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Intelligent Fish Swarm Inspired Protocol (IFSIP) For Dynamic Ideal Routing in Cognitive Radio Ad-Hoc Networks

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Abstract: Poor routing in ad hoc networks affects entire performance that leads to latency and a massive amount of energy consumption. An essential task in Cognitive Radio Ad Hoc Networks (CRAHN) is to discover a better route to the destination from the source where the transmitted data crosses every node in the routing path. In this paper, a novel reactive multicast routing protocol namely Intelligent Fish Swarm Inspired Protocol (IFSIP) proposed to minimize the global latency and energy consumption by finding the best route dynamically. It is difficult to provide a better solution to the issues that arise in route optimization. Routing defines the methodology of selecting the best route. IFSIP aims to find and utilize dynamic ideal routes. By considering service rate and spectrum accessibility, it gradually minimizes congestion on different routes. IFSIP sends data only after checking the quality of route. Optimization of IFSIP helps node to choose the best route. M/G/1 queueing model used to reduce the congestion and provide the service in short. Results indicate IFSIP significantly performs well than other baseline schemes towards finding the best route, minimizing delay and energy consumption. Evaluation of IFSIP conducted with node count and link failure parameters and it is evident that IFSIP has reduced the delay and energy consumption by increasing the throughput and packet delivery ratio.

Keywords: Ad-hoc, CRAHN, Routing, Delay, Energy

1- INTRODUCTION

Networks enabled with Cognitive Radio Technology (CRT) has wireless nodes and have the capability of providing distinctive performance towards (i) spectrum sensing, (ii) setting up radios again, (iii) developing opportunities to utilize spectrum. Primary Users (PU) and Secondary Users (SU) are the two kind of users in CRTN Enabled Networks (CRTN). PU are premium users having licenses, and SU are customary users who do not have the license to access networks, i.e., free users. Generally, PU has a built-in preference to function well in assured bandwidth of licensed frequency. If SU needs to send data, it is mandatory to utilize a licensed spectrum opportunistically, i.e., unused licensed spectrum. Hence, the primary role of SU is to confirm the opportunistic usage of the unused licensed spectrum without disturbing PU.

CRAHN is a specific category of CRTN, which does not have a centralized server for maintaining the nodes. To make CRAHN meet Quality of Service (QoS), SU need to have enhanced cooperation with other users for sending and receiving data. In CRAHN, details of PU count, the configuration of nodes, and available unused spectrum need to synchronize frequently to meet QoS. These details are used to reconfigure nodes, network, and to check the alternate route during failure. Intrinsic features like dynamic topology, heterogeneous spectrum, hop architecture, and control of energy consumption differentiate CRAHN from other networks. These challenging features make researchers to propose new ideas. Therefore, a significant level of effort is necessary for the research in CRAHN to use it more efficiently.

In CRAHN based research, researchers are not giving more importance to routings, and they focus only on sensing the spectrum and its utilization. Generally, routing protocols developed for other networks are not applicable for CRAHN; if used, network performance degradation might occur. Multiple complications may occur during the routing process in heterogeneous cum dynamic topology networks due to the unpredictable mobility of nodes. The availability of channel to node may vary from time to time temporarily and it differs from node to node. Unexpected

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entrance of PU will make the SU to leave the current

channel and will be diverted to another channel. Heterogeneous characteristics in the spectrum and route can also worsen efficient routing. In CRAHN, no guarantee exists for a stable route between nodes. Route disconnects and failures are relatively high in CRAHN when comparing with other ad-hoc networks. Succeeding a new route between nodes seems too costly because of the consumption of precious network resources. Further, during the new route discovery process, multiple control messages are broadcasted in the network and it leads to increased energy consumption.

A. Problem Statement

Mobility provides the benefit of flexibility to nodes in CRAHN; simultaneously, it gives the drawback of unexpected disconnection in node communication that leads to degradation in Quality of Service. The issue of route disconnection occurs when a node moves out of the radio range, which leads to packet drop, delay, and energy consumption, that are intolerable in CRAHN. Traditional routing protocols available for general ad-hoc networks will never give its better performance in CRAHN due to scalability. Hence, it is necessary to address and overcome the issue of mobility while searching for the best alternate route in a limited time.

B. Objective

The main objectives of this research work are: (i) to provide an overview about CRAHN, (ii) to propose a novel reactive multicast routing protocol inspired from swarming nature of fish, (iii) to maximize the lifetime of network by reducing delay and energy consumption, (iv) to conduct NS2 simulation with varying number of nodes and link failures.

C. Motivation and Contributions

This paper focuses on improving routing in CRAHN by finding a better route to the destination. Generally, CRAHN prioritizes PU to utilize the available resources where it does not care about SU or unused spectrum. The natural characteristics of CRAHN is to maximize the challenges in routing. In CRAHN, selecting a reliable route is difficult because of multiple factors like:

- Determining the availability of route only by PU current behaviour
- Switching to the next available route during congestion
- Mobility of nodes will leads to degrading of Quality of Service
- Selection of fault routes may lead to congestion
- Selection of lengthier route leads to increased delay and energy consumption

D. Proposed Solution

This paper proposes an Intelligent Fish Swarm Inspired Protocol (IFSIP) for routing in CRAHN by considering the difficulties discussed in Section 1.3. IFSIP is inspired by the swarming nature of fish towards searching for food. IFSIP falls under reactive multicast protocol family and it aims to maximize the lifetime of the network by reducing delay and energy consumption. IFSIP utilizes M/G/1 queuing model to avoid congestion in CRAHN. The main objectives of IFSIP are summarized as follows:

- To improve QoS demand by enhancing better route selection
- To decrease fault route selection and delay
- To avoid conflicts in the route selection process among nodes
- To perform a comparison between IFSIP with related protocols

E. Research Context

This research work evaluates IFSIP performance against IFLIP [19] and GRP [2], in terms of enhancing network lifetime by reducing delay and energy consumption. Different performance metrics were considered for evaluation, namely, throughput, packet delivery ratio, packet drop, delay, and energy consumption. The efficient performance metrics were chosen based on their significant effect on CRAHN.

2. BACKGROUND STUDY

The current section of this paper describes the state-of-the-art of CRAHN and its routing protocol.

Intelligence enabled Distributed Channel Selection Method [1] is proposed to help the nodes to select the best channel for routing. It classifies the channel based on available PU and channel capacity. Fuzzy logic is applied to estimate the weight of channel capacity. The channels having maximum weight values are chosen to transmit the data, and it helped to avoid selecting the occupied channels. Spectrum Aware Outage Minimizing Protocol [2] proposed to decrease the latency while choosing the path. The communications regarding the selected route made to happen on a session basis. It aimed to provide full priority to primary users in detecting and utilizing the route. Interference Awareness based Routing Protocol [3] is proposed with the aim to utilize free available channels to avoid route-overhead. It works in the manner of opportunistic routing to enhance the performance of the channel by minimizing the collisions and control messages. Network Coding Framework [4] is proposed to address the issues in multicast technology. It specifies the issue in applications that uses packet multicasting in a heterogeneous environment. Retransmissions of packet reduced with broadcasting to enhance the ratio of packet delivery. Further, decoding information is minimized to shorten the packet size. Interference Aware Flooding Schemes [5] was proposed to provide a guarantee for optimizing the network performance in CRAHN. It exploits the global timeout method to manage uncontrolled buffer by inducing the packet replications, but it was not able to face the natural characteristics of CRAHN and faced more delay.

Beam-Forming Method [6] proposed to enhance the efficiency of routing in CRAHN. It finds all available loop-free routes between two SU randomly and calculates hops in the shortest path with nodes location. Probability of connection and hop count made to distribute to neighbour nodes to examine the network topology. Clustering-based Routing Protocol [7] proposed to find the best cluster for effective routing in CRAHN. It focuses on computing the expected time for transmitting the data at each cluster, and then it starts sending the data. Signal-to-Interference and Noise-Ratio considered for selecting a better alternate route. Cross-Layer Design [8] proposed to enhance the security of routing in CRAHN, and it optimizes the routing process based on particle bee. Initially, an analysis is made to check the PU radio features. Extended features utilized to handle the security of routing. Moreover, an Energy-efficient multi-route protocol proposed to analyze the neighbour nodes and their security attacks in CRAHN. QoS Provisioning Approach [9] surveyed the utilization of unused spectrum. The survey conducted to understand the importance of avoiding SU in interfering with the PU, and it found that the implementation of cognitive radio faces different challenges because of occasional use. Further, it attempted to provide suggestions to SU to use the unused spectrum effectively. Distributed Trust Evaluation Protocol [10] proposed to minimize security issues that arise in routing. In CRAHN, sometimes-malicious SU provides false information in sensing the spectrum. To avoid falsification, this method attempt to avoid conflict between SU that will result in enhancing the cooperation between users.

Multi-Channel Cognitive MAC Protocol [11] proposed to address the rendezvous problem that arises in CRAHN while sending the data in the selected route. It works with the idea of an opportunistic reservation mechanism. It aimed to minimize hop frequency to avoid disturbing PU and found that the opportunistic reservation mechanism enhances network performance. Half Slotted Protocol [12] proposed to study the probability of successful transmission where SU made to assist PU in sending data. Cooperative communication used to increase reliability among the primary transmitters. Closed-form expression derived to estimate the probability of transmission success rate. It found optimizing the intensity of SU could enhance the success rate of transmission. Tree-based Routing Protocol [13] proposed to increase the cooperation that exists between the network layer and lower layers of CRAHN. Routing in ad-hoc networks gets affect because of dynamicity and repeated link failures. Spectrum management module enhances the routing decision of tree-based routing protocol and it safeguards the PU from other node interference. Secondary User Blocking Method [14] proposed to overcome issues of spectrum utilization in resource-constrained networks like CRAHN. It is modeled by Markov chain's discrete-time series. It focuses on controlling congestion by reducing the packet delay and loss at PU end than SU. Further, it differentiates the effect of packet loss from congestion loss. Unified Trust Management Scheme [15] proposed to enhance the security level at sensing and transmission processes. It attempts to trace the false sensing data and reduce the packets that get drop during the transmission. It utilizes uncertain reasoning theory to build the trust model in sensing the spectrum.Geographic Routing Protocol [16] was proposed to support the primary users in CRAHN by following the greedy approach. The packets sent by secondary users are delayed to make the primary users data to reach the destination, which leads to an unsecured network and more energy consumption.

Frog Leap based Bio-inspired Protocol [17] proposed to decrease the delay that rises dynamically in CRAHN. It adapts the leaping nature of the frog to find the best route in the network to send the data, but due to poor communication between nodes, the energy consumption, delay, and packet drop were increased. Joint Routing and Channel Assignment Method [18] proposed to overcome underutilizing the licensed spectrum problem. This method utilizes the Markov modulated Poisson process to favor the PU during the congestion period and SU are given a chance to use the licensed spectrum until PU selects a channel. Geographic Segmented Opportunistic Routing Scheme [19] proposed to embrace the CRAHN characteristics for better routing fully. In this scheme, the best available path to the destination are broken into different segments and routing were performed between segments. It makes use of topology information and opportunities available at the local spectrum to face the challenge of a dynamic spectrum environment. Cuckoo Search Inspired Protocol [20] and Wolf Prey Inspired Protocol [21] was proposed from the natural characteristics of uckoo bird and wolf to minimize the routing overhead in CRAHN, but utilization of more energy leads to reduced network lifetime. Eventhough brst routes are found, it lacks in energy and security.

Enhanced Sensing Methodologies [22–24] were proposed to increase spectrum sensing to find a better route in CRAHN and reduce the amount of energy from getting wasted. Energy utilization is considered as a significant metric for spectrum networks. Signal to Noise

Ratio (SNR) was considered for improving performance improvement, where it is the calculation between noise power and signal power. Threshold values are set for SNR and detectors are used for analyzing the energy levels. The detection period of sensing is reduced while considering the cooperative spectrum sensing. Spectrum Sensing helps SU to (i) find alternate port/network during the unavailability, (ii) routing protocol to find a loop-free route. Eventhough the routing protocols aimed to find the best path to destination it lacks in reliability and consumed more energy. Control overhead being the main reason to face the network congestion and increased the delay in delivering the packet to destination

3-Research method

A. Intelligent Fish Swarm Inspired Protocol for Dynamic Ideal Routing

Intelligent Fish Swarm Inspired Protocol (IFSIP) is a novel optimization protocol based on population and natural nourishing behaviour of fishes. IFSIP working mechanism follows swarm intelligence. It is utilized to find the solutions numerically in an optimized manner. IFSIP aims to provide efficient solutions to CRAHN by finding the better route. Typically, the habit of fishes is staying close to each other to defend from predators while searching for food and staying away from difficulties.

B. Principle

Fishes are expected to represent the position in W^j location, where $W^j = \{w^1, w^2, \ldots, w^C\}$ and expected time to reach food is denoted as ET^j. The distance between two fishes are calculated using Euclidean distance i.e., $c^{ji} = W^j + W^i$ .The various parameters, like the representation of visual space, maximum pace length, the strength of swarm d and total count of fish in the populace are involved in IFSIP. Every fish in swarm attempts its best for recognizing the location to satisfy the need for food. In this process, there exist several unique behaviors, which are: (i) seeking behavior (ii) swarming behavior (iii) progressing behavior.

C. Seeking Behaviour

Seeking is an essential behavior of fish and it is natural towards its searching for food, which depends on a random searching manner. Eq.(1) and Eq.(2) mathematically show the seeking behavior of fish.

$$W = W^j - Q[T] \sum_{i,j=1}^{n-1} \frac{W^i + W^j}{||W^i + W^j||}, \qquad ET^i < ET^j \tag{1}$$

$$W^{j-1} = W - Q[T] \tag{2}$$

where W^j denotes current location of a fish, $Q[T]$ indicates the distance between the current location and pace range, which is a random variable. ET is the expected time. W^i represents the new location of fish.

A fish in a location W^j is randomly selected based on its visual capability. If $ET^i < ET^j$ is satisfied means, Eq.(1) is applied to find the next location W^{j-1}, else after continuing a specific number of iteration, a random location will be selected within its pace range by using Eq.(2).

D. Swarming Behaviour

Fishes tend to gather in swarming to reduce their level of the critical situation. The primary aim of swarming incorporates (i) the need to consume adequate food, (ii) to engage swarm members, (iii) making new members join the swarm. Swarming behavior is mathematically expressed in Eq.(3).

$$W^{j-1} = W^j - Q[T] \sum_{i=1}^{n-1} \frac{W^d + W^j}{\|W^i + W^j\|}, \tag{3}$$

$$ET^d < ET^j \text{ and } m^t \times m > \gamma$$

where m indicates the difference between available routes and selected routes, W^d indicates the central position of the swarm and are utilized to describe features of all fishes. If fishes in the middle of swarm have a high level of focus on food from the present location W^j , then the scarcity of food arises, and the fishes move towards a new position W^{j-1} or W^{j+1}, in the direction of W^d. The count of fish within the visual capability is denoted by m^t. Swarming behavior is applied for the fishes which are dependent on W^d, else seeking action continues to identify the next location.

E. Progressing Behaviour

When a fish locates food, its neighbors also continue (i.e., follow) it. Eq.(4) mathematically expresses the progressing behavior of a fish.

$$W^{j-1} = W^j - Q[T] \sum_{i=1}^{n-1} \frac{W^{min} + W^j}{|W^{min} + W^j|}, \tag{4}$$

$$ET^{min} < ET^j \text{ and } m^t \times m > \gamma$$

With visual-capability, only a few fishes could locate better food quantity than its neighbors. One of the natural characters of fish is following a better neighbor (W^{min}) to maximize the level of satisfaction. m^t indicates the count of fishes with its visual capability W^{min}. If fishes could not progress further to find the next location, then seeking behavior, IFSIP checks the best performances of and present state during iterations. Performances of iterations are also tested based on the fitness function.

Removal of Unpleasant Route

IFSIP removes unpleasant (i.e., lengthy, expired, and faulty) routes which create congestion in the network. Considering the number of routes created between source and destination, few selected routes are viewed as essential routes to the destination. If M routes exist to send the data packet to the destination, then there will 2^M routes for the node to deliver data, which is not common to all the nodes. 2^M routes are viewed as unique routes in the network. The ideal location of a node plays a significant role in finding a minimum distance cum perfect route. Instantly, multiple fishes are put in the space (i.e., network), where every fish holds a unique position. At some point, fish start to search food from their location, then automatically all fishes swim towards a pre-eminent place. Fishes may change location after a certain period with the communication of neighbors via a notice (i.e., request message), then it seeks for local and global pre-eminent locations. In the end, the fishes gets united on great and ideal pre-eminent location. It indicates the analysis of intelligence in IFSIP for reducing the unpleasant routes and new routes are discovered with reduced error. Before applying IFSIP, few things are necessary to consider for identifying the congestion level and for setting a threshold value to monitor. The main intention of unpleasant route removal is to find the best route having minimum distance when a need arises for an alternate route. IFSIP takes more concentration towards choosing a loop-free path. IFSIP executes Algorithm 1 to remove the unpleasant route by checking whether the selected path is best cum loop-free. The pseudocode of unpleasant route removal is shown in Algorithm 1.

Algorithm 1: Unpleasant Route Removal

Assumption: Let S be source-node (i.e., the current location of fish), D be destination node (i.e. location of identified food), mD_{SD} be the set of the minimum-distance routes between S and D.

1. If $\left(S \in nodes\left(mD_{S-1,D}\right)\right)$ then
2. Alternative route mD_{SD}^{S-1} is loop-free
3. Else
4. Alternative route mD_{sd}^{s-1} is loop
5. End if

Location Prediction

IFSIP predicts the location of neighbor fishes in N ways, where N indicates an absolute number of routes and are represented in binary bits. Each bit of information were used to describe a path. Judiciously, bit 1 indicates selected-route and bit 0 indicates unselected-route. Neighbor's locations are considered as information related to route, and from this different number of routes are received towards destination.

Algorithm 2: Location Prediction

Assumption: Let S be source-node (i.e., the current location of fish), D be destination node (i.e., location of identified food), $\mathrm{mD}_{\mathrm{SD}}^{\mathrm{S-1}}$ and $\mathrm{mD}_{\mathrm{SD}}^{\mathrm{S-2}}$ be two routes available in alternative route sets.

1. Discover all common nodes between S and D
2. If there exist no common nodes then
3. Assume all routes are disjoint to each other
4. Else if
5. Assume common nodes exist between S and D then
6. Check alternate routes
7. Find two routes mD_{SD}^{S-1} and mD_{SD}^{S-2} having a minimum distance to the destination from the alternative route
8. End if

Based on neighbor location, alternative routes are identified. IFSIP executes Algorithm 2 to predict the neighbors for finding an alternative route that has minimum distance (mD). Pseudocode of Location Prediction is shown in Algorithm 2.

Fishes Distance and Midpoint

Let the binary bits W and Z indicate the location of two different fishes. Hamming distance of W and Z binary bits are estimated to have an equal number of 1′s when performing the XOR operation between the same. According to the hypothesis, the hamming distance of two routes having the same range towards the destination is entirely different. This research uses a hamming distance to calculate the distance that exists between two fishes. Eq.(5) mathematically describes the Hamming distance between W and Z.

$$g[W,Z] = \prod_{j=1}^{M} (w^j)\ XOR\ (z^i) \quad (5)$$

where w^{j} denotes the 0 or 1 in W.

Eq.(6) describes the midpoint of the swarm by assuming $\mathrm{W}^1, \mathrm{W}^2, \dots, \mathrm{W}^{\mathrm{m}}$ as few bits indicating the location of n fishes.

$$W^d = \left(d^1, \dots, d^M \quad if\ m = \prod_{i=1}^{m} w^{j^i} < 1\right) \quad (6)$$

where w^{j^i} denotes j^{th} bit of fish location W^i and W^d indicates the midpoint of the swarm.

Location Updation Method

In each iteration, fishes in swarm randomly begin its search for food. Every fish endeavors to change its current position based on three behaviors: (i) seeking (ii) swarming (iii) progressing. IFSIP utilizes a fitness function to estimate the quality of the route. Behavior with best (i.e., maximum) fitness value is chosen to update the next location.

Fitness Function

Eq.(7) mathematically describes the fitness function.

$$Fitness = \frac{\beta}{\delta Q^C} + \sum_{D}^{D-Q} \alpha \qquad (7)$$

The quality that exists to classify Q routes for choosing C paths is indicated by δQ^C. Q is the total number of 1's in the current location of the fish, and it represents the distance of the selected number of routes. D is the total number of available routes. β and α are the two factors relating to the significance of quality-of-classification and route distance, $\beta \approx (0,1)$ and $\alpha = 1 + \beta$ implies quality-of-classification and distance of the route, which make an impact in selecting the best routes. IFSIP gives more priority to the quality of route than route distance. IFSIP applies Fitness Evaluation Algorithm to assess the goodness of every route utilizing fitness function. The pseudocode of fitness function is shown in Algorithm 3.

Algorithm 3: Fitness Function

Assumption: Let S be source-node (i.e., the current location of fish), D be destination node (i.e. location of identified food), AR be the alternate route, bR_{SD} be the best-route to be chosen

1. Initialize bR_{SD} and mD_{SD}
2. Routes in AR_{SD} are sorted based on route length
3. Further routes for bR_{SD} is chosen from the AR_{SD} collection
4. While ($AR_{SD} = 0$) do
5. Discover mD from AR_{SD}
6. Analyze mD against all routes in AR_{SD}
7. Analyze whether mD satisfy the condition of Fitness Function (Eq.7)
8. If mD satisfies condition (Eq.7) for all routes in bR_{SD} then
9. Add mD to set bR_{SD}
10. Select route based on mD
11. End

Termination Condition

When a route achieves extreme level fitness value, then it is assumed to get expired soon with the reason for maximum utilization. It implies that the protocol has found the best path, but it is expired. Further, iteration starts when all the routes are expired. The termination condition is achieved with the highest number iteration or while reaching the same number of routes after the five successive iterations.

F. $M/G/1$ QUEUE MODEL

To avoid congestion in CRAHN, this research uses $M/G/1$ queueing model. It is the potential to accept the distribution of waiting time by utilizing $M/G/1$ queueing model.

Let N_k indicate a couple of nodes which are waiting next of K^{th} the node that is getting serviced from the server, and let A_k indicate a request of node sent randomly and it arrives station while K^{th} node gets serviced. Association between node and server for receiving service is determined by Eq. (8).

$$N_{k+1} = \begin{cases} \sum N_k - 1 + A_{k+1} & N_k > 0 \\ \sum A_{k+1} & N_k = 0 \end{cases} \qquad (8)$$

It is evident that $\{N_k, k = 0,1,2,\ldots\}$ structure the markov chain, and it is termed as $M/G/1$ markov chain.

Taking into consideration transition probabilities, Eq.(9) defines $M/G/1$ markov chain.

$$P_{ij} = P[N_{k+1} = 1 \mid N_k = i] \qquad (9)$$

where N_k value is lower than N_{k+1}, it has $P_{ij} = 0$ for $j < (i-1)$. Thus, for $j >= (i-1)$, P_{ij} have $(j - i + 1)$ nodes arriving with at least 1 request while doing service for $(k+1)^{th}$ node. While making consideration of $i > 0$, P_{ij} indicates probability j exactly for $(k+1)^{th}$ customer getting serviced.

Assume random variable Z indicate the nodes reaching the system in the middle of service. At that point, the P_{ij} is expressed as Eq.(10).

$$p_Z(n) = \int_{x=0}^{\infty} \frac{(\lambda x)^n}{n!} e^{-\lambda x} f_x(x)\,dx, \quad n > 0 \qquad (10)$$

While defining $\alpha_n = P[Z = n]$, state transition matrix of the Markov chain will be defined as Eq.(11)

$$P = \begin{bmatrix} \alpha_0 & \alpha_1 & \alpha_2 & \alpha_3 & \cdots & \cdots \\ \alpha_0 & \alpha_1 & \alpha_2 & \alpha_3 & \cdots & \cdots \\ 0 & \alpha_0 & \alpha_1 & \alpha_2 & \cdots & \cdots \\ 0 & 0 & \alpha_0 & \alpha_1 & \cdots & \cdots \\ 0 & 0 & 0 & \alpha_0 & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \end{bmatrix} \quad (11)$$

Eq.(12) provides the final transformation of Z.

$$G_Z = M_x(\lambda - \lambda Z) \quad (12)$$

The main reason for congestion in CRAHN is excessive queue length and it ends in increased waiting time to get service from the server. The main intention of using $M/G/1$ queuing model is to avoid the waiting time of nodes for getting service because nodes waiting in the queue will be used to estimate average or expected waiting time. In case of time consideration, nodes will move to the next server to process its request.

3. EXPERIMENTAL ANALYSIS

Experimental results are computed from simulations and the same model thoroughly analyze it as actual experiments.

A. Simulation Setup

This section discusses the NS2 simulation and used to analyze the proposed protocol IFSIP. NS2 is a well known best simulator for network-oriented researches, where it is a discrete and event-based simulator is focusing only on investigations that are related to networking. NS2 considerably supports the wired and wireless networks simulation towards routing, IP and multicasting protocols. It has the advantage of providing network traffic graphically. Also, it supports various queuing and routing algorithms. The performance of IFSIP is evaluated and compared with IFLIP [17] and GRP [19]. During the evaluation, the data packets are made to send through auxiliary channels. NS2 has poor performance when simulating with extensive scalable networks, but the reliability of NS2 simulation is enormously high for all protocols. The mobility model used for routing the packets is a random waypoint. The simulation setting used for this research work is tabulated in Table 1.

TABLE I. SIMULATION CONFIGURATION

Parameters	Settings
Simulation Space	$3000 \times 4000\ m^2$
PU Count	100
SU Count	20
MAC	802.16
Transmission Range	7000 to 10000 meters
Simulation Time	60 seconds
Traffic Source	CBR
Size of Packet	512 bytes
Total Number of Packets	4000
Mobility Model	Random Waypoint Model
Initial Level Energy	1 J

B. Parameters

The parameter is a measure used for analyzing the performance of a protocol under different conditions. This research has chosen the count of nodes as a parameter to check the performance of IFSIP against IFLIP and GRP. This parameter indicates the presence of different number of nodes. In this parameter, performances of the protocols are analyzed under different numbers of nodes to check the consistency of the protocols for providing better service to the user and network.

C. Performance Metrics

- Throughput: The success rate of data received by the receiver node in the simulation time.
- Packet Delivery Ratio: Quantity of data successfully received by the receiver node over the data sent by the sender node.
- Packet Drop: Quantity of data failed to reach the receiver node over the data transmitted by the sender node.
- Delay: Deviation of time that exists between the data packet sent by the sender node and received by the receiver node.
- Energy Consumption: It represents the probability of the total number of nodes over consumed energy on every hop.

In this simulation, network size is made to vary by increasing the nodes count with an interval of 10. The number of flows is kept as 10, and the transmission rate as 500 kb. In Figure 1,3,5,7 and 9, X-axis is plotted with varying numbers of nodes ranging from 10 to 100. Among the total number of nodes, it is set to have 20% of the nodes as PU. For instance: In 10 nodes, 2 nodes are PU. In Figure 2,4,6,8 and 10, X-axis is plotted with a varying number of link failures. That is, to check the reliability of the protocols, nodes are made to fail randomly with different rates. From Figure 1 to 10, Y-axis is plotted with corresponding metrics with the appropriate measures.

D. RESULTS AND DISCUSSIONS

Throughput Analysis

Figure 1 demonstrates the difference of throughput with node density for an exact transfer of data packet from the source node to the destination node. Different node densities are accomplished by varying the PU.

Performance with different rate of link failures is illustrated in Figure 2. From Figure 1 and Figure 2, it is clearly understood that utilizing energy-related metrics

significantly enhances the throughput. Further, performance improvement can be made by utilizing the beamforming concept. Results indicate that existing protocols (i.e., IFLIP and GRP) also provide throughput, but it is not up to IFSIP. Figure 1 demonstrates the enhancement of throughput when there is an increase in the count of nodes. IFSIP has a remarkable level of improvement in throughput due to the following swarming behaviour.

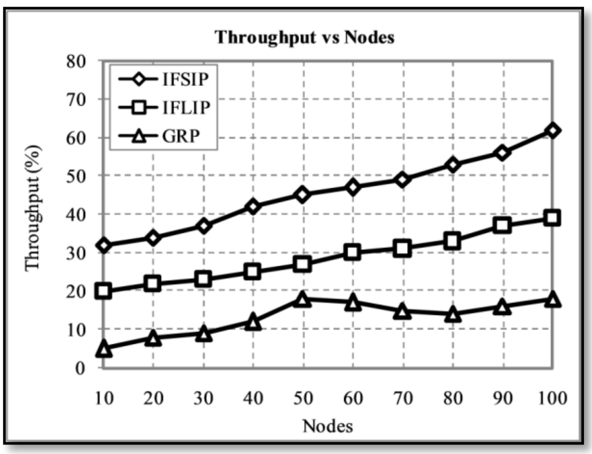
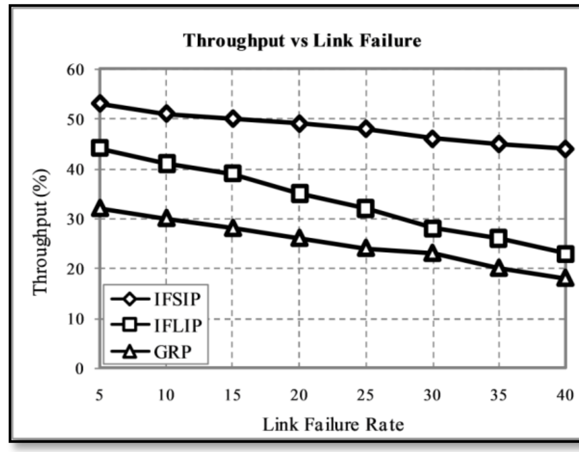


Figure 1. Analysis of Throughput against a varying number of nodes

Figure 2 illustrates the decrease in throughput of all considered protocols. Increasing the link failure rate results in throughput diminishment and decreased retransmissions. IFSIP is facing degradation in throughput but it is lesser when compared with IFLIP and GRP. It is because IFSIP performs calculation of the distance to the next node and midpoint, where IFLIP and GRP simply send data packet without checking length to the next node.



Analysis of Throughput against a varying number of link failures

Packet Delivery Analysis

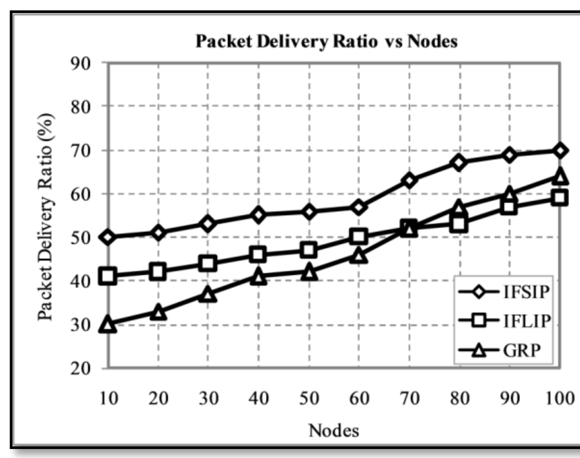


Figure 2. Analysis of Packet Delivery Ratio against a varying number of nodes

Figure 3 reveals the effect of increasing node-density on the packet delivery ratio. IFLIP and GRP exhibit a significant level of less packet delivery than IFSIP. GRP does not consider node density when choosing the next node for forwarding the data packet, which leads to non-conformity in delivering the packets further. In IFLIP, the node section is entirely dependent on the direction in which the data travels and it fails to select the locally best node to forward where it results in minimization of packet delivery ratio. IFSIP dynamically selects the node in directional and non-directional node density based on the minimum distance route to the destination node. Packet Delivery Ratio of IFSIP, IFLIP and GRP gradually increase as node density enhances and it is because of an increase in the connectivity between nodes.

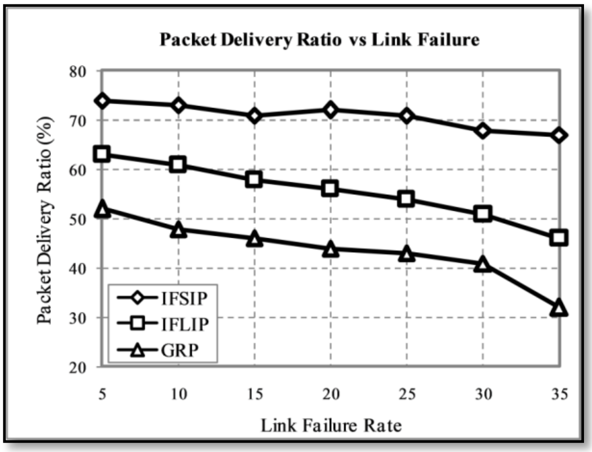


Figure 3. Analysis of Packet Delivery Ratio against a varying number of link failures

Figure 4 plots the packet delivery ratio against the link failure rate. It is also clear to understand that all protocols faces degradation in the packet delivery ratio if the link failure rate is increased. Link failure imposes congestion, which results in the drop of a certain number of packets. Optimization in IFSIP results in a reduced rate of packet sending which causes an increase in packet delivery ratio. In IFLIP and GRP, few nodes in the preselected route broadcasts more number of the packet and lead to the minimization of packet delivery ratio.

Packet Drop Analysis

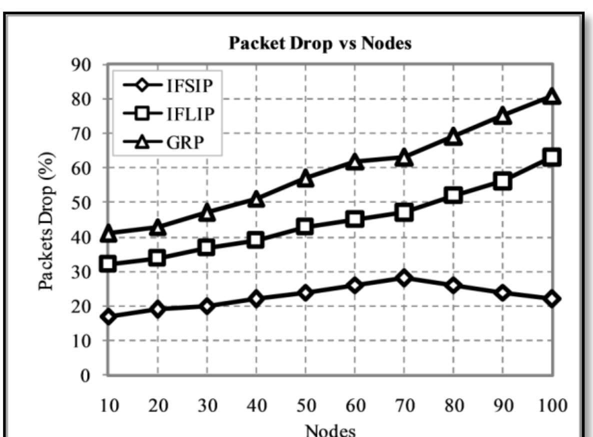


Figure 4. Analysis of Packet Drop against a varying number of nodes

From Figure 5, it is evident that the rate of packet drop is meager in IFSIP when compared with IFLIP and GRP. Because of the following location-sharing principle, IFSIP has the capability of choosing a stable route that leads to a reduced packet drop. Still, IFLIP and GRP follow a table-driven approach to send packet where there exists no synchronization of tables to know the current location of other nodes. Further, when node count is increased, performance degradation happens in IFLIP and GRP, where IFSIP gives the best results.

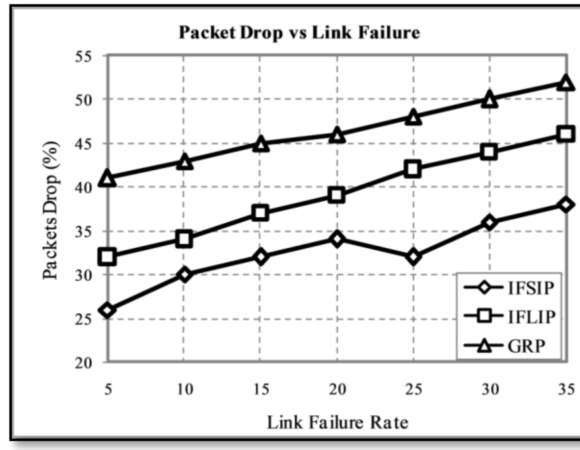


Figure 5. Analysis of Packet Drop against a varying number of link failures

Figure 6 compares the packet drop ratio of IFSIP, IFLIP, and GRP. From Figure 7, it is evident that IFSIP has a lesser packet drop than IFLIP and GRP. Before sending a data packet, IFSIP depicts the location of the destination node. It selects the best route in N available routes by performing optimization, and due to this, IFSIP has low packet drop even in link failures. Also, IFSIP considers every route, saves it, and synchronize the updates frequently for future purpose. Also, IFSIP utilizes a multicasting concept to select a group of neighbor nodes to forward the packet in an ensured manner.

Delay Analysis

Figure 7 indicates that the delay of IFSIP is less when comparing with IFLIP and GRP. The reason for IFLIP and GRP to get increased delay is the usage of a carry-with-forward method. This method provides increased opportunity to point the location of some nodes for forwarding but ends with delay in receiving the packet from source node to destination node. When node density gets increased then, IFLIP and GRP faces more delay. Aggressive use of the primary channel in opportunistically decreases the delay in IFSIP, but IFLIP utilizes primary channel in first come first serve manner, but GRP waits for threshold time to use the primary channel, which results in increased delay. In IFSIP, low level of control overhead provides a way for reducing the delay in delivering the packets to destination and leads a way to control network congestion.

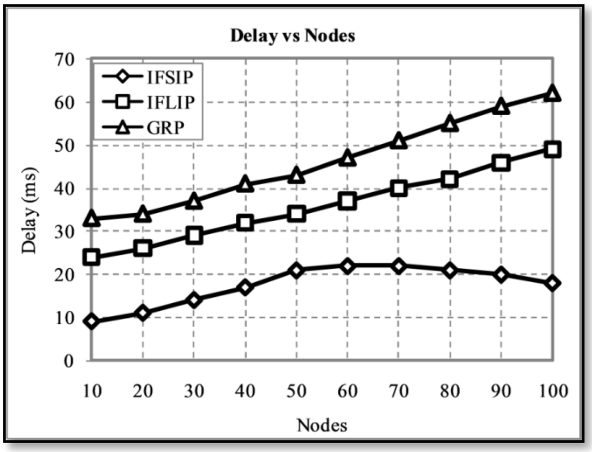


Figure 6. Analysis of Delay against a varying number of nodes

Figure 8 clearly explains the delay faced by IFSIP, IFLIP, and GRP when link failures happen in the network unexpectedly. Delay of IFSIP is less than IFLIP and GRP because route selection strategy precisely selects high-density short routes and sends the packet in the route, where IFLIP and GRP neglect the high-density short routes and send the packet in lengthier routes. However, IFSIP forwards data based on fish visual capability and it results in a shortened route by selecting the nearest neighbor. Decreased hop count gives a way to minimize the delay in IFSIP.

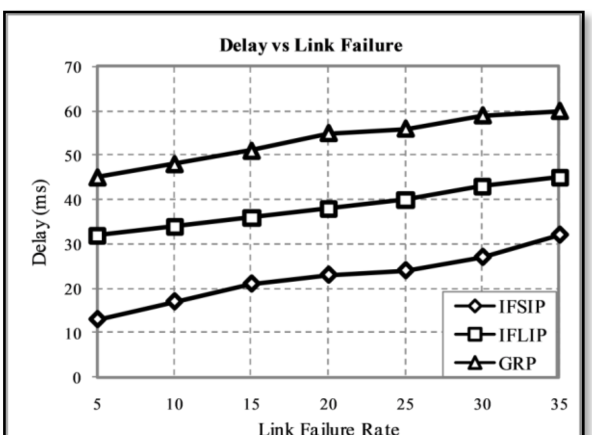


Figure 7. Analysis of Delay against a varying number of link failures

Energy Consumption Analysis

Figure 9 compares the energy consumption of IFSIP against IFLIP and GRP with a varying number of nodes. It conclusively shows the importance of choosing quality routes. With routes that have low collision probability, high levels of failed transmission are avoided and this has its effect in reducing the delay and energy consumption. IFSIP is designed to select a stable route to a destination by using the fitness function. The route that has maximum fitness value is chosen to transmit the data packet to target, where IFLIP and GRP simply send the data packet to the next node available in the routing table.

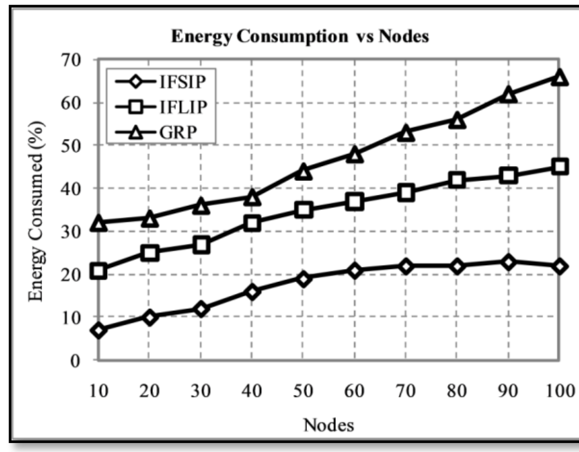


Figure 8. Analysis of Energy Consumption against a varying number of nodes

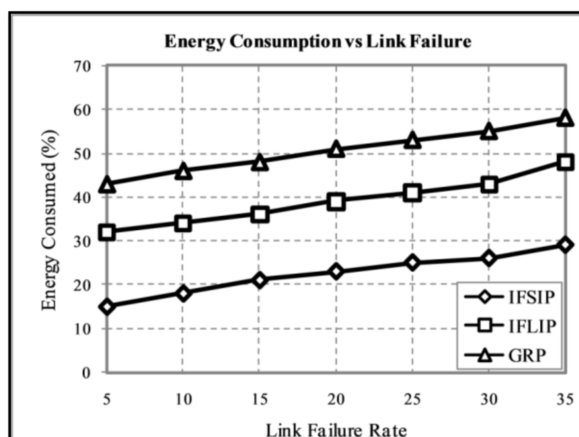


Figure 9. Analysis of Energy Consumption against a varying number of link failures

Figure 10 measures IFSIP energy consumption against IFLIP and GRP with a varying number of link failures. The fitness function in IFSIP plays a significant role in reducing the use of energy because a route with better fitness value is preferred to transmit the data packet, which indicates the quality of the link. IFSIP considers the state of connection into account, nodes that have weak quality links have priority at a low level to send a packet. IFLIP and GRP select the neighbor node that is close to the destination as next hop and it is expected to be in the boundary range. However, these links face increased packet drop because of channel fading. The root cause for the higher energy consumption of IFLIP and GRP non-checking of the link quality before sending the data packet.

4. Conclusion

Minimizing delay and energy consumption is a primary issue in CRAHN, where it leads to unexpected network failure. Currently, CRAHN has stepped in multiple computer domains to monitor and to take timely actions. Various routing protocols have been proposed for CRAHN, but still, there exists no standardized routing protocol to overcome delay and energy consumption issues. In this paper, a new multicast reactive routing protocol namely Intelligent Fish Swarm Inspired Protocol (IFSIP), proposed to overcome barriers in CRAHN by inheriting the behavior of fish in searching for food. When the expected route fails, IFSIP seeks for best alternative way to avoid congestion based on th fitness function value. Optimized routes are established between source and destination dynamically. $M/G/1$ Queuing model applied to prevent IFSIP from congestion. Simulations were carried with two parameters to check the efficacy of IFSIP against existing protocols. IFSIPs result shows it has outstanding performance in terms of throughput, packet drop, packet delivery ratio, delay, and energy consumption. The future dimension of this research work focuses on utilizing nature-inspired algorithms to enhance the performance of CRAHN even more.

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