

## MULTI-POPULATION FIREFLY ALGORITHM (MFA) FOR RELAY ASSISTED EFFICIENT ROUTING IN COGNITIVE RADIO AD-HOC NETWORKS (CRAHN)

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### ABSTRACT

The existing routing techniques in Cognitive Radio ad-hoc networks (CRAHN) do not consider the delay, energy consumption, interference, traffic load parameters and success rate of data delivery. In order to solve these problems, in this paper, we propose to design a relay assisted cost effective routing protocol for CRAHNS. In this routing protocol, some of the secondary users are designated as relay nodes along the route towards the destination. Multi-population Firefly Algorithm (MFA) is used to establish the routing path based on the Interference to PUs, Number of Hops and Average current traffic load, Packet reception ratio and Average residual energy metrics. By simulation results, we show that the proposed technique improves the data delivery rate and reduces the energy consumption.

**Keywords:** Multi-population Firefly Algorithm (MFA), Cognitive Radio Ad-Hoc Networks (CRAHN), Efficient Routing.

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### INTRODUCTION

#### *Cognitive Radio Ad-Hoc Networks (CRAHN)*

A cognitive radio (CR) is a talented skill to address the band shortage difficulty and increase band use that permits secondary users (SUs) unscrupulously admits the empty spectrum bands assigned to primary users (PUs). Owing to the precise features of CR, it has wide use predictions. For instance, CR skill can be united with mobile ad hoc networks, which is known as cognitive radio ad hoc networks (CRAHNS), in which wireless expedients can vigorously create systems by means of the empty spectrum bands allotted to PUs deprived of the necessity of stable substructures. [1]. Cognitive radio (CR) has been suggested to allow uninhibited customers (or secondary users, SUs) to use the underutilized approved networks (or white spaces) possessed by the qualified customers (or primary users, PUs). Maximum out-dated routing systems approve a rule-based method in which every nodule retains and monitors a group of predefined guidelines in its deed choice for diverse system situations; and this may not outfit CR because of its inherent feature of the dynamicity and impulsiveness of the system circumstances (i.e., PUs' doings and network excellence) which need context consciousness and intellect [2]. Since PUs are the possessors of the network; and the CR strategies (also termed Secondary Users (SUs)) unscrupulously utilise the network when PUs have no data to transfer. That is why vacant band (known as spectrum hole) must be utilised competently to make CRN fruitful. In addition that, if broadcasts of CUs do not cause risky interventions with PU broadcasts, then CUs can interconnect amid themselves. CU and SU fundamentally mean the similar. [3].

As established in, routing encounters in CRAHNS are categorized into three chief sorts: channel-based, host-based and network-based routing [4].

Routing in CRAHN is a very significant job having a countless result on the complete presentation of the system. Routing in CRAHN varies from routing in out-dated ad hoc systems as it has to familiarize to active variations of band because of stochastic performance of PU and SU. Furthermore, routing procedures in CRAHN must contract with heterogeneity of sources (accessible networks and accessible dynamism) [5].

#### *Efficient Routing in CRAHN*

The shortest track does not constantly mean the ideal track for systems like CRAHNS. A path with the least dynamic price does not mean the maximum effectual one; e.g., the energy fatigued dispatch nodules can cause the disappointment of routing. Numerous supplementary presentation metrics such as endwise suspension, outstanding dynamism, output, package distribution proportion, intrusion, steadiness and dependability ought to be deliberated too. In energy-constrained CRAHNS, it is obligatory to take dynamism effectual routing into strategy deliberation. Likewise, the routing procedures must consider the influence of primary user action, path ruptures because of nodule movement and network tenure, problems of dispersed multi-hop system construction, and multi-channel transportations [7].

#### *Multi-population Firefly Algorithm (MFA)*

Multi-population Firefly Algorithm (MFA) and it is regarded as the one among the meta-heuristic method built to resolve optimization problems utilizing the simulation of behavior of the fireflies. The algorithm derives its inspiration from the flashing lights of fire-flies in nature. It consists of three kinds of fireflies: searching firefly, listening firefly, and updating firefly. Attractiveness depends on the brightness and distance between the firefly. Attractiveness is directly proportional to the brightness of the firefly and indirectly proportional to the distance between them. So one firefly moves forward to the next firefly depending on the attraction between them. There is a specific entry of objective function in sorted list [11][12].

#### *Problem Identification*

Generally the routing metrics in CRAHNS should be based on: Distance, Delay, Energy, Bandwidth, Channel quality, Interference and success rate of data delivery, traffic load [6].

In [2], Q-learning has been applied in CRQ-routing in which the best-possible route is selected based on the link cost metric. The link cost metric is derived from the link layer delay. In WCRQ, packet retransmissions and the packet queue length of SUs along a route are considered for deriving the link cost metric. But it did not consider the energy consumption and success rate of data delivery.

In Interference-aware routing game [4], relay efficient value (RCV) metric is used to reduce the end-to-end delay and decrease the interference from SUs. The RCV is resultant regarding space amid the impart and terminus, the efficacy function of the game theory exemplary is resultant regarding RCV, entire movement load on nodule and intrusion. But it did not deliberate the suspension, dynamic ingestion and triumph level of data transfer.

In LBOR [9], the metric of effective forwarding rate (EFR) is introduced, which indicates the success rate of data transmission of each candidate link in the opportunistic module. But it did not consider the delay, energy consumption, interference, traffic load parameters.

In order to solve these problems, we propose to design a relay assisted cost effective routing protocol for CRAHNS.

**RELATED WORKS**

Mahdi Zareei et al [5] have suggested a new on-demand cluster-based fusion routing procedure for cognitive radio ad hoc network with uneven nodule circulation. Initially, a new spectrum-aware grouping device is familiarized. The planned grouping device splits nodule into groups based on three principles: band obtainability, power level of nodule and nodule steadiness. Hence, groups are made with the maximum steadiness to evade recurrent reclustering. Then, a routing procedure is familiarised to curtail the suspension while accomplishing tolerable distribution proportion. In that article, routing is well-defined as a multi-objective optimization difficulty to pool dissimilar distinct routing metrics to form a universal metric.

Christian H.W. Oey et al [8] have suggested a novel energy- and cognitive-radio-aware routing (ECR) procedure that addresses the exclusive encounters in CRSNs, comprising active band admittance, solitary transceiver, and energy restraint. In specific, their suggested routing procedure does united nodule-channel task by considering energy, is conscious of cognitive radio at the system layer, and can grab band chance in other spectrum bands. They offered a modest investigative exemplary of the suggested ECR in the perspective of network-wide dynamism and associate it with that of the ad hoc on-demand distance vector (AODV) routing procedure.

Wenxuan Duan et al [9] have suggested a load balancing opportunistic routing (LBOR) system to exploit the entire output of

the entire system. They initially expressed the issue of exploiting the entire output of the system as a rectilinear encoding issue. Then, they established experiential load balancing applicant forwarder arranging and choice procedures.

Kaushik R. Chowdhury et al [10] have suggested a dispersed CR routing procedure for ad hoc networks (CRP) that types the subsequent offerings: (i) obvious guard for PU recipients that are normally not sensed for the duration of band identifying, (ii) permitting manifold periods of paths centred on provision variation in CR networks, and (iii) ascendable, combined route-spectrum choice. A vital innovation of CRP is the plotting of band choice metrics, and indigenous PU intrusion explanations to a package advancing suspension towards the control network. This permits the path creation assumed over a control channel to seize the ecological and band evidence for all the transitional nodules, thus decreasing the computational overhead at the terminus.

**PROPOSED SOLUTION**

**Overview**

In this paper, we propose to design a relay assisted cost effective routing protocol for CRAHNS. In the proposed routing protocol, some of the SUs are designated as relay nodes along the route towards the destination. Multi-population Firefly Algorithm (MFA) is regarded as the one among the meta-heuristic method built to resolve optimization problems utilizing the simulation of behavior of the fireflies. The algorithm derives its inspiration from the flashing lights of fire-flies in nature. It consists of three kinds of fireflies: searching firefly, listening firefly, and updating firefly. An objective function is derived in terms of reward and punish metrics. The punish metric consists of Interference to PUs, Number of Hops and Average current traffic load. The rewards metric consists of Packet reception ratio and Average residual energy. So for better route establishment, the objective function value is to be maximized.

**System Model**

We consider a multi-hop CRAHN consisting of M location-aware SU nodes and n PUs, which are randomly distributed.

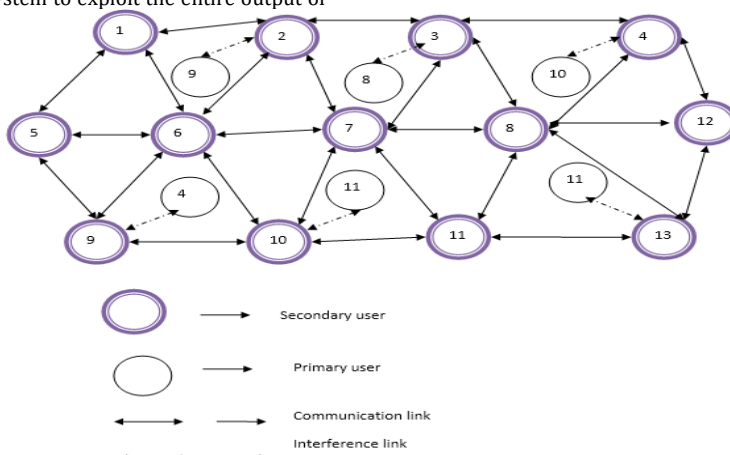


Figure 1: Multi-hop CRAHN

Each PU transmits in one of the n different channels.

**Estimation of Metrics**

**Interference to the Primary Users**

The total interference (Q) to the primary users for a path P among the nodes  $N_i$  and  $N_j$  is defined using the following equation:

$$Q = \sum_{i=1}^n P_{tx}(i)\alpha_i \tag{1}$$

where  $P_{tx}$  = transmission power of node

$\alpha_i$  = propagation loss from SU to the PU

$$\alpha_i = z_{i,PU}$$

where  $z_i$  = Euclidean distance between  $N_i$  and PU

#### Average Current Traffic Load

The amount of traffic at  $N_i$  should satisfy the following condition:  
Let  $y_i$  be the amount of generated traffic by  $N_i$  in a unit of time

$$y_i + \sum_{j \in N} \delta_{ji} \times y_{j,i} - \sum_{j \in N} \delta_{ij} \times t_{i,j} = 0 \quad (2)$$

$$y_{i,j} \leq W_{ij} \quad (3)$$

where  $\delta_{ji}$  reveals the existence of a potential directed link from  $N_i$  to  $N_j$

$W_{ij}$  represents the capacity of link (i,j)

Eq (2) reveals that outgoing flow should be equal to the sum of incoming flow and generated traffic.

Eq (3) shows that flow on each link cannot be greater than its capacity.

#### Packet Reception Ratio (PRR)

Packet reception rate is the time average of the ratio of number of received packets to those transmitted. It is a metric of link quality. Link Quality is measured in terms of expected transmission time (ETT).

The expected transmission time (ETT) for a single link is defined as the expected time to successfully transmit a data packet at the MAC layer. ETT route metric can be obtained by summing all ETT values of the individual links in the route.

$$ETT = ETX * (z/BW) \quad (4)$$

Where  $z$  = average size of a packet

$BW$  = current link bandwidth

$ETX$  = Expected transmission count metric

The expected transmission count metric (ETX) is the measure of link and path quality.  $ETX$  metric for a single link is defined using Eq 5

$$ETX = \frac{1}{(Pr_{tx} * Pr_{rx})} \quad (5)$$

Where  $Pr_{tx}$  = successful packet delivery probability in forward direction.

$Pr_{rx}$  = successful acknowledgement packet reception probability.

#### Average residual energy

Let  $E_i$  be the initial energy of a node

After the time period  $t$ , the energy consumed by the node ( $E(t)$ ) is given using following equation [6]

$$E(t) = n_{tx} * \mathcal{E} + n_{rx} * \delta \quad (6)$$

where  $n_{tx}$  and  $n_{rx}$  are the number of data packets transmitted and received by the node after time  $t$ .

$\mathcal{E}$  and  $\delta$  are constants in the range (0,1)

The residual energy (RE) of a node at time  $t$  is computed using the following equation

$$RE = E_i - E(t) \quad (7)$$

The residual energy ratio of a route is obtained by summing up all nodes' residual energy and dividing it by the number of intermediate nodes along the route.

$$RE_{avg} = \sum RE / N_i \quad (8)$$

#### Objective Function

An objective function (OF) is derived in terms of reward and punish metrics. The punish metric (PM) consists of Interference to PUs, Number of Hops and Average current traffic load (Estimated in section 3.3.1 and 3.3.2). The rewards metric (RM) consists of Packet reception ratio and Average residual energy. (Estimated in section 3.3.3 and 3.3.4)

$$OF = \{ \max \sum_{i=0}^N RM_i, \min \sum_{i=0}^N PM_i \}$$

Let  $S$ ,  $L$  and  $U$  be the searching, listening and updating firefly respectively.

The steps involved in Multi-population Firefly Algorithm (MFA) are as follows:

Let  $R$  be the routing path

Let  $S$  and  $D$  be the source and destination nodes respectively

Let  $RN$  be the relay node

1. Initially  $R$  is set to be empty and  $RN$  retrieves the information (estimated in section 3.3).
2.  $RN_i$  will create  $U$  with the following initial fluorescence intensity.

$$V(U) = \frac{V_S}{\|D_U - D_S\|^\beta}$$

where  $V_S$  = fluorescence intensity of  $S$  at the sink node

$0 < \beta < 1$  = fluorescence update rate

$D$  = represents the Euclidean distance

$U$  then travels along  $R$  and updates  $L$ 's fluorescence intensity for each nodes it visited as per following equation:

$$\Delta V_i = \frac{V(U) \cdot \|D_U - D_i\|}{\sum_{n \in R} \|D_U - D_j\|}$$

where,  $n$  is the random node in  $R$

3. Otherwise  $R$  will be added in the mobile data store of the current routing node.
4. If  $RN_i$  is not the sink node, then it will retrieve the data packet and create  $S$  in order to find the routing path.
5.  $RN_i$  is added to  $R$
6.  $RN_i$  will move to neighbour  $N_j$  as per the following probability

$$P_{ij} = \frac{V_j - V_i}{\sum_{k \in N_i} (V_k - V_i)}$$

where  $N_i$  is the neighbour set of  $RN_i$

7. The displacement value of the firefly that is attracted to more attractive firefly is determined using the following equation:

$$\Delta D_i = \alpha_0 e^{-\alpha d^2} (D_j - D_i) + \lambda \cdot f$$

$d$  = distance between two fireflies

$\alpha_0$  = attractiveness

$F$  = random variable from a Gaussian Distribution.

$\lambda$  = step factor in the range (0, 1)

8. Simultaneously, fluorescence intensity of  $L$  at  $N_j$  should be updated as per the following equation

$$\Delta V_i = (D_j - D_i)^w \cdot e^{-\alpha d^2}$$

Here,  $w$  represents the fluorescence depletion rate.

9. The objective function is estimated (as per section 3.3.5).
10. If the data correlation of packet is within the pre-defined threshold, then the two packets will be merged into a new packet.
11.  $S$ ,  $L$ , and  $U$  will access the information not only from their own group but also from other fireflies groups to conduct their own optimization in the evolution.

12. For better route establishment, the objective function value should be maximized.

**EXPERIMENTAL RESULTS**

**Experimental Settings**

The simulation of the proposed Multi-population Firefly Algorithm (MFA) for Relay Assisted Efficient Routing (MFARAER) protocol is conducted in NS2 and it is compared with Reinforcement Learning Routing (RLR) [2] and Interference Aware Routing Game (IARG) [4]. The performance is evaluated with respect to End-to-End Delay (E2D), Packet Delivery Ratio (PDR), throughput and average residual energy. The experimental settings are listed in Table 1.

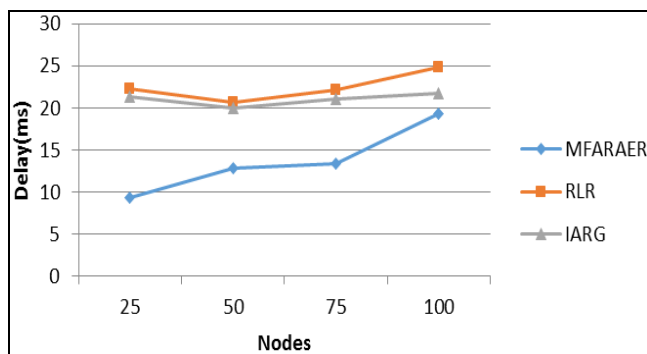
**Table 1: Experimental Settings**

<b>Number of Nodes</b>	<b>25,50,75 and 100</b>
<b>Topology Size</b>	<b>500 X 500</b>
<b>MAC</b>	<b>802.11</b>
<b>Simulation Time</b>	<b>50 sec</b>
<b>Traffic Source</b>	<b>CBR</b>
<b>Rate</b>	<b>0.25,0.5,0.75 and 1.0 Mb</b>
<b>Propagation Model</b>	<b>Two Ray Ground</b>
<b>Antenna Type</b>	<b>Omni Antenna</b>
<b>Initial Energy</b>	<b>10.1J</b>
<b>Transmission Power</b>	<b>0.3</b>
<b>Receiving Power</b>	<b>0.3</b>

**Results & Analysis**

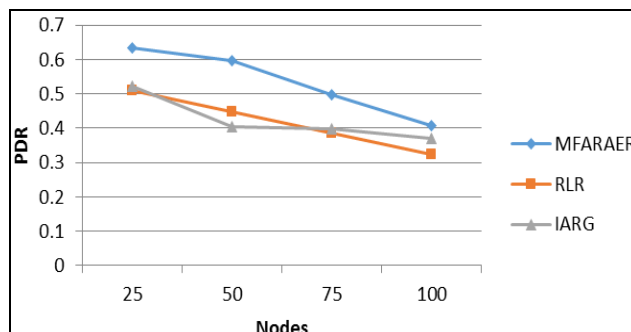
**Varying the Nodes**

In this section, the results for varying the number of nodes from 25 to 100 are presented in this section.



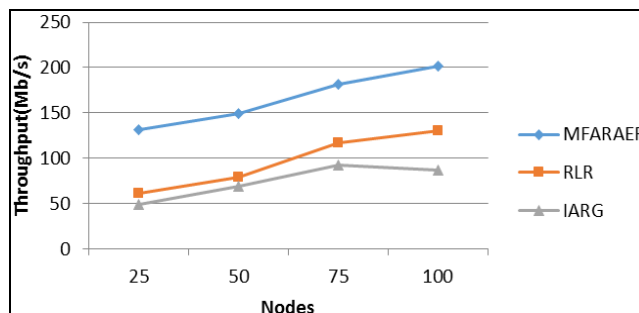
**Figure 2: E2D for Varying the Nodes**

The graph showing the results of E2D for varying the nodes is shown in Figure 2. The figure depicts that the E2D of MFARAER ranges from 9.3 to 19.3 seconds, the E2D of IARG ranges from 21.3 to 21.7 seconds and the E2D of RLR ranges from 22.2 to 24.8 seconds. Ultimately, the E2D of MFARAER is 36% less when compared to RLR and 31% less than IARG.



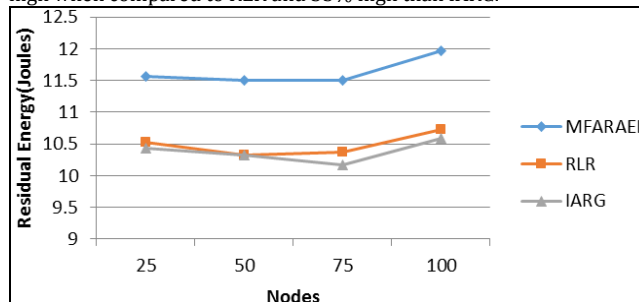
**Figure 3: PDR for varying the nodes**

The graph showing the results of PDR for varying the nodes is shown in Figure 3. The figure depicts that the PDR of MFARAER ranges from 0.63 to 0.40, the PDR of IARG ranges from 0.52 to 0.37 and PDR of RLR ranges from 0.51 to 0.32. Ultimately, the PDR of MFARAER is 21% high when compared to RLR and 19% high than IARG.



**Figure 4: Throughput for varying the nodes**

The graph showing the results of throughput for varying the nodes is shown in Figure 4. The figure depicts that the throughput of MFARAER ranges from 131.0 to 201.9 Mb/s, the throughput of IARG ranges from 49.3 to 86.4 and throughput of RLR ranges from 61.1 to 130.7 Mb/s. Ultimately, the throughput of MFARAER is 42% high when compared to RLR and 55% high than IARG.



**Figure 5: Residual Energy for varying the nodes**

The graph showing the results of residual energy for varying the nodes is shown in Figure 5. The figure depicts that the residual energy of MFARAER ranges from 11.5 to 11.9 joules, the residual energy of IARG ranges from 10.4 to 10.5 joules and residual energy of RLR ranges from 10.5 to 10.7 joules. Ultimately, the throughput of MFARAER is 10% high when compared to RLR and 11% high than IARG.

**B. Based on Data Rate**

In this section, the results for varying the data rate from 0.25 to 1Mb are presented in this section.

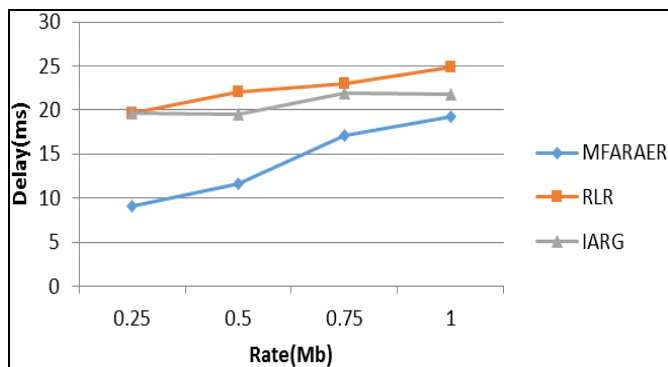


Figure 6: E2D for Varying Rate

The graph showing the results of E2D for varying the rate is shown in Figure 6. The figure depicts that the E2D of MFARAER ranges from 9.1 to 19.3 ms and E2D of RLR ranges from 19.6 to 24.8 ms and the E2D of IARG ranges from 19.6 to 21.7 ms. Ultimately, the E2D of MFARAER is 37% less when compared to RLR and 31% less than IARG.

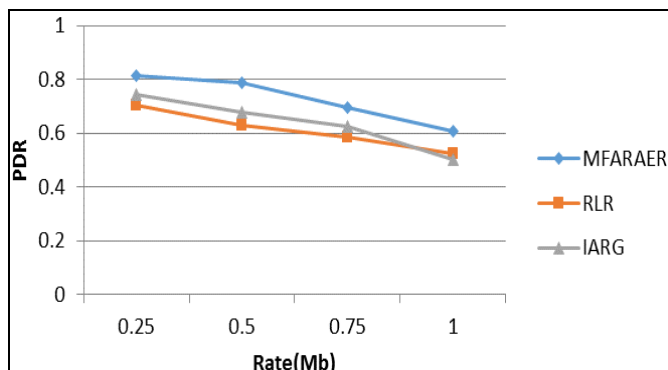


Figure 7: PDR for Varying the Rate

The graph showing the results of PDR for varying the rate is shown in Figure 7. The figure depicts that the PDR of MFARAER ranges from 0.81 to 0.60 and PDR of RLR ranges from 0.70 to 0.52 and the PDR of IARG ranges from 0.74 to 0.50. Ultimately, the PDR of MFARAER is 15% high when compared to RLR and 12% high than IARG.

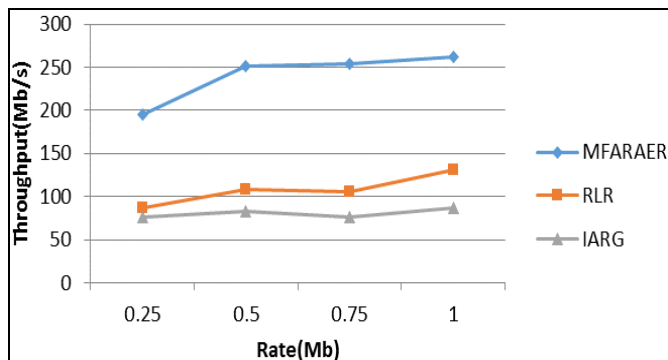


Figure 8: Throughput for Varying the Rate

The graph showing the results of throughput for varying the rate is shown in Figure 8. The figure depicts that the throughput of MFARAER ranges from 195.7 to 261.9 and throughput of RLR ranges from 86.3 to 130.7 and the throughput of IARG ranges from

75.4 to 86.4. Ultimately, the throughput of MFARAER is 55% high when compared to RLR and 66% high than IARG.

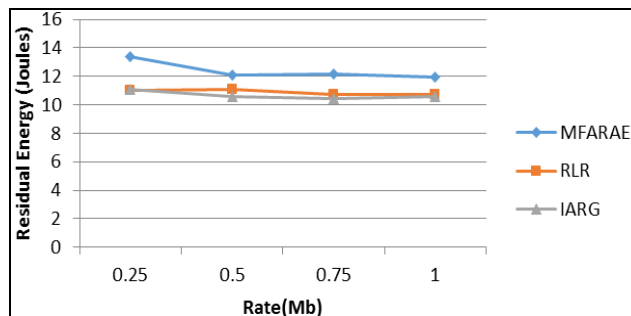


Figure 9: Residual Energy for Varying the Rate

The graph showing the results of residual energy for varying the rate is shown in Figure 6. The figure depicts that the residual energy of MFARAER ranges from 13.3 to 11.9 and residual energy of RLR ranges from 11.0 to 10.7 and the residual energy of IARG ranges from 11.0 to 10.5 joules. Ultimately, the throughput of MFARAER is 12% high when compared to RLR and 14% high than IARG.

CONCLUSION

In this paper, we have proposed to design a relay assisted cost effective routing protocol for CRAHNS. In this routing protocol, some of the secondary users are designated as relay nodes along the route towards the destination. Multi-population Firefly Algorithm (MFA) is used to establish the routing path based on the Interference to PUs, Number of Hops and Average current traffic load, Packet reception ratio and Average residual energy metrics. By simulation results, we have shown that MFARAER improves the PDR and throughput by reducing the E2D and energy consumption.

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