IJDACR
ISSN: 2319-4863

IJDACR
International Journal Of Digital Application & Contemporary Research

International Journal of Digital Application & Contemporary Research
Website: www.ijdacr.com (Volume 7, Issue 07, February 2019)

Fuzzy Logic based Optimized Relay Selection Protocol for Cooperative Wireless Network

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Abstract – **Cooperative communications can be extremely proficient in combating fading multipath channels and enhance scope with complexity and cost. Furthermore there is also possibility of improving performance of cooperative communication by optimal relay selection strategies. Relay selection is a technique that can considerably increase the performance of cooperative communications. This paper presents a fuzzy logic based relay selection protocol for cooperative wireless network. The transmit power for broadcast phase is optimized by Artificial Bee Colony (ABC) algorithm. The performance of proposed system is evaluated on the basis of Bit Error Rate (BER).**

Keywords – **ABC, BER, BEP, Cooperative Communication.**

I. Introduction

As wireless communication becomes more prevalent, the demand for higher data rates and uninterrupted connectivity is increasing. Future wireless systems are provisioned to be highly heterogeneous and interconnected. On one side, wireless sensor networks are emerging for a wide range of new applications, on the other side; infrastructure based broadband wireless systems are expanding to provide increasing number of services with ubiquitous coverage.

In wireless broadband networks cooperative communication emerged as an upgrade to single hop cellular architecture. In infrastructure based wireless networks, enabling multi-hop relaying brings many opportunities at different network layers. Replacing long and weaker links with short and stronger links can mitigate the burden on the link budget. Alternative routes between the users and the base station provide robustness against shadowing and multi-path fading, and introduce new design options for scheduling and routing [1].

In physical layer an important opportunity arises with cooperation; due to the broadcast nature of wireless medium, as the data is transmitted to its destination in multiple hops, many nodes in the vicinity can hear these transmissions. Transmissions from different nodes are generally affected by different and statistically independent fading. Hence, the final destination of the data can combine all the received signals using traditional combining methods such as Maximal Ratio Combining (MRC) or Selection Combining (SC) and obtain diversity against the harming effects of fading.

Diversity obtained through multihop transmissions is usually referred to as cooperative diversity [2]. Diversity is a very powerful technique to increase robustness against channel fading. Cooperative diversity is a kind of spatial diversity that can be obtained without multiple transmit or receive antennas. It is especially useful when time, frequency, and spatial diversity through multiple antennas are not feasible. The first examples of practical cooperative diversity protocols were studied by Laneman et al. [3]. It was shown that diversity relaying has the potential to improve end-to-end (e2e) performance in slow fading environments despite the penalty of relaying in terms of bandwidth expansion [4].

Since the source node in the cooperative communication scheme depends on the relay nodes to forward the transmission, relay selection and resource allocation for the relay nodes become important in order to obtain optimal performance of the cooperative communication system. By choosing the right nodes to relay the transmission, the system can achieve higher capacity. In this work,

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optimal relay selection and power allocation issue is addressed.

The main objective of this paper is to develop an ABC and fuzzy logic based relay selection protocol for cooperative wireless sensor network. The performance of proposed system is based on Bit Error Rate.

This paper is organized as follows. Section 2 describes the proposed methodology based on fuzzy logic. System model is described in section 3. Section 4 illustrates the simulation results and analysis. Conclusions are drown in the last section.

II. Proposed Methodology

Fuzzy logic is a multi-valued logic, which allows intermediate values to be defined by conventional evaluations as true / false, yes / no, up / down, and so on. Concepts such as "big enough" or "very fast" can be mathematically formulated and processed by computers in order to apply thought in computer programming more humanely. Fuzzy logic uses Fuzzy inference system.

The operating principle of a Fuzzy inference system is as follows: the digital input is converted to fuzzy using a fuzzification method. After fuzzification, a rule base will be formed. The rule base and the database are jointly designated by the knowledge base. Defuzzification is used to convert the fuzzy value to a real value that represents the output. The steps of the fuzzy reasoning (fuzzy inference operations on "IF-THEN" type rules) performed by a FIS are:

- Compare the input variables with the membership functions on the "antecedent" part in order to obtain the membership values of each linguistic label. This step is often called fuzzification.
- Combine (by a specific operator, usually multiplication or min) the membership values of the "premise" part to obtain the strength (weight) of each rule.
- Generate qualified consequences (either fuzzy or digital).
- Aggregate the consequences qualified to produce a digital output. This step is called defuzzification.

II. SYSTEM MODEL

Consider a cooperative diversity scenario 100×100 square meters having a source S, a destination D and a set of relays $(R_1, R_2, \dots, R_N)$ as shown in Figure 1. Also considering the communication link between Source-to-relay and Relay-to-destination terminal is half duplex, i.e. relay can either receive or send data at any given time.

Furthermore it is assumed that each node is equipped with single antenna terminal. For the first simulation scenario the channel between source and destination terminal is considered to be corrupted and there is no direct transmission possible. The transmission from source node is divided into two phases;

- Broadcast Phase
- Relaying Phase

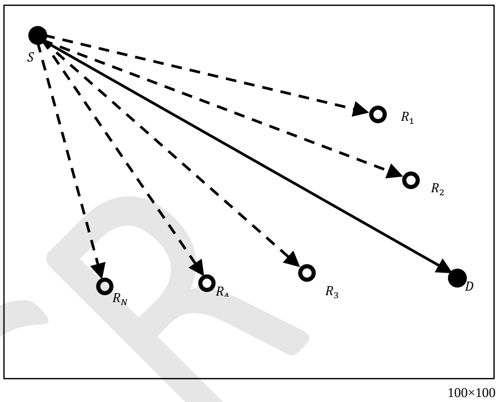

Figure 1: Random area of 100×100m^2

There are several cooperative relaying techniques depending on how the relay processes the information. In this research work, we have used Amplify and Forward (AF) relaying. In Amplify and Forward relaying, information is sent to the relay through a noisy channel, where it is amplified and forwarded to the destination without further processing [5].

Let S be a complex-valued M-point constellation data obtained from MPSK or MQAM modulation scheme of length $1 \times N$, where N is frame length. Then equation (1) express the signal received at destination node and relay node in broadcast phase can be given as.

$$Y_{SD} = x.H_{SD} + n_{SD} \quad (1)$$

$$Y_{SR_i} = x.H_{SR_i} + n_{SR_i} \quad \text{for } i = 1,2,\dots n \quad (2)$$

Where H_{SD}, H_{SR_i} are channel coefficient between source to destination node and relay to destination node respectively. n_{SD}, n_{SR_i} are additive white Gaussian noise with zero mean and σ^2 variance.

At the end of broadcast phase, the destination node calculates the BER and if any error is found then relaying phase is evaluated otherwise the algorithm terminates. At the start of relaying phase each relay node first calculates its distance from destination node given by the formula:

$$Dist_{R_iD} = \sqrt{\left(X_{SR_1} - X_D\right)^2 + \left(Y_{R_1} - Y_D\right)^2} \quad (3)$$

And based on the respective distance path loss for each relay is calculated using the formula given as:

IJDACR
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$$\text{Path Loss} = 10 \cdot \text{alpha} \cdot \log_{10}(\text{Dist}_{R_iD}) + C \quad (4)$$

The fuzzy logic based relay selection algorithm is then evaluated for finding relay with minimum path loss with the help of trapezoidal membership function given by:

$$\text{trap}(x;\ a, m_1, m_2, b) = \begin{cases} \frac{x-a}{m_1-a} & \text{if } x \in [a, m_1] \\ 1 & \text{if } x \in [m_1, m_2] \\ \frac{b-x}{b-m_2} & \text{if } x \in [m_2, b] \\ 0 & \text{otherwise} \end{cases} \quad (5)$$

Where $[a, b]$ represent the support and $[m_1, m_2]$ represent the kernel of the trapezoid, such that $a < m_1 \leq m_2 < b$. Note that, for the particular case when $m_1 = m_2$, the function migrates into a triangular function.

The trapezoidal membership function is based on the following fuzzy rules [6-8]:

1. If (path loss is reachable) and (Residual energy is low) then (Degree of relevance is low)
2. If (path loss is reachable) and (Residual energy is adequate) then (Degree of relevance is Very high)
3. If (path loss is reachable) and (Residual energy is high) then (Degree of relevance is highest)
4. If (path loss is considerable) and (Residual energy is low) then (Degree of relevance is medium)
5. If (path loss is considerable) and (Residual energy is adequate) then (Degree of relevance is high)
6. If (path loss is considerable) and (Residual energy is high) then (Degree of relevance is medium high)
7. If (path loss is far) and (Residual energy is low) then (Degree of relevance is lowest)
8. If (path loss is far) and (Residual energy is adequate) then (Degree of relevance is very low)
9. If (path loss is far) and (Residual energy is high) then (Degree of relevance is medium low)

Based on these rules the node with highest degree of relevance is selected, these node will act as the relay node for the current round, for next round the procedure repeats.

Relay with maximum degree of relevance then computes channel gain and forwards the amplified version of information received in broadcast phase to the destination. The channel gain can be calculated as:

$$\text{Gain} = \sqrt{\frac{P_b}{|H_{SR}|^2 \cdot P_a + N_0}} \quad (6)$$

Where, H_{SR} is channel coeffiecient for source node to relay node. P_a is transmit power for broadcast phase which is optimized by artificial bee colony (ABC) algorithm. P_b is transmit power for relaying phase and N_0 is noise power spectral density.

Therefore, the received data at the destination end can be expressed as follows:

$$Y_{RD} = (\text{Gain} \times Y_{SR} \times H_{RD}) + n_{RD} \quad (7)$$

Finally bit error rate is calculated for respective values of signal to noise ratio.

Next section describes the ABC optimization algorithm.

Initialization of the ABC Algorithm

The initial solution population consists of an NFS number of randomly generated food sources in the search space. Assuming that the i^{th} food source of the population is represented by $X_i = [x_{i1}, \ldots x_{ij}, \ldots, x_{in}]$ where n is the dimension of the problem, then each food source is generated by [9]:

$$x_{ij} = X_{\min j} + rnd(0,1)(X_{\max j} - X_{\min j}), j = 1, \ldots n, i = 1, \ldots, N_{FS} \quad (8)$$

These food sources are randomly assigned to the worker N_0 of the hive and the values of the corresponding cost functions are evaluated. We will assume here that $N_0 = N_{FS}$.

Similarly we will assume that the number of bees spectators N_S is equal to N_0. Finally each food source has an abandon counter initialized to 0. The k^{th} iteration consists of successively performing the three phases described below.

Worker Phase: In this phase, each employed bee generates a new food source x_{new} chosen near the position currently found:

$$x_{new_{ij}} = x_{ij} + rnd(-1,1)(x_{ij} - x_{kj}), \quad i = 1, \ldots, N_0 \quad (9)$$

Where $k \in \{1,2,3, \ldots N_{FS}\}$ such that k≠i and $j \in \{1,2,3, \ldots n\}$, are randomly chosen.

We then proceed to a selection after evaluation of the cost function for this new solution. X_{new} replaces X_i in the population if $f(X_{new}) \leq f(X_i)$ (and its abort counter is reset) otherwise X_i is retained and its abort counter is incremented.

Spectator Phase: In this stage the spectators recover from the workers of the information on the quantity of nectar of the source X_i. The probability p_i that spectators choose the source X_i is determined as follows:

$$p_i = \frac{fit_i}{\sum_{k=1}^{N_{FS}} fit_k} \quad (10)$$

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Where fit_i is the quantity of nectar of the i^{th} food source X_i.
The following expression is also found in the literature [10]:

$$p_i = 0.1 + \frac{0.9fit_i}{\max_k(fit_k)} \quad (11)$$

The quantity of nectar associated with the source X_i is determined by:

$$fit_i = \begin{cases} \frac{1}{1+f(X_i)}, & \text{if } f(X_i) \geq 0 \\ 1 + |f(X_i)|, & \text{if } f(X_i) < 0 \end{cases} \quad (12)$$

According to equations (10) and (12), it is clear that the higher the fit_i, the greater the probability of selecting the corresponding source X_i.
Once the i^{th} source is selected by the spectators, they make a modification using equation (9).
If the source thus modified is better than X_i then the modified source replaces X_i in the population (its abort counter is then reset), otherwise X_i is kept and its abort counter is incremented.
Scout Phase: The i^{th} food source is abandoned if it cannot be improved after a predetermined number of T_{limit} tests (i.e. if its abandon counter exceeds T_{limit}) and the corresponding worker bee becomes a scout bee. The scout bee then generates its food source randomly:

$$x_{ij} = X_{min\,j} + rnd(0,1)(X_{max\,j} - X_{min\,j}),$$
$$j = 1, \ldots, n \quad (13)$$

III. Simulation and Results

Simulation Parameters: Simulation parameter are shown in table 1:

Table 1: Simulation parameter

Modulation scheme	BPSK
Relaying protocol	Amplify and forward
No. of relay	50
Initial Energy of node	10
Power allocation factor	r= 0.3, r=0.4, r=0.5
Path loss exponent	3
SNR	0:3:30
Simulation software	MATLAB 9.0.0.341360 (R2015a)

Simulation Results: For simulation a fuzzy tool box present in MATLAB is being used. Type “fuzzy” in command prompt of MATLAB, this will open the fuzzy tool box window.

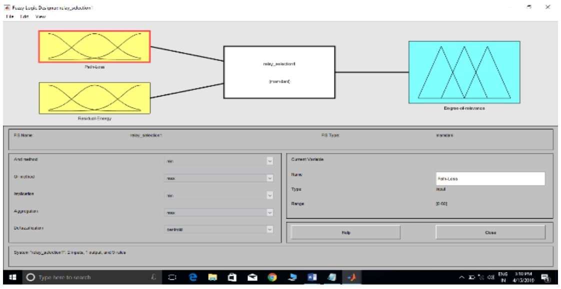

Figure 2: Fuzzy FIS system

There are two fuzzy inputs in proposed protocols path loss and residual energy as shown in Figure 1. This is fuzzy FIS toolbox in MATLAB which is used to implement fuzzy logic in proposed work.

Figure 3 and 4 shows the fuzzy input membership function of distance and residual energy respectively.

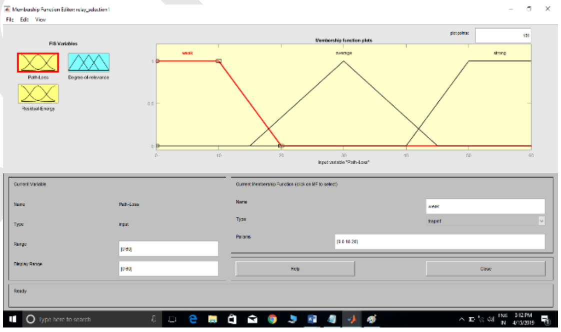

Figure 3: Fuzzy input membership function (path loss)

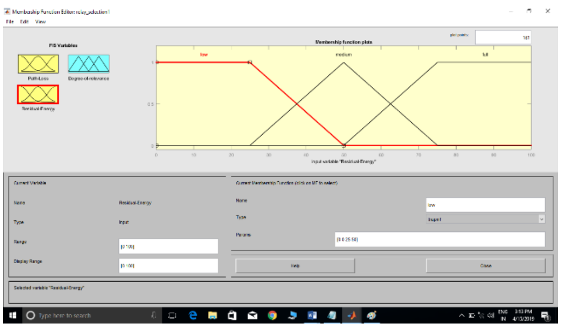

Figure 4: Fuzzy input membership function (residual energy)

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ISSN: 2319-4863

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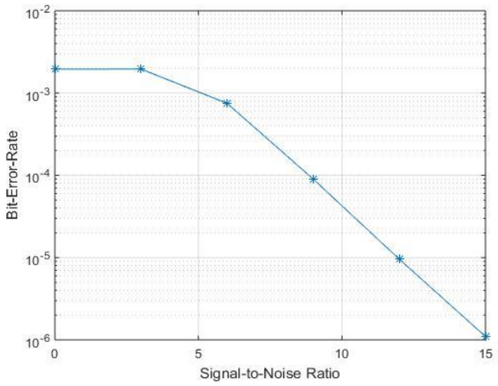

Figure 5: BER performance of Fuzzy based relaying system

The above simulation result in figure 5 shows the BER performance of Fuzzy Logic based relay selection in cooperative communication system. At 15 db SNR, bit error rate value is 10^{-6}. Beyond this point Fuzzy logic based relaying system shows Zero bit error rate.

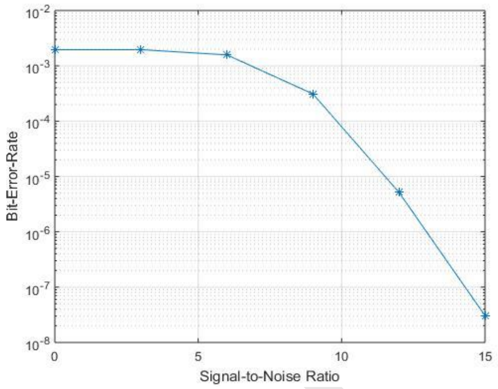

Figure 6: BER performance of Fuzzy based relaying system using Artificial Bee Colony (ABC) optimization

The above simulation result in figure 6 shows the BER performance of Fuzzy Logic based relay selection in cooperative communication system. At 15 db SNR, bit error rate value for Artificial Bee Colony optimization is $10^{-7.7}$. Beyond this point Fuzzy logic based relaying system shows Zero bit error rate.

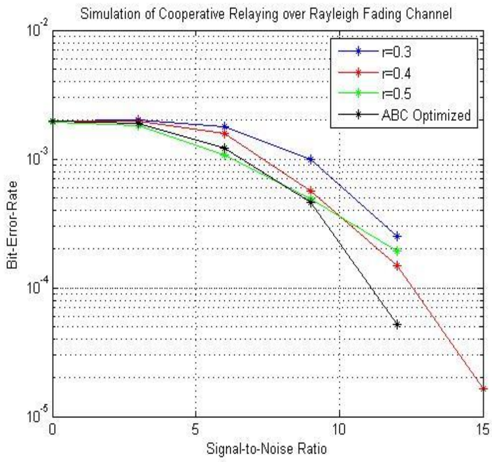

Figure 7: Comparative analysis of BER performance for power allocation factor r=0.3, r=0.4, r=0.5 and ABC (Artificial Bee Colony) optimization

The above simulation result in figure 7 shows the comparative analysis of BER performance of Fuzzy Logic based relay selection in cooperative communication system. At 12 db SNR, bit error rate value for Artificial Bee Colony optimization is $10^{-4.5}$ while for power allocation factor r=0.5 is $10^{-3.9}$. Beyond this point both power optimization techniques shows Zero bit error rate. Clearly Artificial Bee Colony optimization technique outperforms all other techniques. Comparison of different technique employed is given in Table 2.

Table 2: Comparative results for power allocation factor r=0.3, r=0.4, r=0.5 and ABC optimization

SNR (db)	Bit Error Rate for different power allocation factor			
	R=0.3	R=0.4	R=0.5	ABC Optimization
0	0.00194	0.00194	0.00194	0.00194
3	0.00189	0.00195	0.00195	0.00195
6	0.00088	0.00123	0.00117	0.00028
9	1.59e-03	5.07e-04	6.18e-04	7.078e-05
12	8.55e-04	9.55e-04	9.03e-04	6.55e-05
15	0	9.03e-05	0	0
18	0	0	0	0

IV. CONCLUSION

This paper presents a new distributed relay selection algorithm using fuzzy logic and artificial bee colony (ABC) algorithm. Our goal is to provide a mechanism to decrease the energy consumption. The proper selection of the relay can effectively improve the overall performance of the network in terms of higher data rate, lower power consumption and better bit error rate performance. Simulation results show the BER performance for BPSK

IJDACR
ISSN: 2319-4863

International Journal of Digital Application & Contemporary Research

International Journal of Digital Application & Contemporary Research
Website: www.ijdacr.com (Volume 7, Issue 07, February 2019)

modulation schemes. For lower power consumption, power optimization algorithm artificial bee colony is used in the transmission phase of relaying and comparison is carried out with the different power allocation factors r=0.3, r=0.4, r=0.5. Comparative results simulation shows that at 12 db SNR, maximum BER is reduced by artificial bee colony algorithm, which optimizes the power and give improved system.

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