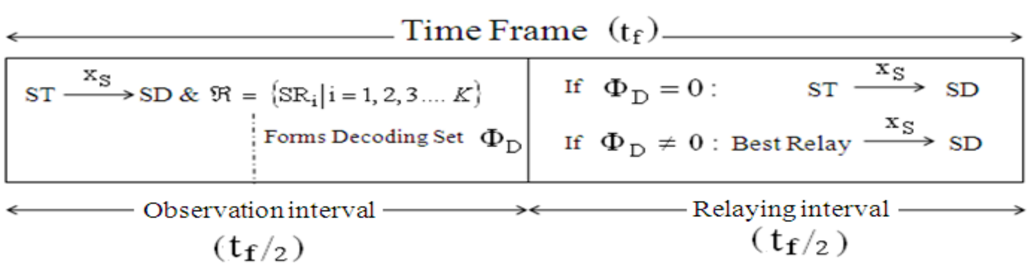


Figure2: Time slots of secondary transmission consisting of Observation interval and relaying interval

In Observation interval $\langle t_f(\iota=1)\rangle$: Secondary Transmitter communicates its data $\left(x_S\langle t_f(\iota=1)\rangle\right)$ with data rate R_{ST} to both secondary destination (SD) and secondary Relays (SRs) with power P_{ST} together with the PT, who transmits its data $\left(x_P\langle t_f(\iota=1)\rangle\right)$ with data rate R_{PT} with power P_{PT}.Thus the messages received by the secondary relays (SRs) and SD are:

$$Y_{SR_{i\in\Re}}\langle t_f(\iota=1)\rangle=\sqrt{P_{ST}}h_{ST,SR_i}\langle t_f(\iota=1)\rangle x_S\langle t_f(\iota=1)\rangle + \sqrt{P_{PT}}h_{PT,SR_i}\langle t_f(\iota=1)\rangle x_P\langle t_f(\iota=1)\rangle + n_{SD}\langle t_f(\iota=1)\rangle \tag{3}$$

$$Y_{SD}\langle t_f(\iota=1)\rangle=\sqrt{P_{ST}}h_{ST,SD}\langle t_f(\iota=1)\rangle x_S\langle t_f(\iota=1)\rangle + \sqrt{P_{PT}}h_{PT,SD}\langle t_f(\iota=1)\rangle x_P\langle t_f(\iota=1)\rangle + n_{SD}\langle t_f(\iota=1)\rangle \tag{4}$$

ST to SD and PT to SD channels have fading coefficients $h_{ST,SD}$ and $h_{PT,SD}$ respectively and $n_{SD}\langle t_f(\iota=1)\rangle$ is as usual additive white Gaussian noise. As discussed earlier that the highest level of secondary transmission is constrained and is considered to be

$$P_{ST} \le \frac{\sigma^2_{PT,PD}P_{PT}}{\sigma^2_{ST,PD}\Xi}\Psi \tag{5}$$

Where $\Xi_P=2^{R_{PT}}-1$, $\gamma_{PT}=\frac{P_{PT}}{N_0}$ is the transmit SNR at PT,

$$\Psi=\max\left[\left(\frac{1}{1-Pout_{Pri,Thr}}\exp\left(-\frac{\Xi}{\sigma^2_{PT,PD}\gamma_{PT}}\right)-1\right),0\right] \tag{6}$$

and

$$Pout_{Pri,Thr}=\Pr\left\{\log_2\left(1+\frac{P_{PT}\left|h_{PT,SD}\langle t_f(\iota=1)\rangle\right|^2}{P_{ST}\left|h_{ST,PD}\langle t_f(\iota=1)\rangle\right|^2+N_0}\right)<R_{PT}\right\} \le Pout,Thr \tag{7}$$

$P_{ST}=0|_{\Psi=0}$ states that the unavailability of the primary channel towards secondary transmission for massive propagation losses and so zero power is assumed. All the SRs try to decode the message received from ST and only those who decode the message flawlessly become eligible to be the member of a group Decoding Set and is depicted as below:

$\Phi_D\langle t_f(\iota=1)\rangle = \left\{\varphi \,\middle|\, \varphi \in \phi \cup \varphi_K\ ,\quad k=1,2\ldots,2^K-1\right\}$ Here ϕ denotes null set and φ_K is a non empty sub set of 'K' SRs.

In the Relaying interval $\langle t_f(\iota=2)\rangle$: In this phase if $\{\varphi \neq \phi \text{ and } \varphi = \varphi_k\}$ i.e. - the Best Relay (SR_{BEST}) is chosen out of the decoding set (φ_k) which is non empty and conveys the properly decoded information to the SD.

The condition of successful decoding of the secondary source (ST) message is:

$$\left[\frac{1}{2}\log_2\left(1+\frac{P_{ST}\left|h_{ST,SR_i}\langle t_f(\iota=1)\rangle\right|^2}{P_{PT}\left|h_{PT,SR_i}\langle t_f(\iota=1)\rangle\right|^2+N_0}\right)>R_{ST}\right] \quad i\in\varphi_K \tag{8}$$

In this paper we have proposed a new Fuzzy Logic based Best Relay Selection scheme (FLBRS). Thus the signal received at SD is as follows:

$$\begin{aligned} Y_{SD}\langle t_f(\iota=2)\rangle\big|_{\varphi=\varphi_k} &= \sqrt{P_{ST}}\,h_{SR_{BEST},SD}\langle t_f(\iota=2)\rangle x_S\langle t_f(\iota=2)\rangle \\ &+\sqrt{P_{PT}}\,h_{PT,SD}\langle t_f(\iota=2)\rangle x_p\langle t_f(\iota=2)\rangle + n_{SD}\langle t_f(\iota=2)\rangle, \quad SR_{BEST}\in\varphi_K \end{aligned} \tag{9}$$

Situation $\varphi=\phi$ reflects that the Decoding set is Null which basically indicates the inability of the SRs to decode the signal properly and is expressed as $\left[\frac{1}{2}\log_2\left(1+\frac{P_{ST}\left|h_{ST,SR_i}\langle t_f(\iota=1)\rangle\right|^2}{P_{PT}\left|h_{PT,SR_i}\langle t_f(\iota=1)\rangle\right|^2+N_0}\right)<R_{ST}\right]$. Consequence followed by is the retransmission of the original message by ST to the SD via the direct link. Ultimately, SD has to carry out MRC (Maximum ratio combining) operation on both the versions of the signals received and thus $\overset{\Theta}{Y}_{SD}\langle t_f(\iota=2)\rangle$ is obtained as:

$$\overset{\Theta}{Y}_{SD}\langle t_f(\iota=2)\rangle = W_1\times Y_{SD}\langle t_f(\iota=1)\rangle + W_2\times Y_{SD}\langle t_f(\iota=2)\rangle\big|_{\varphi=\varphi_k}\ , \quad W_1 \text{ and } W_2 \text{ are the weights} \tag{10}$$

Problem Formulation

I. Introduction to Fuzzy Logic

In this section, fuzzy logic, which was introduced by Dr. L. Zadeh is discussed briefly. Generally the steps followed in fuzzy logic are summarized as follows:

1. Receiving input parameters to be analyzed.
2. Generation of Rule base by if-then fuzzy rules.
3. Derivation of single output by averaging and putting weights to the results of every individual rule.
4. Defuzzification of the output.

The use of fuzzy logic facilitates in smoothening the steep segregation between normality and abnormality.

II. Proposed FLBRS Scheme

In this letter, authors consider SINR with other parameters not only to select the best relay but also to achieve better outage performance though the available research works have considered only received SINR at SD. Here, we have adopted Fuzzy Logic (FLBRS) to determine the Best Relay from the Decoding set (φ_k) . Additionally we have proposed two new input parameters like Relative Link Quality (RLQ) and Reliability along with SINR for selection of the Best Relay and are described below:

Signal-to-Interference-Plus-Noise Ratio ($\mathbf{SINR_{SD}}$): The mostly used metric to determine the Best Relay is SINR, which is measured at the destination point by executing MRC on both the versions of the received signal from ST and SRi nodes respectively.

$$\mathrm{SINR}_{SD}(SR_i)\Big|_{i\in\varphi_k} = \frac{P_{ST}\left|h_{ST,SD}\langle t_f(\iota=1)\rangle\right|^2}{P_{PT}\left|h_{PT,SD}\langle t_f(\iota=1)\rangle\right|^2+N_0}+\frac{P_{ST}\left|h_{SR_i,SD}\langle t_f(\iota=2)\rangle\right|^2}{P_{PT}\left|h_{PT,SD}\langle t_f(\iota=2)\rangle\right|^2+N_0}\ ,\ SR_i\in\varphi_k \quad (11)$$

Relative Link Quality (RLQ): It explains the channel quality of the particular Relay node with respective to the other nodes present in the decoding set (φ_k). In other words it is actually the quality of the link persisting between the selected relay node SR_i & destination node SD and is termed as Relative Link Quality (RLQ) denoted by $\gamma_{SR_i,SD}$ and is defined as follows

$$\gamma_{SR_i,SD}\Big|_{i\in\varphi_k} = \frac{H_{SR_i,SD}}{\frac{1}{K}\sum_{i=1}^{K} H_{SR_i,SD}} = \frac{\left|h_{SR_i,SD}\right|^2}{\frac{1}{K}\sum_{i=1}^{K}\left|h_{SR_i,SD}\right|^2} \quad (12)$$

Where $h_{SR_i,SD}$ is the channel impulse response between nodes SR_i and SD .

Measurement of Reliability of a particular Relay node: By the very parameter Reliability we mean, a particular node's ability to transmit a signal to the destination without fail. To ensure the faithful communication of the transmitted message to the receiver end, an Acknowledgement message (ACK) is conveyed to both the Secondary Transmitter and the corresponding SR_i as soon as the signal reaches the destination and similarly NACK (Negative Acknowledgement) is sent to indicate failure transmission. Let during a small time interval Δt total number of ACK and NACK received by the relay node SRi are $N^{ACK}_{SR_i|\Delta t}$ and $N^{NACK}_{SR_i|\Delta t}$ respectively and the feedback mechanism by SD is shown the figure3.

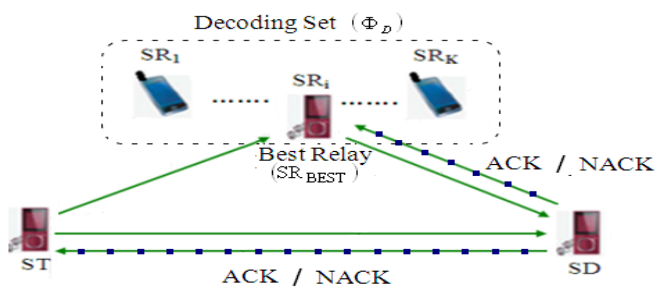


Figure3: ACK/NACK based transmission process in secondary network

Rate of successful transmission of node SRi denoted by $(\lambda_S(SR_i, \Delta t))$, may be defined as the ration of the number of ACK received over the total number of ACK and NACK received and is formulated as in Eq. (13) below:

$$\lambda_S(SR_i, \Delta t)\big|_{i\in\varphi_K} = \frac{N^{ACK}_{SR_i|\Delta t}}{N^{ACK}_{SR_i|\Delta t} + N^{NACK}_{SR_i|\Delta t}} \qquad (13)$$

Rate of Failure transmission of SRi node denoted by $(\lambda_F(SR_i, \Delta t))$ may be defined as the reverse of rate of successful transmission and is formulated as follows:

$$\lambda_F(SR_i, \Delta t)\big|_{i\in\varphi_K} = 1 - \lambda_S(SR_i, \Delta t) = \frac{N^{NACK}_{SR_i|\Delta t}}{N^{NACK}_{SR_i|\Delta t} + N^{ACK}_{SR_i|\Delta t}} \qquad (14)$$

Further, let us consider the probable number of transmissions carried out by the SRi , during a short time span Δt is $\xi(SR_i, \Delta t)\big| \in \varphi_K$ $\therefore$ Relay node SRi conducts average number of successful transmissions

$$\bar{\Gamma}_S(SR_i, \Delta t)\big|_{i\in\varphi_K} = \lambda_S(SR_i, \Delta t)\big|_{i\in\varphi_K} \times \xi_{(SR_i, \Delta t)\big|\in\varphi_K} \quad (15)$$

Thus the Reliability (β_{SR_i}) of a particular node which is nothing but the average number of successful transmissions conducted by the Relay node SRi over a longer period of time say $T\left(\text{Where} T = t\times\Delta t\big|_{t\text{ is any integer and} \neq 0}\right)$ can be calculated as:

$$\beta_{SR_i} = \sum_{j=1}^{T} \bar{\Gamma}_S(SR_i, \Delta t_j) \qquad , \quad T = t\times\Delta t\big|_{t\text{ is any integer and} \neq 0}$$
$$= \sum_{j=1}^{T} \lambda_S(SR_i, \Delta t_j)\big|_{i\in\varphi_K} \times \xi_{(SR_i, \Delta t)\big|\in\varphi_K} \quad (16)$$

Based on the above discussions the following Fuzzy Controller based relay selection framework (see fig 4) may be constructed; where inputs to the Fuzzy Controller are three significant parameters viz. Reliability, RLQ, and SINRSD as measured for the SRi members of the Decoding set to take the decision regarding the Best Relay.

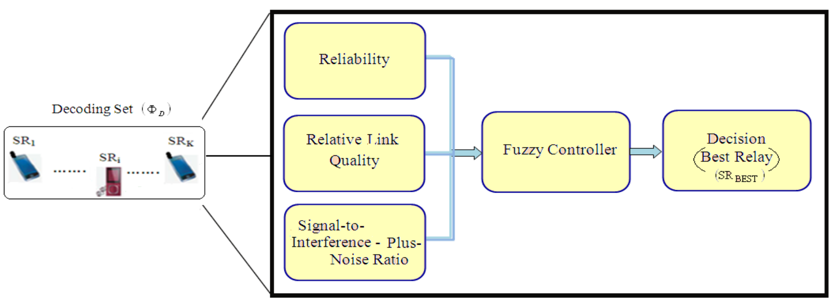


Figure4: Fuzzy Controller for Best Relay Selection

III. Relay Selection Criteria Provided by the New FLBRS Scheme

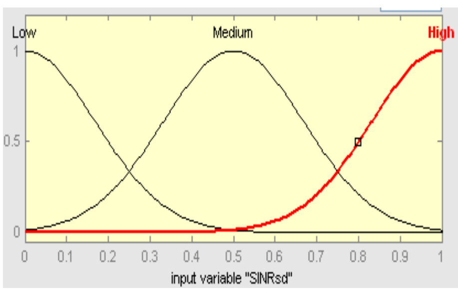
Hence according to the three inputs mentioned above, the Relay selection criteria based on Fuzzy Logic (FLBRS) may be formulated as:

$$\mu_{D_q}(W) = f\left\{T\left(\mu_{A_m}(X), \mu_{B_n}(Y), \mu_{C_p}(Z)\right)\right\}$$
$$= \arg\mathrm{Max}\left[\mathrm{Min}\left\{\mu_{A_m}(X)\, t\, \mu_{B_n}(Y)\, t\, \mu_{C_p}(Z)\right\}\right], \quad m,n,p,q \in (1,2,3) \quad (17)$$

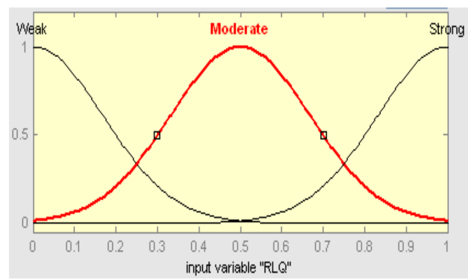
Where X, Y, Z are input variables and the corresponding Output vaiable is W and are described as follows:

$$X = SINR_{Sd} \in \{A_1, A_2, A_3\} \in \{\text{Low}, \text{Medium}, \text{High}\},$$
$$Y = \text{Relative Link Quality (RLQ)} \in \{B_1, B_2, B_3\} \in \{\text{Weak}, \text{Moderate}, \text{Strong}\},$$
$$Z = \text{Reliability} \in \{C_1, C_2, C_3\} \in \{\text{Risky}, \text{Acceptable}, \text{Desired}\},$$
$$W = \text{Relay} \in \{D_1, D_2, D_3\} \in \{\text{Rejected}, \text{Good}, \text{Best}\}$$

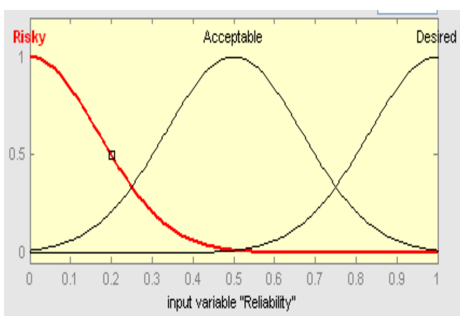
The fuzzy membership functions for the three inputs and one output criteria are shown in the Fig.5.



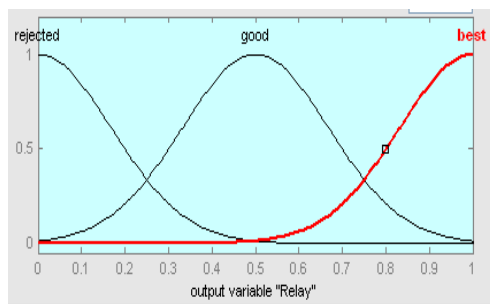
(a) SINRSd –Input Membership Function



(b) RLQ - Input Membership Function



(c) Reliability -Input Membership Function



(d) Relay - Output Membership Function

Figure5: Membership functions of different input and output fuzzy sets

Mamdani type Fuzzy Inference System (FIS) (as shown in the Fig 6.) processes the inputs applied in it and derives the membership value of the fuzzy set Relay, which is the output of this system. FIS fires any of the 27 rules from the rule base (as defined in table 1) in order to produce the membership value of the output parameter Relay and thus Best Relay is selected whose output membership function value $\left(\mu_{BEST}\left(SR_i|_{i \in \varphi K}\right)\right)$ belong to the group 'Best' and is of the highest value.

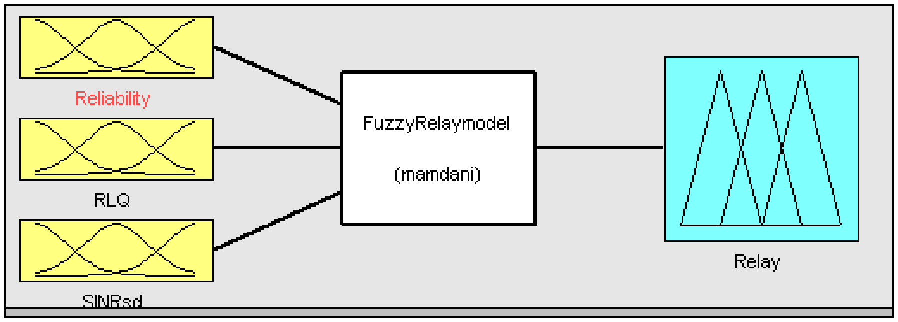


Figure6: Mamdani Type FLBRS system

$$\therefore \quad \mu_{BEST}\left(SR_i\big|_{i\in\varphi_K}\right) = f\left\{T\left(\mu_{A_m}(SINR_{Sd}), \mu_{B_n}(RLQ), \mu_{C_p}(Reliability)\right)\right\} \quad (18)$$

$$\therefore \text{Best Relay}(SR_{BEST}) = \arg \underset{i}{Max}\left\{\mu_{BEST}\left(SR_i\big|_{i\in\varphi_K}\right)\right\}$$

$$= \arg Max\left[Min\left\{\mu_{A_m}(SINR_{Sd})\, t\, \mu_{B_n}(RLQ)\, t\, \mu_{C_p}(Reliability)\right\}\right], \; m,n,p\in(1,2,3) \quad (19)$$

Table.1 presents a rule base consisting of 27 IF-THEN linguistic constructions or rules to combine heterogeneous inputs like SINRSD, RLQ, and Reliability in order to take the decision about the quality of the selected relay. The rules are of the form IF X IS A1 AND Y IS B2 AND Z IS C3 THEN W IS D1, where A1, B2, C3 and D1 are linguistic labels of variables X, Y, Z and W used in the rules respectively. For example, the rule shown in the first row of Table1denotes that all the three input components are Low, Weak, and Risky, and consequently the combined fuzzy decision regarding the quality of Relay becomes 'Rejected' type, i.e. the SR cannot be selected for data transmission to SD. The rule in the last row denotes all the three input components are High, Strong, and Desired, and consequently the combined fuzzy decision regarding the quality of Relay becomes 'Best' type, i.e. the SR gets selected for data transmission to SD. The remarkable aspect of fuzzy inference is that several rules can be partially true at the same time because the input variables can partially belong to several input membership functions at the same time.

Table1: Rule base for Best Relay Selection

IF			THEN
$SINR_{SD}$	**RLQ**	**Reliability**	**Relay**
Low	Weak	Risky	Rejected
Low	Weak	Acceptable	Rejected
Low	Weak	Desired	Rejected
Low	Moderate	Risky	Rejected
Low	Moderate	Acceptable	Rejected
Low	Moderate	Desired	Rejected
Low	Strong	Risky	Rejected
Low	Strong	Acceptable	Rejected
Low	Strong	Desired	Good
Medium	Weak	Risky	Rejected
Medium	Weak	Acceptable	Good
Medium	Weak	Desired	Good
Medium	Moderate	Risky	Rejected
Medium	Moderate	Acceptable	Good
Medium	Moderate	Desired	Good
Medium	Strong	Risky	Rejected
Medium	Strong	Acceptable	Good
Medium	Strong	Desired	Good
High	Weak	Risky	Rejected
High	Weak	Acceptable	Good
High	Weak	Desired	Best
High	Moderate	Risky	Rejected
High	Moderate	Acceptable	Good
High	Moderate	Desired	Best
High	Strong	Risky	Good
High	Strong	Acceptable	Best
High	Strong	Desired	Best

IV. Steps of Best Relay Selection Process

Step1: ST transmits data to SD and all the ‘K’ SRs.

Step 2: The SRs those are fruitfully decode the signal construct a decoding set Φ_D and otherwise the decoding set remains NULL, and in that case ST has to retransmit the message to SD.

Step 3: Fuzzy Inference System (Mamdani) has been chosen to calculate the Fuzzy membership values of all the SRs who belong to the non empty decoding set Φ_D.

Step 4: The SR with the highest membership value to be of type Best Relay gets selected as the BEST relay (SR_{BEST}) and forwards the message to the SD.

Step 5: As the SD receives the signal successfully it acknowledges (ACK) to both ST and SR_{BEST} and otherwise it transmits (NACK) to both ST and SR_{BEST} .

In the following, we discuss our proposed Best Relay selection algorithm (FLBRS) using Fuzzy logic in cognitive radio networks;

Algorithm: Proposed Best Relay Selection Using Fuzzy Logic in Cognitive Radio Networks

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1: $ST \longrightarrow SD, \Re = \{SR_i \mid i = 1, 2, 3 \ldots . K\}$ /*ST transmits data to both SD and SRs */

2: $\Phi_D \langle t_f (\iota = 1) \rangle = \{\varphi \mid \varphi \in \phi \cup \varphi_K \;, \quad k = 1, 2 \ldots, 2^K - 1\}$ /* The SRs which successfully decode the message & form the decoding set Φ_D */

3: **if** $\{\varphi = \phi\}$ at $\langle t_f (\iota = 2) \rangle$ **then** /*If decoding set is null, ST has to retransmit the message to SD */

$ST \longrightarrow SD$

4: **else** /* When decoding set is not null, SINR, RLQ and Reliability membership values of individual member is calculated */

5: **for** all $j \mid_{j \in \varphi_k}$

do

6: $SR_j \longleftarrow \mu(SINR_{SD})$

7: $SR_j \longleftarrow \mu(RLQ)$

8: $SR_j \longleftarrow \mu(Reliability)$

9: Perform calculation operation

$$\mu_{BEST}\left(SR_j \big|_{j \in \varphi_K}\right) \leftarrow f\left\{T\left(\mu_{A_m}(SINR_{SD}), \mu_{B_n}(RLQ), \mu_{C_p}(Reliability)\right)\right\}$$

10: **end for**

11: Formulate FLBRS

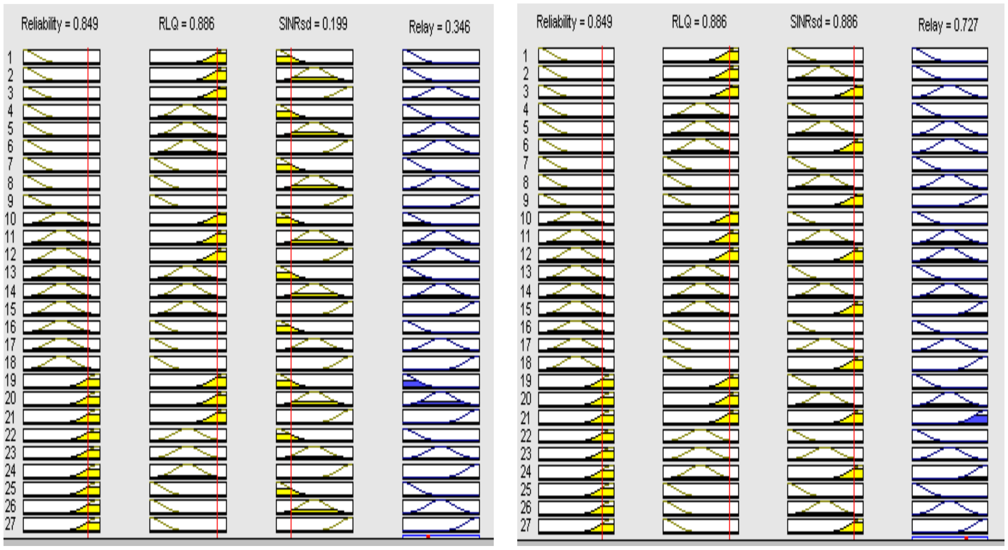
$$\text{Best Relay}(SR_{BEST}) \leftarrow \arg \underset{j}{\text{Max}} \left\{ \mu_{BEST}\left(SR_j \big|_{j \in \varphi_K} \right) \right\}$$ /*the member with the highest value is considered to be the BEST Relay*/

12: $\text{Best Relay}(SR_{BEST}) \longrightarrow SD$ /* The BEST relay transmits data to the SD */

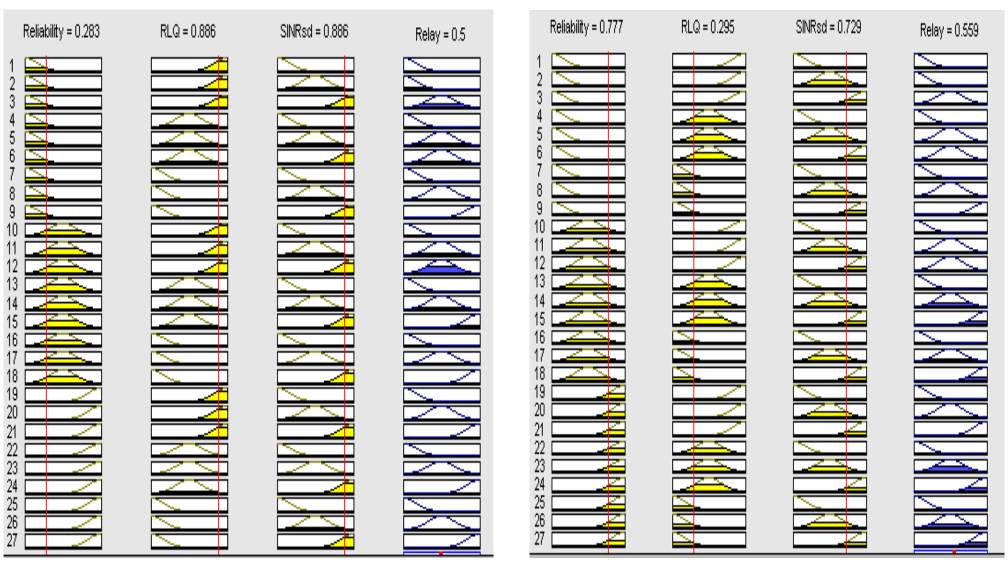
```
    if SD successfully received the original signal then    /*SD sends ACK to both ST and Best Relay */
    SD --ACK--> Best Relay(SR_BEST), ST
    else /* if SD can't decode the message properly, it sends NACK to both ST and Best Relay */
    SD --NACK--> Best Relay(SR_BEST), ST
    end if
end if
```

Results and Discussion

Here authors give simulation results to establish the analytical results. For simulation purpose Fuzzy logic has been chosen as it allows multi-valued logic as well as multiple inputs to drive the decision. The simulation results are shown in Fig.7 and 8. Figure.7 illustrates the Relay selection scenario based on different input conditions. Figure.7(a) shows that the selected relay is of group ‘Rejected’ as SINRSD is Low in spite of Reliability and RLQ are ‘Desired’ and ‘Strong’ respectively. Figure 7(b) demonstrates the scenario where the selected relay is the Best as all the three inputs are having high values. Likewise figure 7(c) and (d) describes that the selected relays are of type ‘Good’.



(a) Rule base declare the selected Relay is of group 'Rejected'   (b) Rule base declare the selected Relay is of group 'Best'



(c) & (d) Rule base declare the selected Relay is of group 'Good'

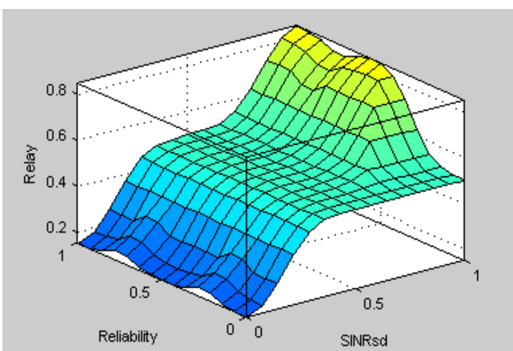
Figure7: Simulation results of the fuzzy inference rules

Calculation of Membership values of the cooperating relay nodes are executed varying different relay selection parameters like Reliability, RLQ and $SINR_{SD}$ and are observed in the following Table 2.

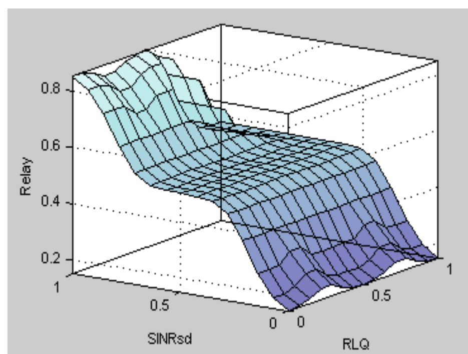
Table2: Membership values of relay nodes obtained from Mamdani-type FIS

Reliability	RLQ	$SINR_{SD}$	Relay	Comment
0.259	0.235	0.151	0.333	Rejected
0.849	0.886	0.199	0.346	Rejected
0.283	0.886	0.886	0.5	Good
0.777	0.295	0.729	0.559	Good
0.211	0.283	0.729	0.551	Good
0.259	0.548	0.886	0.591	Good
0.849	0.886	0.886	0.727	Best

Figure.8 (a) and (b) describes the surface view of the system which shows the chances of the selected relay type to be 'Best' as both SINRsd and Reliability are 'High' and 'Desired' (shown in Figure.8(a)) Figure 8.(b) shows even if the RLQ is WEAK, if SINRsd is 'High', selected relay is the 'Best' provided Reliability is 'Desired'.



(a)



(b)

Figure 8. Surface view of Fuzzy Inference System (Mamdani Type)

Outage Probability Analysis

In this context, we inspect the outage probability performance for the Fuzzy based Relay Selection scheme. With the objective to have a comparative study first we are considering the conventional non-cooperative transmission method. Equation (4) enables us to calculate the secondary outage probability of non-cooperation based transmission scheme as follows:

$$\mathrm{Pout}_{\mathrm{Secondary}}\left|\left\{ST \xrightarrow{\mathrm{Direct}} SD\right\} = \mathrm{pr}\left\{\frac{1}{2}\log_2\left(\mathrm{SINR}_{ST,SD}\right)\right\} < 2^{R_{ST}} - 1\right. \quad (20)$$

For the Best Relay selection scenario, mutual information between ST and SD may be shown to be

$$I_{ST,SD} = \frac{1}{2}\log_2\left[1 + SINR_{ST,SD} + SINR_{SR_{BEST}}\right] \quad (21)$$

Where $SR_{BEST}(\text{Best Relay}) = \arg \underset{i}{Max}\left\{ \mu_{BEST}\left(SR_i \middle| i \in \varphi_K\right)\right\}$ (22)

Again secondary outage probability $\left(Pout_{Secondary}\right)$ is bounded as follows:

$$Pout_{Secondary} = pr\left(I_{ST,SD}\right) < \Xi_S \,, \quad \text{where } \Xi_S = 2^{R_{ST}} \quad (23)$$

In the above equation (23) substituting the value of $I_{ST,SD}$ from (21), we obtain both the secondary outage probabilities of SINR and FLBRS based relay selection methods as below in (24) and (25).

$$\therefore Pout_{Secondary}\left|\{\varphi \neq \phi \text{ and } \varphi = \varphi_k\} = pr\left\{\frac{1}{2}\log_2\left(SINR_{ST,SD} + SINR_{\text{Best Relay(SINR Based)}}\right)\right\} < 2^{R_{ST}} - 1\right. \quad (24)$$

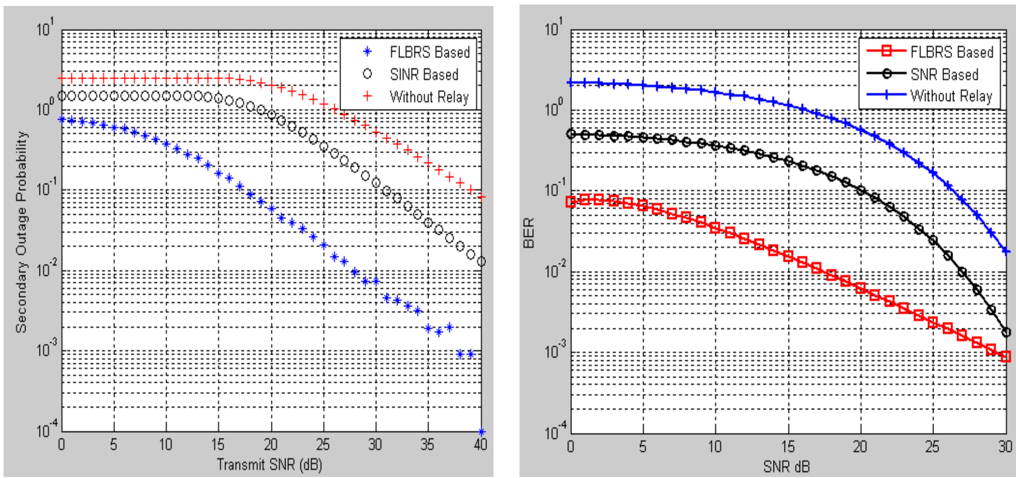
$$\therefore Pout_{Secondary}\left|\{\varphi \neq \phi \text{ and } \varphi = \varphi_k\} = pr\left\{\frac{1}{2}\log_2\left(SINR_{ST,SD} + SINR_{\text{Best Relay(FLBR S Based)}}\right)\right\} < 2^{R_{ST}} - 1\right. \quad (25)$$

In Fig .9 authors illustrate the secondary outage probability versus the transmit SNR(dB) of the traditional non-relay, SINR and the proposed FLBRS based cognitive transmission schemes for best-relay selection considering the parameters given in table .3 for simulating in MATLAB software. The outage probability of the proposed FLBRS scheme is much lower in comparison to both non-relayed approach or SINR based approach of relay determination.

Table 3. Parameters of the Simulation environment in MATLAB

Simulation parameters	
Primary Data Rate	0.4 bits/s/Hz
Secondary Data Rate	0.2 bits/s/Hz
$\sigma^2_{PT,PD} = \sigma^2_{ST,SD} = \sigma^2_{ST,SRi} = \sigma^2_{SRi,SD}$	1
$\sigma^2_{PT,SD} = \sigma^2_{ST,PD}$	0.1
$\sigma^2_{PT,SRi} = \sigma^2_{SRi,PD}$	0.2
Transmit SNR	25dB
Number of Cooperating Relays	4

In figure.9 we have plotted Eq. (20), (24) and (25). These figures illustrate that the secondary outage probability and BER performance are improved as FLBRS scheme is adopted.



(a) (b)

Figure9: (a) Secondary outage probability versus the transmit SNR (dB) (b) BER versus SNR (dB)

Conclusion and Future Scope

In this correspondence, the selection technique of Reliable Best Relay based on fuzzy logic is proposed for secondary transmission in multi-user cooperative cognitive radio systems. This approach considers three input parameters for relay node selection jointly viz, SINR, RLQ and Reliability, which claims to be novel among other available research studies. This fuzzy logic–based innovative solution for secondary data transmission is not complex, practicable, and less time consuming. Hence, it can be easily developed into application programs and can be utilized for real-time systems. In this paper, we have calculated the membership values of the relay nodes those are member of decoding set and in future it is possible to redefine a new relay selection scheme which may combat the unsuccessful data transmission.

References

I . Akyildiz, I. F.; Wang, X. and Wang, W. “Wireless mesh networks: a survey”. Computer networks, 47(4), pp 445-487 (2005).

II. Akyildiz, I. F.; et. al. “CRAHNs: Cognitive radio ad hoc networks”. Ad Ho Networks, 7(5), pp 810-836 (2009).

III. Beres, E. and Adve, R. “Selection cooperation in multi-source cooperative networks”. IEEE Transactions on Wireless Communications, 7(1) (2008).

IV. Banerjee J.S.; Chakraborty A and Chattopadhyay A. “Fuzzy Based Relay Selection for Secondary Transmission in Cooperative Cognitive Radio Networks”. In: Proc. OPTRONIX, Springer, pp 279-287 (2017).

V. Banerjee J.S.; Chakraborty A and Chattopadhyay A. “Relay node selection using analytical hierarchy process (AHP) for secondary transmission in multi-user cooperative cognitive radio systems”. In: Proc. ETAEERE, Springer, pp 745-754 (2018).

VI. Chakraborty, A.; Banerjee, J. S. and Chattopadhyay, A. “Non-Uniform Quantized Data Fusion Rule Alleviating Control Channel Overhead for Cooperative Spectrum Sensing in Cognitive Radio Networks”. In: Proc. IACC, pp 210-215 (2017).

VII. FCC (2003). ET Docket No 03-222 Notice of proposed rule making and order.

VIII. Gao, X.; Wu, G. and Miki, T. “End-to-end QoS provisioning in mobile heterogeneous networks”.Wireless Communications, IEEE, 11(3), pp 24-34 (2004).

IX. Jing, T.; Zhu, S.; Li, H.; Xing, X.; Cheng, X.; Huo, Y.; ... and Znati, T. “Cooperative relay selection in cognitive radio networks”. IEEE Transactions on Vehicular Technology, 64(5), pp 1872-1881(2015).

X. Kandukuri, S. and Boyd, S. “Optimal power control in interference-limited fading wireless channels with outage-probability specifications”. IEEE transactions on wireless communications, 1(1), pp 46-55 (2002).

XI. Laneman, J. N.; Tse, D. N. and Wornell, G. W. “Cooperative diversity in wireless networks: Efficient protocols and outage behavior”. IEEE Transactions on Information theory, 50(12), pp 3062-3080 (2004).

XII. Mitola, J. and Maguire Jr, G. Q. “Cognitive radio: making software radios more personal”. IEEE Personal Communications, 6(4), pp 13-18 (1999).

XIII. Mitola,J. III.”Cognitive Radio--- An Integrated Agent Architecture for Software Defined Radio”. Sweden: Royal Institute of Technology, (2000).

XIV. Paul S.; et. al. "A Fuzzy AHP-Based Relay Node Selection Protocol for Wireless Body Area Networks (WBAN)". In: Proc. OPTRONIX 2017 (Press), IEEE, Nov. (2017).

XV. Paul S.; et. al."The Extent Analysis Based Fuzzy AHP Approach for Relay Selection in WBAN". In: Proc. CISC (Press), AISC-Springer, (2018).

XVI. Saha O.; Chakraborty A. and Banerjee J. S. "A Decision Framework of IT-Based Stream Selection Using Analytical Hierarchy Process (AHP) for Admission in Technical Institutions". In: Proc. OPTRONIX 2017 (Press), IEEE, Nov. (2017).

XVII. Saha O.; Chakraborty A. and Banerjee J.S.: A Fuzzy AHP Approach to IT-Based Stream Selection for Admission in Technical Institutions in India. In: Proc. IEMIS (Press), AISC-Springer, (2018).

XVIII. Simeone, O.; Gambini, J.; Bar-Ness, Y. and Spagnolini, U. "Cooperation and cognitive radio". In ICC, IEEE, pp 6511-6515 (2007)

XIX. Zou, Y.; Zhu, J.; Zheng, B.; Tang, S. and Yao, Y. D. "A cognitive transmission scheme with the best relay selection in cognitive radio networks". In GLOBECOM, IEEE, pp 1-5 (2010).

XX. Zhang, Q.; Jia, J. and Zhang, J. "Cooperative relay to improve diversity in cognitive radio networks". IEEE Communications Magazine, 47(2), pp 111-117 (2009).