Fuzzy Logic Based Relay Search Algorithm For Cooperative Systems

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***Abstract*— Cooperative systems provide spatial diversity in wireless communications that is advantages when multiple antennas at wireless nodes are not cost effective. In this work, we propose fuzzy logic based relay search algorithm for 2- hop cooperative systems with the goal of maximizing the performance of a system in terms of SER (Symbol error rate). The algorithm requires effective SNR (signal to noise ratio), and total time delay of the link (propagation delay and processing delay at relay) as fuzzy parameters. The performance of the proposed algorithm is compared with Blind-Selected Algorithm and Informed-Selected Algorithm. Simulation results shows that Fuzzy logic based relay search results in substantial improvement over the existing relay selection algorithms.**

Keywords- Virtual Cellular Network (VCN), Relay Selection, Rayleigh Fading, Fuzzy logic.

I. INTRODUCTION

FORTH-GENERATION(4G) wireless system will offer broadband multimedia services at the rate of around 100Mbps~1Gbps. The peak-transmit power increases with data transmission rate. Reducing the cell size is an efficient way to avoid larger transmit power while increasing the data transmission rate [1], [2], [3]. In order to comprehend much higher data rate transmission with low transmit power, multihop virtual cellular network (VCN) was proposed [4].

Multi-relay cooperation is a promising method to achieve spatial diversity in order to combat the fading conditions. Cooperative relaying in the two-hop VCN enables one or more relay nodes to process multicast signal overheads from a source and retransmit it to the destination. The transmitted signals are then combined in the destination using a suitable combining technique. Thus, relay selection is an important issue to attain better system throughput.

Many studies have been carried out on relay selection since 2-hop cooperative relaying system was introduced. As the related research about relay selection method: Zinan Lin et. al. proposed simple relay search algorithms that only utilize the knowledge of average received SNR's at the destination [5]. D. S. Michalopoulos et. al. reported a novel relay selection method to achieve the optimal balance between the error performance and total consume energy [6]. Hiraku Okada et. al. suggested a route selection scheme for multi-hop cellular network based on BER [7]. Bletsas et. al. proposed an opportunistic relaying scheme which used high SNR among multiple cooperating terminals. But this scheme uses only one relay [8]. Abbas El Gamal et. al. analytically proved that link delays can change the nature of cooperation in a network and hence its capacity [9]. The main role of relay selection controller is to determine whether a relay can be selected or not. This decision shall be based on the availability of the resources (bandwidth and buffer length) and whether the QoS can be guaranteed. An analytical model may not be able to capture the statistical nature of the traffic. With increasingly complex control problem in high speed future network, the fuzzy logic controller is able to make intelligent decisions based on imprecise information. We includes effective link SNR (considering Rayleigh fading, shadowing, and path loss) as well as total link delay (considering processing time in relay and the link propagation delay) for the relay selection parameters.

The main contribution of this article is the proposal of a fuzzy logic based relay selection method for a cooperative communication system. This method considers the fuzzy variables: effective signal to noise ratio (γ_i), and link delay (t_i). Fuzzy logic has been developed as a mathematical model to implement human logic in engineering solutions based on uncertain or imprecise information. In fuzzy logic, individual elements can be members of a set to only a certain degree. In fact, Fuzzy reasoning is neither exact nor absolutely inexact, but only to a certain degree exact or inexact

II. SYSTEM MODEL

Consider a wireless network with fixed K relay terminals between a source and a base station (BS) as shown in Figure 1(a). The whole cell is covered by a BS placed at the center of the circular cell and every radio terminal contains 1 transmit and 1 received antennas. In order to prevent the relays from receiving and transmitting on the interference channels, we allocate orthogonal channels $C_k(k=1,2,...,K)$ (different time slot or frequency slot) to each radio system.

Channel propagation model takes in path loss with distance, shadowing effect and Rayleigh fading.

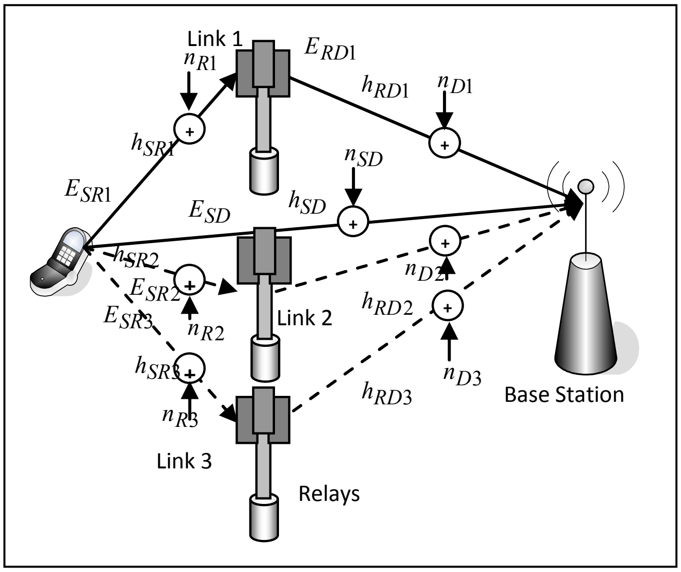


Figure 1: System Model

The fading is considered constant during two transmission times slot, independent from one transmission to next, fading is mutually independent among three links. Consider, E_s is the transmit power of each node, $h_{SD,i}$ $h_{SR,i}$ and $h_{RD,i}$ are the complex unit power channel gains through S-D, S-R and R-D links; $n_{D,0}$, $n_{R,i}$ and $n_{D,i}$ are AWGN with variance $N_{D,0}$, $N_{R,i}$, and $N_{D,i}$ of the S-D, S-R and R-D links and $t_{d,i}$ is the processing delay at the i^{th} relay is captured by $t_d \geq 1$. The different delays t_d with induce the inter symbol interference (ISI) channel with length of at least two between the MS and BS.

Let us consider, at the time slot 1, the MS broadcast the information symbol $x[n]$ to the destination as well as to fuzzy logic based selected relay(s). The relays are not allowed to communicative with each other, and monitor the channel condition solely. The destination station (BS) received the information symbols from the relay on the time slot 2. The received signal at the BS ($y_{D,0}[n]$) and the received signal at the relay i ($y_{R,i}[n]$) after the first transmission time can be written as

$$y_{D,0}[n] = h_{SD,0}\sqrt{E_s}\,x[n] + n_{D,0}[n] \qquad (1)$$

$$y_{R,i}[n] = h_{SR,i}\sqrt{E_s}\,x[n] + n_{R,i}[n] \qquad (2)$$

Whereas the signal received at the BS during the second transmission time can be written as

$$y_{D,i}[n] = h_{RD,i}\sqrt{E_s/2}\,y_{R,i}[n] + n_{D,i}[n]$$

$$= h_{RD,i}\sqrt{E_s/2}\,\beta\left(h_{SR,i}\sqrt{E_s}\,x[n-t_{d,i}] + n_{R,i}[n]\right) + n_{D,i}[n]$$

$$= h_{SR,i}h_{RD,i}\sqrt{E_s/2}\sqrt{E_s}\,\beta x[n-t_{d,i}] + h_{RD,i}\sqrt{E_s/2}\,\beta n_{R,i}[n] + n_{D,i}[n] \qquad (3)$$

with the amplification factor[8] $\beta = \dfrac{1}{\sqrt{|h_{SR,i}|^2 E_s + N_{R,i}}}$

where, $1/\sqrt{2}$ comes from the equal distributed energy assumption. We can rewrite (2) and (3) as

$$\begin{bmatrix} y_{D,0}[n] \\ y_{D,i}[n+t_{d,i}] \end{bmatrix} = \sqrt{E_s}\begin{bmatrix} h_{SD,0} \\ h_{SR,i}h_{RD,i}\sqrt{E_s/2}\,\beta \end{bmatrix} x[n] + \begin{bmatrix} 0 \\ h_{RD,i}\sqrt{E_s/2}\,\beta n_{R,i}[n] \end{bmatrix} + \begin{bmatrix} n_{D,0}[n] \\ n_{D,i}[n+t_{d,i}] \end{bmatrix}$$

It can be written in the following form

$$Y = \sqrt{E_s}HX + N \qquad (4)$$

with, $H = \begin{bmatrix} h_{SD,0} \\ h_{SR,i}h_{RD,i}\sqrt{\dfrac{E_s}{1+(|h_{RD,i}|^2 E_s + N_{D,i})\beta^2}}\,\beta \end{bmatrix}$

Equation (4) can be calculated for any number of relays.

The BS receives amplified signals from the M fuzzy logic based selected relays and from the source directly depending on the threshold SER (Symbol Error Rate). In order to achieve maximum likelihood performance, the signals from the $M+1$ diversity branches are combined using Maximum Ratio Combining (MRC).

The information signal is delayed until all the relayed signals are received by BS. The estimated information symbol at the output of the MRC can be written as

$$\hat{x}[n] = \frac{h^*_{SD,i}\sqrt{E_s}}{N_{SD,0}}y_{D,i}[n] + \sum_{i=1}^{M}\frac{h^*_{SR,i}h^*_{RD,i}\sqrt{E_s}}{|h_{SR,i}|\mathrm{N}_i}y_{D,i}[n+t_{d\,i}]$$

$$= \left(\frac{|h_{SD,i}|^2 E_s}{N_{SD,0}} + \sum_{i=1}^{M}\frac{|h_{RD,i}|^2 E_s}{\mathrm{N}_i}\right)x[n] + \frac{h^*_{SD,i}\sqrt{E_s}}{N_{SD,0}}n_{D,0}[n]$$

$$+ \sum_{i=1}^{M}\left(\frac{|h_{RD,i}|^2\sqrt{E_s}}{h_{SD,i}\mathrm{N}_i}n_{R,i}[n+t_{d,i}] + \frac{h^*_{SR,i}h^*_{RD,i}\sqrt{E_s}}{|h_{SR,i}|\mathrm{N}_i}n_{D,i}[n+t_{d,i}]\right)$$

where $\mathrm{N}_i := N_{RD,i} + N_{SR,i}\dfrac{|h_{RD,i}|^2}{|h_{SR,i}|^2}$ is the total noise power on branch $i \in [1, M]$ [9].

1000-fading level within the course of transmission is considered. The fading values in the different course of transmissions are independent. Consider a 2-hop system scenario a mobile station (MS) is communicating to a base station (BS) with/without the cooperation of relay. The system contains $K = 3$ relay stations. Considering the impact of path loss and shadowing, the general expression of the SINR can be written as

$$SNIR_i = \frac{E_s . |h_i|^2 L_i}{\sum_{j=1, j\neq i}^{k} E_s . |h_i|^2 L_j + N_i}$$

$L_i = d_i^{-\alpha} 10^{\xi/10}$ [10] is the path loss, α is the propagation constant (typically α =3.5), and ξ is the lognormal random variable with Gaussian distribution random variable with (0, σ) and the pdf is defined as

$$f_\xi(\xi) = \frac{1}{\sigma\sqrt{2\pi}} \exp(-\frac{\xi^2}{2\sigma^2})$$

Since the channels are fixed during the multiple access time frames, the channel is time independent during transmission. The pdf of the channel gain be defined as

$$P(r) = \frac{r}{\sigma_r^{\ 2}} \exp\left(-\frac{r}{2\sigma_r^{\ 2}}\right) \quad r > 0$$

where, σ_r is the Rayleigh distribution parameter. Ignoring the path loss and shadowing, *Cooperative Gain:* It is the ratio of the FER of the non-cooperative direct transmission to the FER of the cooperation of relay R_i

$$G_{f,i} = \frac{P_{f,i}^{no-co}}{P_{f,i}^{co}}$$

III. Selection Criterion

A. Effective SNR:

Direct transmission: The effective SNR for the direct transmission scheme can be written using equations (1) and (3) as

$$SNR_{direct} = \frac{E_s |h_{SD,i}|^2 L_{SD,i}}{N_{SD,i}} \quad \text{as } [\sum_{j=1, j\neq i}^{k} E_s |h_i|^2 L_j = 0]$$

Two hop transmission: The effective SNR for the two hop transmission can be written using equations (1), (4) and after normalization with taking the variance of the noise into account as

$$SNR_{two-hop,i} = \frac{SNR_{SR,i} SNR_{RD,i}}{1 + SNR_{SR,i} + SNR_{RD,i}}$$

Where $i \in (1,2,3)$ is the link as shown in Figure 1.

Cooperation with multi (m)-relay: The effective SNR for the source direct transmission with cooperation with multi-relay can be expressed as

$$SNR_{Direct\&two-hop} = SNR_{direct} + \sum_m \frac{SNR_{SR,m} SNR_{RD,m}}{1 + SNR_{SR,m} + SNR_{RD,m}}$$

B. Total link delay:

If $t_{SD,i}$, $t_{SR,i}$,and $t_{RD,i}$ are the transmission delay in the S-D link, S-R link, R-D link where as $t_{d,i}$ is the delay time in the relay, the total link delay can be expressed by

$$t_i = \begin{cases} t_{SD,i} \text{; for the direct transmission} \\ t_{SR,i} + t_{RD,i} + t_{d,i} \text{; for the two-hop transmission} \\ \max(t_{SD,i}, t_{SR,i} + t_{RD,i} + t_{d,i}) \text{; for the relay cooperation} \end{cases}$$

But the system capacity (C) $= \dfrac{\text{Total transmitted data bits}}{t_i}$

Outage probability: The outage probability P_{OUT} can be written as

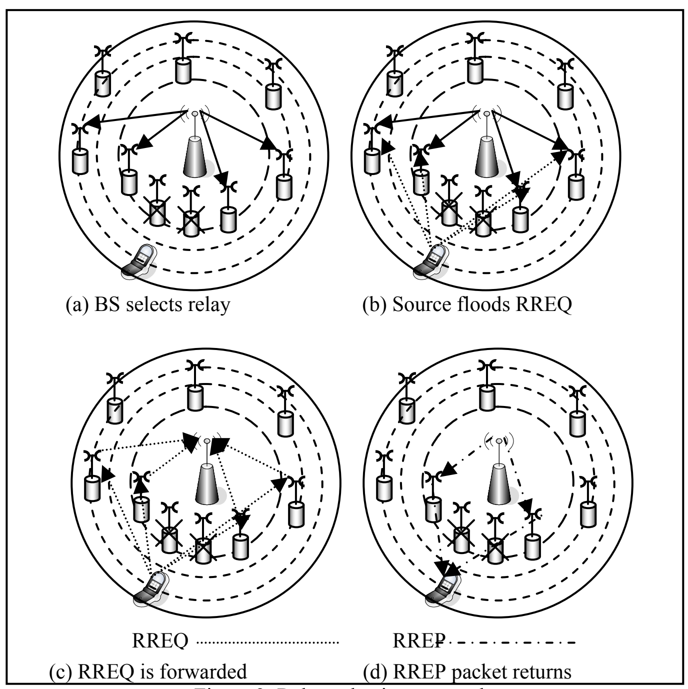
$$P_{OUT} = P_r((SNR(h,\xi) < SNR_{Threshold}) \cap (t_d > t_{Threshold}))$$

IV. Relay Selection Technique

For the simplicity of our proposed protocol, it is assumed that the BS (or wireless port) is connected to the relay stations previously based on the $SNR_{threshold}$. After that MS establishes links to the BS reactively. This can reduce the control overhead. The procedure of the proposed protocol is as follows:

Step 1: At every wireless link SNR is measured periodically. If the $SNR_i < SNR_{threshold}$, this wireless link or the relay is not selected, that is, the data and the control packets are not transmitted through this relay station (Figure 2(a)).

Step 2: As mentioned earlier, the links between the BS and the relays are established proactively. A base station broadcasts a reference packet for route establishment. All relays having $SNR_{RDi} > SNR_{threshold}$ receives that reference packet.



(a) BS selects relay
(b) Source floods RREQ
(c) RREQ is forwarded
(d) RREP packet returns

Figure 2: Relay selection protocol

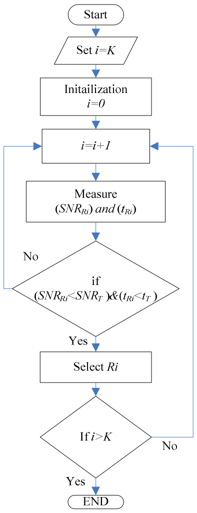


Figure 3(a): BS to Relays

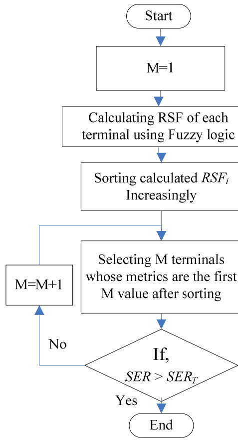


Figure 3(b): MS to Relays

Figure 3: Flow chart of the relay selection algorithm.

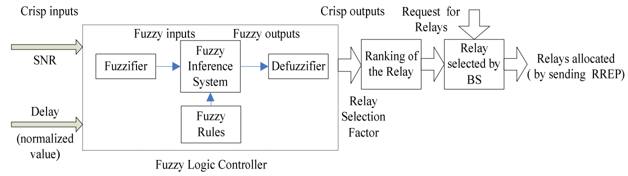
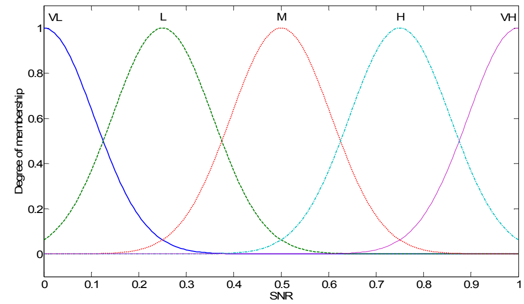
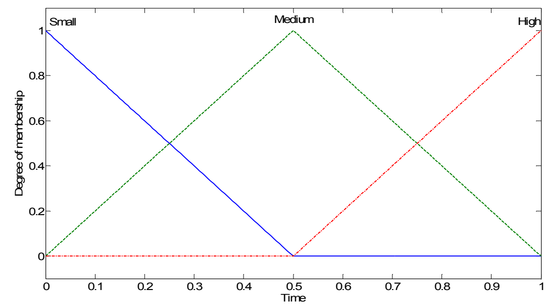


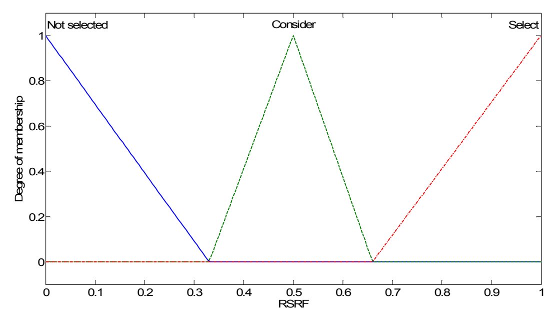
Figure 4: Fuzzy Logic Controller for Relay Selection



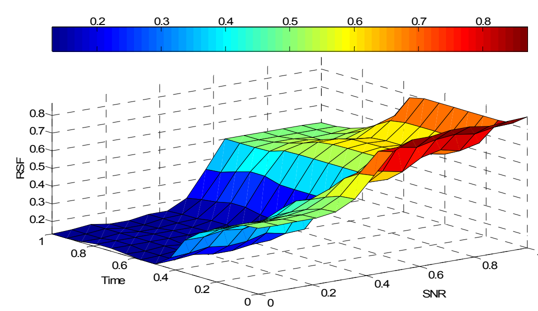
a) Membership function for SNR



b) Membership function for Delay



c) Membership function for RSF



d) Surface graph for the rule base system

Figure 5: Membership functions for linguistic parameters and surface graph (rule base system).

If one relay receives the same packed again, the duplicate packet is discarded, otherwise the packet is broadcasted. This process is repeated and finally routes from the base station to the relay are established.

Step 3: The source also select relay(s) reactively. First, the source floods the relay request (RREQ) packets (Figure 2(b)). Those relay stations having $SNR_{SD_i} > SNR_{threshold}$ and delay time $t_i < t_{Threshold}$, receiving this packet forward it to the BS or wireless port by referring to the routes established in the proactive phase (Figure 2(c)). BS measures the Relay selection factor, RSF, (m_i) of the each selected relay by $m_i = nor(SNR_i) - nor(t_i)$

Step 4: The BS sorts the relays by descending order and select at number of relays based required SER value. After the selection of the relays for that particular source, the wireless port returns the route reply (RREP) packet to the source station (Figure 2(d)). The flow chart of this selection scheme is shown in Figure 3.

V. Fuzzy Logic Based Relay Selection

A. *Fuzzification:*

Fuzzification is a mapping from the crisp domain to the fuzzy domain i.e. assigning of linguistic value defined by a relatively small number of membership functions to variables (effective SNR and link delay). The membership function is used to associate a grade to each linguistic term. This preprocessing of a large range of values into linguistic fuzzy sets represented by the membership functions greatly reduces the number of values that need to be processed [11]. Then the linguistic values for each fuzzy variable are assigned using intuition method. Intuition method is simply derived form the capacity of humans to develop membership functions through their own intelligence and understanding.

The membership functions ($G((\gamma), G(t_i))$) for each of the considered fuzzy parameters and their range of linguistic values are shown in Figure 5. The fuzzy relay selection scheme forms a fuzzy set of dimension $G(\gamma) * G(t_i)$. The values of fuzzy variables assigned depends on the system designer or m_i.

B. Inferences:

Since there are two input variables: effective SNR and delay time and effective SNR has 5 membership functions (VL: Very Low, L: Low, M: Medium, H: High, VH: Very High), delay time has 3 membership function (Small, Medium and High), and the total number of rules is 15. In this case, the rule base is in a form called functional fuzzy system where each rule i is written as: Rule i

IF *SNR* is *High* and *Delay* is *Low* THEN *RSF* is *High*

Where *RSF* linguistic values (Selected, Consider, Not selected) are decided based on membership function $G(\gamma), G(t_d)$. To decide an appropriate output membership function, the strength of each rule must me considered.

C. Defuzzification:

It converts a fuzzy set or fuzzy number into a crisp value or number. Defuzzification is such inverse transformation which maps the output from the fuzzy domain back into the crisp domain. The Center-of-Area (COA) method computes the centroid of the composite area representing the output fuzzy term. Figure shows the membership functions of a linguistic output variable RSP COA defuzzification method computes the centroid of this area. Let, u_i be the values of RSP and the $\mu_{OUT}(u_i)$ be the corresponding membership grade. The COA defuzzification formula provides crisps value $u*$ as follows:

$$u* = \frac{\sum_{i=1}^{N} u_i \mu_{OUT}(u_i)}{\sum_{i=1}^{N} \mu_{OUT}(u_i)}$$

VI. Simulations Results

To review the effectiveness of the proposed relay selection technique, we set the simulation parameters as shown in Table 1. Figure 6 shows plot of error rate probability versus SNR for the direct path, 2-hop transmission path and direct path cooperated with 2-hop paths. It is observed that R1 is the best relay in terms of SNR. If the SER of the direct path is less than some threshold, the proposed algorithm will select the direct path cooperated with R1. If the SER of the direct path cooperated with one relay is less than that of threshold SER, the algorithm will also select R3 in addition to R1. To review the effectiveness of the proposed relay selection technique, we set the simulation parameters as shown in Table 1.

TABLE I
SIMULATION PARAMETERS FOR THE NUMERICAL EXAMPLE OF RELAY SELECTION METHODS

Modulation	QPSK
Channel Model	AWGN+1000-ray Rayleigh&Shadowing
Reception Method	Maximum-ratio-combining (MRC)
Access Method	TDMA
Path loss exponent α	3.5
The noise variance in the channel N_o	-143dB
Cell radius of BS	1.2 km
Relays and BS distance	700m
Relay distance from source [d_{r1} d_{r2} d_{r3}] in m	[300,700,400]

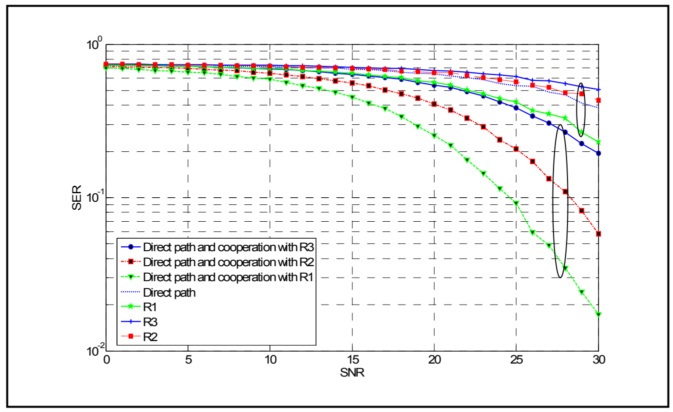


Figure 6: SER versus SNR for the direct path, 2-hop path, and cooperation of one relay

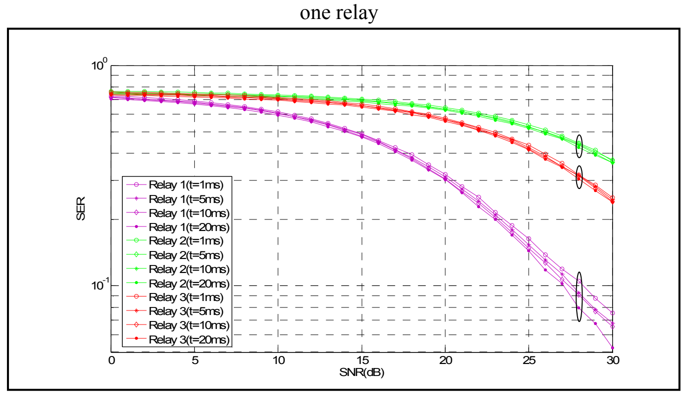


Figure 7: The effect of delay on SER versus SNR curve for different delay condition, Case 1 [700, 1000, 1500]

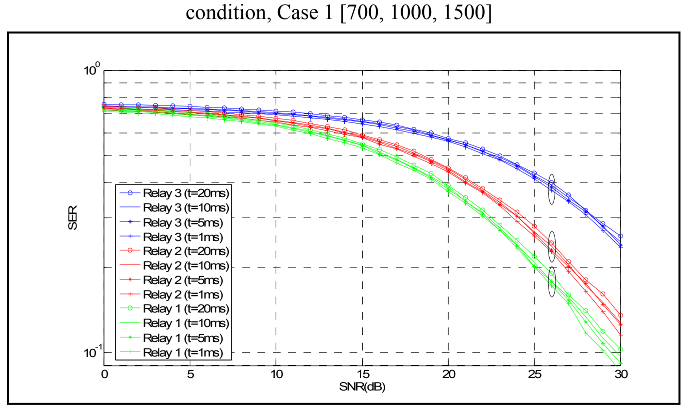


Figure 8: The effect of delay on SER versus SNR curve for different delay condition, Case 2 [700, 800, 1500]

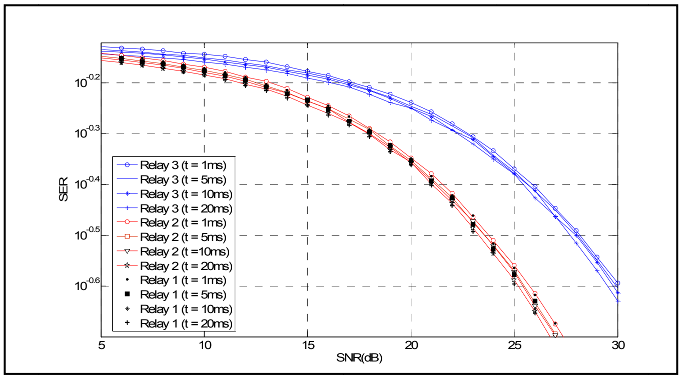


Figure 9: The effect of delay on SER versus SNR curve for different delay condition, Case 3 [840, 850, 1500]

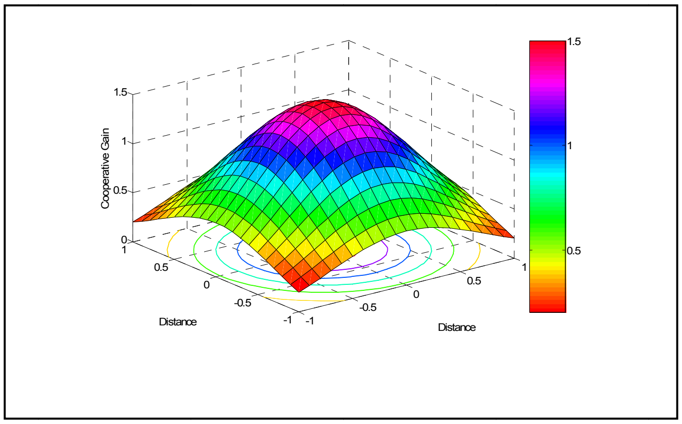


Figure 10: Cooperation gain as a faction of relay positions.

Figure 6 shows plot of error rate probability versus SNR for the direct path, 2-hop transmission path and direct path cooperated with 2-hop paths. It is observed that R1 is the best relay in terms of SNR. If the SER of the direct path is less than some threshold, the proposed algorithm will select the direct path cooperated with R1. If the SER of the direct path cooperated with one relay is less than that of threshold SER, the algorithm will also select R3 in addition to R1. Figure 7 to 9 show the effect of processing delay at relays on SER for the different effective SNR conditions(three different case: Case 1, Case 2 and Case 3). As the processing delay increases, SER will increases the system capacity as well as the system throughput decreases. When the effective SNR of the two links are close or same random search algorithm and SNR based relay search algorithm will not be able to select best relay. Figure 9 shows the SNR of R1 and R3 are close, if the processing delay in R3 is less than 10 ms then R3 but the processing delay in R1 is higher than 10 ms, R3 will be the best relay instead of R1. The proposed algorithm will select R3 where as the random selected method and SNR based algorithm will select R1 as the best relay. Figure 10 shows the cooperative gain and cooperative region as a function of relay position for the *SNR=10dB*. During the simulation it is considered that the relay is at (0,0) position, source and destination are at (1,0) and (-1,0) position respectively.

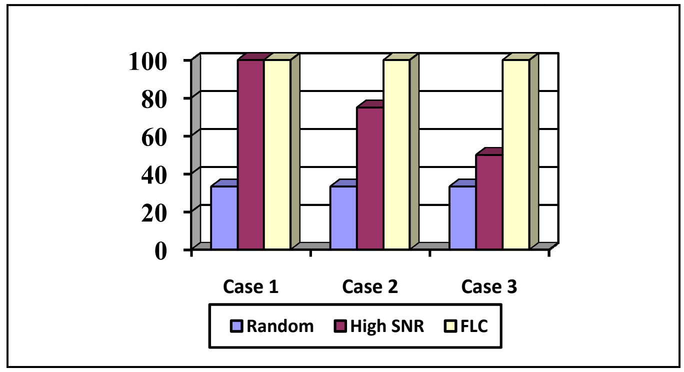


Figure 11: Comparison of efficiency achieved for the random relay search, SNR based search and fuzzy logic based relay search algorithm for three different cases

It is shown from Figure 10 that the cooperative gain is maximum for the relay at the centre between source and destination, the gain decreases as the MS moves towards the relay i.e. the distances between source-relay and relay-destination are not equal. Figure 11 shows the efficiency achieved for the random relay search, SNR based search and fuzzy logic based relay search algorithms for three different cases.

VII. Conclusions

In this paper, we proposed the fuzzy logic based relay selection algorithm considering the fuzzy variables: link SNR and delay at the relay. Simulation results show that the proposed algorithm performs better than the traditional relay search algorithm reported in different research paper. We also observe that the cooperation gain depends on relay location; the cooperation gain become maximum as the relay is at center between source and destination. The proposed fuzzy logic based relay search algorithm shows better performance over the conventional approaches reported in different article if incomplete uncertain and heterogeneous information are considered for relay selection. In future, we extend our work by considering queue length and mobile node power for the relay selection parameters in addition to effective SNIR and link delay.

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