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Multi-Adaptive Routing Protocol for Internet of Things based Ad-hoc Networks

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Abstract
Internet of Things (IoT) based applications are being evolved in multiple fields to provide enhanced service to the world. IoT is a recent computing concept interconnecting the wired and wireless networks through the internet. Most mobile devices function only in an ad-hoc manner. Infrastructureless networks are called ad-hoc networks. IoT is an effective technology to utilize in Cognitive Radio Mobile Ad-hoc Network (CRMANET) instantaneously. The protocols that are developed for common ad-hoc networks will never suit for IoT-based-CRMANET because the delay they face is inversely proportional with real-time applications. Hence, there exists a need for designing and developing a better routing protocol that suits IoT-based ad-hoc networks. Multi adaptive route indicates the optimum cum efficient path which is selected when the priority of the node gets changed or failed, it may be due to problems that arise in nodes or network components. Multi-adaptive routes make sure the connectivity of the network and its operations before sending the data packet. This paper focuses on developing a Multi-Adaptive Routing Protocol (MARP) inspired by natural characteristics of fish for IoT-based ad-hoc networks to minimize the delay and the energy consumption to extend a network lifetime. NS3 simulation results indicate that MARP gives its best performance than other routing protocols in terms of Throughput, Packet Delivery Ratio, Packet Drop Ratio, Delay and Energy Consumption.

Keywords Routing · Ad-hoc · IoT · Delay · Energy · CRMANET

1 Introduction

'Internet' denotes the immeasurable kind of protocols and applications. It was developed for complication cum interconnection-oriented computer networks. These computer networks are used by infinite trillions of people across the globe 24/7. Terms ubiquitous computing and its connectivity are no more challenging for computer users belonging to the modern era of communication. Researchers have shifted towards integrating the individual,

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wired and wireless devices to make a territory with the virtual environment created by humans denoted as IoT [1]. Two keys essential for IoT are (i) Internet, (ii) Things. Differences between these two things are the object that has the capability of linking ‘Internet’ coming under the category called ‘Things’. Term ‘Thing’ represents the standard entities like user, device and sensor. The object knows about its framework and configuration to communicate with other entities which allows anytime anywhere computing. It indicates that the object needs accessibility without the restriction of time and place. Connectivity of ubiquitous computing is a mandatory need for IoT [2]. To accomplish this, applications are necessary to support heterogeneous devices and protocols used for communication. In IoT, tiny sensors play a significant role in sensing and sending the collected data to servers for processing and extracting hidden information. For this, it is necessary to have cooperation from devices (i.e., mobile devices and edge devices) and user control [3].

1.1 IoT Smartness

The essential distinctive feature of IoT is ‘Smartness’. It differentiates IoT from sensor networks and ad-hoc networks. Two types of smartness available in IoT are (i) Object Smartness (ii) Network Smartness. Object smartness indicates the support of Object-Oriented Concepts [4]. Network smartness denotes the infrastructures used for communication. It distinguishes from other networks with the following characteristics [5, 6]:

- Communication standard.
- Transparency in layer-to-layer communication.
- Object address accessing for different needs.

1.2 Quality of Life Improvement

IoT has been perceived by its quality and usage in the business world [7]. It can restructure the framework of many fields with the following conditions:

- Increase the channels used for communication by giving an enhanced mode of communication from sensors at a different location.
- Promote the process of automated controls by administrators, who are responsible for the remote management of objects.
- Reduce the general expenses spent between starting to ending (i.e., from designing to maintenance) by giving precise estimations to analyze the status of devices from the remote location.

1.3 Cognitive Radio Mobile Ad-hoc Network

Cognitive Radio Technology (CRT) enabled networks are composed of wireless nodes. It can give extraordinary performance towards (a) spectrum sensing (b) setting up of radio (c) strategies development to full utilization of spectrum. Two different types of users present in CRT Enabled Networks (CRTN) are primary users (PU) and secondary users (SU) [8]. PU has the license to utilize the network at any time they want and SU does not have the license to fully utilize the network but they opportunistically utilize the network [9, 10].

For data transmission, SU will scan the network for the availability of spectrum which is not being used by PU and if spectrum not available means SU needs to wait for using the network [11].

Cognitive Radio Mobile Ad-Hoc Network (CRMANET) falls under the category of CRTN. CRMANET does not have distributed or centralized servers like other networks for data or route management. To make CRMANET successful, SU needs to cooperate with other users to transfer data to other users. By default, spectrum devices gather the user details to perform network functions [12]. Availability of channel, the configuration of nodes, count of PU and SU and available bandwidth are details gathered by spectrum devices. During route failure, node failure and while reconfiguring the route these details are fully utilized. CRMANET is differentiated from other networks with the features [13–15]: (i) dynamicity of features (ii) heterogeneity (iii) network architecture (iv) hop distance and (v) controlling of energy consumption. These features are a challenge to researchers to propose new solutions that focus on mobile communication having high-speed [16].

Routings are treated as a secondary level in CRMANET which is not focused on by researchers due to their unawareness. In general, routing protocols specifically developed for MANET or VANET or are not applicable for CRMANET, even though if applied means network may face poor performance [17, 18]. Channel availability to the node differs periodically among different nodes because the entrance or presence of PU makes an impact on network performance. Heterogeneous characteristics in spectrum and path can worsen the routing efficiency. In CRMANET, there exists no guaranty for having a stable route to the destination. The ratio of route disconnection or failure will be high when comparing with networks [19–21].

1.4 Collaboration of IoT and Cognitive Radio Mobile Ad-hoc Networks

The primary objective of IoT is to utilize the available energy efficiently because these nodes are energy-constrained. IoT is a critical factor of a forthcoming paradigm of the Internet. IoT is expected to make rapid communication, which is available through various communication networks. In the communication world, nodes are expected to identify, communicate and cooperate with other nodes to provide enhanced quality of service through the internet. Interconnection between objects and their ability to make universal communication is a prime factor of integrated IoT-based networks [22]. The main intention of IoT-based CRMANET is to minimize the energy consumption of nodes to send data, where the protocols intents to choose the shortest cum efficient route for data transmission. Effective usage of energy (i.e., battery power) is a key factor to sustain network connectivity [23, 24]. Hence, the reason for collaborating IoT and Mobile Ad-hoc Network is to save more energy and enhance the quality of service. Besides, there exists a need for providing an optimum solution for routing in IoT-CRMANET for increasing the network lifetime by minimizing the energy consumption [6].

1.5 Problem Statement

In IoT-based networks, nodes get flexibility because of the mobility feature, but it provides a way for increasing the unexpected route disconnection or failure. When a node moves its position immediately chances for route disconnection start and it leads to packet delay, enhanced energy consumption and packet drop which are not tolerable in IoT-based networks. It becomes mandatory to address the issue of route failure to avoid packet delay, enhanced energy consumption and packet drop.

1.6 Objective

The main intention of this paper is: (a) to provide an outline about IoT and CRMANET (b) to propose a multi-adaptive routing protocol (MARP) for IoT-CRMANET (c) to increase network lifetime by minimizing packet delay, energy consumption and packet drop (d) to simulate the proposed protocol MARP against previous benchmark routing protocols using NS2.

1.7 Contribution

This paper proposes a routing protocol for IoT-CRMANET to minimize energy consumption and delay. The finding of an optimized route is performed based on natural characteristics of fish in swarm towards searching for food. For finding the shortest path to the destination, the proposed routing protocol MARP utilizes Foraging Behavior, Social Behavior, Follow-up behavior and Stochastic Behavior of fishes. To optimize the selected route, node locations are monitored, compared and synchronized. Results of simulation indicate that MARP is better in terms of chosen performance metrics and suitable for IoT-CRMANET.

1.8 Motivation

IoT-CRMANET is an autonomous network made up of nodes having the feature of mobility. The nodes use CRT for communicating with other nodes. Standards of 802.16 are defined by IEEE and currently utilized in home, businesses and institutions. Technologies used in 802.16 influence the design and implementation of IoT-CRMANETs where the devices are limited to battery power. Without the efficient routing protocol, IoT-CRMANET will face exhaustive energy consumption and it will lead the network to fail.

1.9 Organization of the Paper

Section 1 of the paper, provided an overview of the collaboration of IoT and CRMANET, followed by the Problem Statement, Objectives, Contribution and Motivation to research work. Section 2 attempts to reviews the related literature overview with a comparison. Section 3 presents the proposed Multi-Adaptive Routing Protocol. Section 4 analyzes the proposed routing protocol theoretically in terms of Computational Complexity, Packet Embedding Overhead, Guaranteed Connection cum Delivery and Network Coverage. Section 5 confers the results and discussion with simulation models, parameters and performance metrics. Section 6 provides the details about the data used in this research work, the funding and conflicts of interest. Lastly, Sect. 7 concludes the paper with future dimensions.

2 Related Works

Secure-Trusted Framework [25] proposed to embed routing information in the data packet that travels in lossy IoT networks. Its main intention was to lessen the exhausting energy consumption of nodes. The performance of the protocol gets weak and consumes more energy which leads to a poor packet delivery ratio due and network congestion. Content-Centric Routing Methodology [26] proposed to find the route to the destination in IoT networks. The routes are estimated depending on content sent by the source node. It aimed to increase the data aggregation, but it ended with increased delay and energy consumption. Cluster-based Routing Protocol [27] proposed for balancing the load in IoT networks. It focused on reducing the delay by choosing the best path. A channel interference issue was also considered. The unexpected result in throughput and delay shows that it is suitable for IoT-based networks. Lightweight Distribution based Geographic Multicasting Routing Protocol [28] proposed to solve the problem of finding the best route to the destination in a short duration. Initially, intermediate nodes were selected to make the packet reach the targets. Secondly, looping paths are identified and removed. Finally, multicast routes are merged to form the best route. While combining the multicast routes, unexpected link failures have occurred leading to network failure.

Machine-learning-based Automated Routing Decisions Protocol [29] proposed for opportunistic IoT networks to decrease the packet drop. A Gaussian mixture model combined with machine learning to enhance the results. The poor results in delivery ratio, overhead and message drop indicate that the data mining concepts are not suitable for IoT networks. Location Prediction Based Forward Routing Protocol [30] proposed to increase the interaction among IoT nodes to attain connectivity, reliable communication and enhanced network lifetime. It has faced multiple hurdles in finding the opportunity to communicate with neighbor nodes and resulted in reduced hop count and packet delivery ratio. Hybrid Routing Protocol [31] proposed to discover a better route by using a directional antenna. Firstly, nodes were designed to connect with the root node to transfer the data. Further, it was made to transfer the data to unconstrained IoT networks but due to this, the primary users were affected by the connectivity error. Enhanced Data Delivery Framework [32] proposed to increase the packet delivery ratio and reduce the consumption of energy in large-scale IoT networks. To avoid network load, nodes were designed to receive the data packets based on available battery and memory capacity. Due to this, multiple nodes have avoided receiving the data packet. The results indicate that the framework will create a network imbalance issue leading to reduced network lifetime.

Artificial-Intelligence-based Geographic Routing Protocol [33] proposed with an idea of applying the deep-learning concept. It was based on a stateless greedy method, to detect and proactively minimize the network traffic by providing the alternative path to reach the destination. The routing was performed in a cloud-computing environment for efficiency, but it was found that the alternative paths were not fit for data transmission leading to network failure. Self Route Discovery Protocol [34] proposed to address the problem of link failure during data transmission. It aimed to work as a self-healing strategy towards the link failure in a scalable network where routings are considered opportunistic by default. The best-fit algorithm was applied to resume the communications that were interrupted for a lengthy time. The result showed that the method had degraded the performance by maximizing the delay.

Game Theory-Based Routing Protocol [35] proposed to choose the possible hop to send the data packets efficiently. The best selection of next-hop entirely depends on the cooperation-based game between two nodes, where it considers the distance between the sender and receiver node. Due to the increased waiting time between the nodes, the overall delay was increased and resulted in reduced network lifetime. Hybrid Energy Cluster Protocol [36] proposed to address the challenge of increased energy consumption and connectivity issues in heterogeneous IoT networks. This attempt was made to implement a homogeneous protocol in a heterogeneous environment by using the clustering concept. Different weights were fixed for nodes of the IoT network and used for finding the routes to the destination, but the increased overhead and delay indicated that the proposed protocol was not fit for the IoT network. Global Information Decision Routing Protocol [37] proposed to enhance the performance of data transmission. This protocol aimed to estimate the delay in each route and look for the alternative route. The ignored path has an increased delay than expected. Based on residual energy, nodes receive the packet for forwarding. Due to having too much process and calculation, the delay level was increased.

When the licensed user (i.e., primary user) enters the network for usage, the secondary users should disconnect from the network which also increases the consumption of energy. To overcome this issue, Spectrum Energy-Aware Routing Protocol [38] proposed for enabling the communication between nodes in IoT networks. Due to this, network load got imbalanced and network lifetime got reduced. Feasible Reactive Routing Method [39] proposed to address the issues that arise in the physical layer of cognitive networks. It aimed to (i) avoid the inference of SU when PU utilizing the network, (ii) to achieve the joint path and (iii) to use the multiple channels to increase the network performance. The results indicate that the protocol faces decreased throughput and packet delivery ratio. Perceptron-Detection-based Protocol [40] proposed to increase the IoT network performance in terms of throughput. K-means algorithm was used to classify the route between source and destination. Due to focusing on security issues, the network faced a reduced network lifetime.

Smart Management Routing Protocol [41] aimed to provide a better service to networks during different disasters. It utilizes cloud-computing and bio-inspired optimization for enhancing the network performance, but due to the non-applicability of an optimization technique in cloud-computing, the delay got increased and affected packet delivery ratio. Adaptive Routing Protocol [42] proposed to support the IoT heterogeneous network to reduce control overhead. It focused on gaining information regarding the node location to provide better routing. It depends on the availability of data on different servers. This approach did not suit IoT networks, where the control overhead increased a lot and gave way for performance degradation. Interoperable Awareness Routing Protocol [43] aimed to increase the throughput of the IoT network by considering energy consumption. It has taken steps to minimize energy and memory utilization. Also, it has considered avoiding packet broadcasting. The results denote that the network performance has degraded due to having more clusters. Low-Power Lossy Network Protocol [44] to provide better routing in lossy IoT networks. It utilizes several routing policies in the IoT network to perform routing. Due to lacking routing information, the end-to-end delay has exhausted.

Survivable-Path Routing Protocol [45] proposed to avoid congestion in IoT networks, where it focuses on preventing interference. It intends to prevent unnecessary energy utilization by sending data only in a survivable path. The factors considered for selecting the next hops were: (a) network noise ratio, (b) link quality and (c) congestion level. Results make an indication that the throughput and network lifetime got decreased enormously. Ring Loop Routing Protocol [46] to provide privacy to the location of nodes in IoT networks. Backtracking strategy applied to maximize the transmission rate of different domains. The fake packets concept was used to maintain the nodes from attacks, but the network delay got increased too much and resulted in reduced network lifetime.

Pilot Study [51] analyzed the protocols available for IoT networks. It considered the IPV4 and IPV6 enabled networks for analyzing the performance. Results indicate that routing protocol available for regular wired and wireless networks cannot be applied for IoT-based networks, where optimization is necessary for routing in IoT networks. Particle Filter Routing Protocol [49] proposed to utilize smart devices for communication. It aimed to minimize the congestion in wireless networks. It has provided a way to use aerial vehicles in IoT networks. It has given 40% of packet delivery, which acts as a significant drawback. Energy-Aware Cluster Routing Protocol [50] proposed for IoT-based wireless sensor networks to reduce energy consumption. It aimed to increase the quality of service by reducing packet drops. Due to checking all the aspects in the network, the delay was increased leading to a reduced network lifetime.

Wolf Prey Inspired Protocol (WPIP) and Improved Frog Leap Inspired Protocol (IFLIP) [48, 52] are bio-inspired routing protocols aimed to minimize the packet delay that arises dynamically in CRAHN. Poor communication made nodes face unexpected route disconnection leading to exhaustive energy consumption. Geographic Routing Protocol (GRP) [47] proposed to support PU in CRMANET with a greedy approach. In GRP, SU communication are blocked to make PU communication better where this approach faces low security and an enormous number of broadcast request that leads to network congestion.

In the computer networks world, multiple routing protocols were proposed to overcome the drawbacks and to attain better results. So far, proposed routing protocols focus only on a single objective, where they failed to address all the issues. The current section of the paper has discussed recent proposals in IoT-based ad-hoc networks with their drawbacks. Table 1 provides the pros and cons of the selected routing protocols discussed above.

3 Multi-Adaptive Routing Protocol

Multi-Adaptive Routing Protocol (MARP) is a bionic protocol inspired by the food searching behavior of fish in an independent environment. MARP attains optimum level (i.e., finding the best route) by simulating natural characteristics of fishes which are swarming, foraging, clustering and targeting. MARP involves local and global optimization. Local optimization assists in achieving global optimization. During the simulation, the processes involved in the foraging and cooperative behavior of fishes are simulated to increase efficiency. The foraging process involves (i) competing (ii) surviving and (iii) coordinating. During the foraging process, fishes have the better ambiguous ability and seeking ability. To apply fish swarm algorithm in IoT-based CRMANET for route optimization, there exists no need for knowing the values related to (i) objective function (ii) gradient and (iii) search space. Hence, MARP does not have any high-level requirement for initial settings and parameter values.

MARP is an optimization-based protocol that iteratively progresses the results. MARP is applied in IoT-based ad-hoc networks and object-oriented concepts are adopted. Huge class holding variables and functions are set to act as artificial fish. Parameter involved in MARP contains the current state of individual fish F, step size of fishes, crowd size, perceived distance and count of retries. Member functions include two things which are: (i) concentration of food in current location and (ii) behavior of fishes. Once completing the parameter setting, information regarding the individual fish is set in a label format using the encapsulation concept. The entire optimization is done via a swarm of fishes. The different states of individual fishes are observed and followed by different fishes. Hence, in a

Table 1 Comparison of recent ad-hoc routing protocols

Author	Year	Objective	Pros	Cons
Feasible Reactive Routing Method [39]	2012	Achieve joint path	Avoidance of interference	Increased packet drop and not focused on IoT
Geographic Routing Protocol [47]	2014	Reduce energy consumption	Network coverage	Exhaustive consumption of energy
Content-Centric Routing Methodology [26]	2016	Improve routing based on the type of data	Content-based routing with improved privacy	Increased delay and energy consumption
Geographic Multicasting Routing Protocol [28]	2017	Finding the best route to the destination	Removal of looping paths	Increased link failures Not focused on IoT
Cluster-based Routing Protocol [27]	2018	Overcome channel interference issue	Improved load balancing across channels	Poor result in throughput and delay
Adaptive Routing Protocol [42]	2018	Find the best route in the heterogeneous network	Node location-based deep-routing Focused on IoT	Increased energy consumption with delay
Survivable-Path Routing Protocol [45]	2018	Congestion Avoidance	Route survivability Focused on IoT	Reduced network lifetime
Machine-learning based Automated Routing Decisions Protocol [29]	2019	Utilize machine learning algorithms in routing decisions	Sharing of nodes location to improve the route utilization	Increased control overhead and packet drop
Location Prediction Based Forward Routing Protocol [30]	2018	Increase interaction between nodes	Improved node connectivity with route handling	Reduced hop count and poor prediction of nodes
Improved Frog Leap Inspired Protocol [48]	2018	Utilize least-cost route to reduce delay	Dynamic prediction of congestion	Increased delay and energy consumption
Secure-Trusted Framework [25]	2019	Reduce energy consumption	Security to route till delivery of the packet	Poor packet delivery ratio with more delay
Enhanced Data Delivery Framework [32]	2019	Improving packet delivery ratio	Improved load balancing and data delivery	Reduced network lifetime.Not focused on IoT
Particle Filter Routing Protocol [49]	2019	Utilize smart devices for communication	Utilization of IoT and route security	Poor route optimization
Artificial-Intelligence-based Geographic Routing Protocol [33]	2019	Reduce congestion across the geographical area	Finding multiple alternate routes in a short duration	Unexpected network failures and more energy consumption
Ring Loop Routing Protocol [46]	2019	Provide privacy to nodes location	Avoidance loops in route and attacks	Increased Delay and energy consumption
Smart Management Routing Protocol [41]	2019	Improve throughput by using IoT	Route optimization Focused on IoT	Increased Delay Poor Throughput

Table 1 (continued)

Author	Year	Objective	Pros	Cons
Energy-Aware Cluster Routing Protocol [50]	2019	Minimize packet drops in network traffic	Better node communication	Not focused on IoT to reduce delay

specific search space of dimension n, the count of artificial fish will be M and its state is defined as Eq. (1)

$$F = \{F_1, F_2, F_3, \dots, F_{n-2}, F_{n-1}, F_n\} \quad (1)$$

In search space, $F_i = (1,2,3,\dots,n-2,n-1,n)$ represent the variables that are to be optimized. The concentration of current food by an artificial fish is expressed as:

$$Obj\_Fn = f(y) \quad (2)$$

where Obj_Fn indicates the objective function and the distance present between two artificial fish is expressed as

$$dist_{p,q} = \|y_p - y_q\| \quad (3)$$

The current state of fishes is a solution towards reaching the target, which indicates zero compulsion towards the optimum solution. The current state is passed as an input to Eq. (2) and its results are utilized for comparing the status of other fishes.

3.1 Foraging Behavior

In IoT based ad-hoc network, core simulation is done by imitating the foraging behavior of fishes in the swarm. Throughout the foraging behavior, fishes focus to gain more information about food to determine its next behavior. In specific, if more information is gained through the movement of fish, then as a choice fishes prefer swimming in that same direction which assists in simulating and setting the parameters. The current state of the fish swarm can be indicated as F_i, the concentration of food is utilized as a significant tool to motivate fish swarm to move further towards reaching the target. If the concentration of food is better than the current one, then the fishes move to the location having a rich concentration of food. In contradiction, the swarm of fishes performs a reselection to choose a new state in a random manner F_j. Suppose, the condition of forwarding is lower than the iteration number, then the searching is made to continue till the condition gets satisfied. Once after satisfying the search condition, the parameter is calculated as

$$F_j = F_i + visual\_distance \times rand() \quad (4)$$

where $rand()$ is used to generate a random number among 0 and 1. If$F_j > F_i$, then fishes move in the direction ofF_j. If$F_i > F_j$, then fishes move in the direction ofF_i.

$$F_i^{g+1} = F_i^g + \left(\left(F_j - F_i^g\right) / \left(\|F_j - F_i^g\|\right)\right) \times (step\_size \times rand()) \quad (5)$$

If a subsequent state does not satisfy the condition, then the fishes randomly move one step.

$$F_i^{g+1} = F_i^g + (visual\_distance \times rand()) \quad (6)$$

3.2 Social Behavior

One of the natural characteristics of fish is to form a swarm with its neighbors to safeguard them from risk. This strategy assures safety to every fish in the swarm. All fishes in a swarm move as close as possible to the center of the swarm with individual interaction. The mode of interaction to maintain the integration is indicated as a state of individual fish. MARP can be exposed as a specific interaction that is executed to avoid overload of swarm during the progression.

It is assumed that the current process set the state of artificial fish as F_i and the view of other individual fishes can be denoted as num_f. The current status of the midpoint of the swarm is F_{mid}. If $Obj\_Fn_{mid}/num_f > Obj\_Fn_i$ becomes true, then it indicates that the location is having no crowd and the concentration of food is high. Then, the individual fishes forward its movement towards the midpoint of the swarm and if it is not satisfied then the foraging behavior keeps continued. This process is mathematically expressed as

$$F_i^{g+1} = F_i^g + \left(\left(F_{mid} - F_{mid_i}\right)/\left(\|F_{mid} - F_{mid_i}\|\right)\right) \times (step\_size \times rand()) \tag{7}$$

3.3 Follow-up behavior

In a fish swarm, if a specific number of fishes discovers food at an equivalent time then the nearby fishes attempt to follow the same food where this scenario is described as follow-up behavior. This behavior is a tailing aspect. In MARP, this scenario represents nodes that look for an optimum route to the destination. MARP assumes the present state of artificial fishes as F_i and highly concentrated food by other artificial fishes as F_{high}. On satisfying $F_{high} > Obj\_Fn_i$ and $Obj\_Fn_{high}/num_f > Obj\_Fn_i$ conditions, it denotes that the neighbor artificial fish has discovered the highly concentrated food F_{high} and other fishes focus to move in the same direction, else foraging behavior is continued. Follow-up behavior is mathematically expressed as:

$$F_i^{g+1} = F_i^g + step_{size} \times rand() \times \left((F_{high} - F_i)/\|F_{high} - F_i\|\right) \tag{8}$$

3.4 Stochastic Behavior

Fishes in the swarm have stochastic movement which will assist the entire swarm to seek food. In general, fishes stochastically select a state within their coverage area and spontaneously shift move a step towards that direction. This is typical behavior of foraging animals since it consists of individual small process.

3.5 Monitoring Board

The purpose of monitoring is to record the optimum state of artificial fish which represents the maximum concentration of food in the swarm. Fishes in the swarm perform different operations to reach the objective, but all the operations are recorded, compared and analyzed. If a better value than the original value found means then it is replaced with the previous best value, else the previous best value is kept as it is. Once MARP begins its process of finding the best route, the monitoring board keeps recording the optimum values (i.e., available routes) found by it.

3.6 Process of MARP

The processes involved in MARP are:

1. Perform the parameter setting which includes swarm size, the maximum range of visual field, step size, threshold value for iterations and the factors regarding congestion.
2. With several fishes initialize the fish swarm in a specific range.
3. Calculation of food concentration level at individual fish is performed and the parameters related to it are recorded in the monitoring board.
4. The distribution of concentrated food and foraging behavior is simulated. Necessarily every fish in the swarm is expected to perform this simulation and a decision is made whether to continue with concentrated food or move to the next available better-concentrated food.
5. While completing corresponding behavior by a swarm of fishes, the monitoring board records the optimum results and then the comparison is performed. If better results are found means, it is replaced with the old results in monitoring boards.
6. On attaining the maximum count of iterations, MARP automatically gets stop and the monitoring board cannot provide output. If the count of iteration has not attained the maximum means, MARP continues its operation with iteration.

M nodes are initialized in a random location of simulation area, but geographically. The monitoring range of node is *rad* and nodes in the simulation area can be expressed as:

$$S = \left\{ s_1, s_2, s_3, \dots, s_M \right\} \tag{9}$$

where $s_i = (p, q, rad)$ represents a circle in location (p, q) with radius rad. Since there exists no option to perform a calculation of monitoring area during the simulation this research work segregates the simulation area into $p \times q$ pixels. If the pixel (p, q) is occupied by j^{th} node, then the routing event is called rad_j and its probability is indicated as $P\{rad_j\}$. Mathematically it can be expressed as

$$P\{rad_j\} = \begin{cases} 1, & if\left((p-p_j)^2 + (q-q_j)^2\right) \le rad^2 \\ 0, & otherwise \end{cases} \tag{10}$$

If the distance between a particular node i and (p, q) is minimum than *rad*, then MARP considers (p, q) is in the transmission range.

$$P\left\{\overline{rad_i}\right\} = 1 - P\left\{rad_i\right\} \tag{11}$$

If irrelevancy is present between rad_i and rad_j, then its relationship is indicated as

$$P\left\{rad_i \cup rad_j\right\} = rand(0,1) - P\left\{rad_i \cap rad_j\right\} \tag{12}$$

Similarly, if a node focus on (p, q) for a prolonged time, then its probability is entirely covered by rad_i. If random events rad_i are independent, then its coverage is mathematically expressed as:

$$P(p, q, s_i) = 1 - P\left\{ \sum_{i=1}^{M} \overline{rad_i} \right\} \tag{13}$$

If none of the nodes focuses on (p, q) for a threshold time, then it is not focused further.

MARP refers to the area $H_{area}(S)$ covered by S to monitor the area H and it is mathematically expressed as

$$U_{area}(S) = \frac{H_{area}(C)}{H} \tag{14}$$

Vector of controlling $F = \{b_1, b_2, b_3, \dots, b_{M-2}, b_{M-1}, b_M\}$ describes the state of nodes in IoT-based ad-hoc networks. Nodes coverage in the network to find the best route is mathematically expressed as:

$$fn_1(F) = \frac{H_{area}(S)}{U \times V} \tag{15}$$

where $U \times V$ represents the total monitoring area.

Utilization of node in the network is expressed as

$$fn_2(F) = \sum_{i=1}^{M} \left(\frac{b_i}{M} \right) \tag{16}$$

Two aspects are considered for optimizing the routes in IoT-based ad-hoc networks which are: (i) increase the coverage of network and nodes (ii) decrease the utilization of node.

4 Theoretical Analysis

4.1 Computational Complexity Analysis

Theorem 1 *Computational complexity of MARP in removing the fault routes in the network.*

Proof MARP consists of two main steps in removing fault routes. The first step is to perform the basic network segregations i.e., to form n sub-networks for network N. For each N^h network, it has h destinations for node w and it serves as intermediate nodes for delivering the data packet to the other $(p - h)$ targets. This step needs n/p assessments. The second step assesses the energy level at n sub-networks and chooses the sub-network that has the maximum energy among the complete segregation, where other sub-networks are ignored. The number of time assessment made is $\sum_{initialenergy}^{thresholdenergy} \left(\frac{n/[n+1]}{2n} \right)$.

Therefore, the complexity of MARP to remove the fault routes is $b[n^2 - n/p]$.

4.2 Packet Embedding Overhead Analysis

Theorem 2 *Packet embedding overhead of MARP is* $b[p]$.

Proof Let w be one of the destinations and $x_1, x_{2,} \cdots, x_p$ be the other destinations located in different parts of the network. When node w receives the data packet, initially it removes its location information from the header and it inserts the location information of $x_1, x_{2,} \cdots, x_p$. Lastly, it forwards the data packet by using the anycasting concept, where it depends only on the distance to save energy. Let l^h denote the count of direct destinations (i.e., having only 1 hop) from the source h. The total embedding overhead in delivering the data packet from destination h to l^h direct targets will be equal to k. Mathematically, it is expressed as.

$$b[\prod_{h=1}^{p} l^h[< 1]] = b[p] \tag{17}$$

Therefore, the packet embedding overhead of MARP is $b[p]$.

4.3 Stable Connection for Packet Delivery

Theorem 3 *For independent forwarding node w and receiving node x, if the distance between them is higher than or equivalent to maximum or threshold distance, then at least one route exists to connect w and x.*

Proof When a route is found to send the data to the destination, MARP immediately checks for void node and avoids the same. For the forwarding node w, the intermediate nodes that violate the network rules are removed and crossing edges are also dismissed. But for the nodes that have only one neighbor, intermediate nodes will not be removed. Edge value of $[w, x]$ lies in the neighborhood node value, i.e., if the distance of w and x is greater than the expected distance, then w makes a connection with x using the bi-direction communication principle.

Therefore, MARP faces a stable connection for packet delivery.

4.4 Network Coverage Analysis

Consider P and Q be the ideal set of nodes. The data communication between the two non-dominated sets of nodes is determined by using this metric. The network coverage function NCF traces P and Q to the interval [0,1] and it mathematically expressed as:

$$NCF(P, Q) = \frac{\|(q \subseteq Q| \bigvee p \subseteq P : q \preccurlyeq p)\|}{\|Q\|} \tag{18}$$

$||Q||$ represents the count of alternate routes to the destination and $q \preccurlyeq p$ indicates the available routes to destination and q is loosely dominated by a route available to p. The three major case are:

$$NCF(P,Q) = \begin{cases} 1 \ \ indicatesweakdomination \\ 0 \ \ indicateszerodomination \\ -1 \ \ indicatesbestroutingsolution \end{cases} \tag{19}$$

Therefore, MARP faces a stable connection for packet delivery.

5 Simulation Results

5.1 Simulation Models

NS3 simulator is used to analyze the proposed protocol MARP against IFLIP and GRP. NS3 has the advantage of supporting (i) Event and Discrete based Simulation (ii) Wired and Wireless Network Simulation (iii) Multicasting Simulation (iv) Geographic Simulation and (v) Queuing and Routing Simulation. These advantages make MARP compare with GRP, WPIP and IFLIP by sending data packets randomly over auxiliary and secondary channels. The reliability of simulating protocols in NS3 can be highly trusted. Random waypoint is the mobility model used in the simulation. MARP is simulated in the IoT-CRMANET environment for assessing the performance against IFLIP and GRP. Table 2 provides the setting used for the simulation.

5.2 Parameter

To measure the performance of routing protocols with different conditions a parameter is needed. In this paper, the count of nodes is taken as a parameter to analyze the performance of MARP against GRP [47], WPIP[52] and IFLIP [48]. This parameter is used to measure the protocols performance with varying numbers of nodes and it is used to analyze the consistency of protocols.

Table 2 Simulation Parameters and Settings

Parameters	Settings
Simulation Area	$3000 \times 4000\,m^2$
User Count	100
MAC	802.16
Transmission Range	350 *meters*
Simulation Time	300 *seconds*
Traffic Source	*CBR*
Size*ofPacket*	512 *bytes*
Packet Count	4000
Mobility Model	*Random Waypoint Model*
Initial Energy Level	5 *Joules*

5.3 Performance Metrics

- *Throughput* It refers to the ratio of packets sent against the total number of packets. It can also be described as the percentage of successful delivery of a message over a communication channel.
- *Packet Delivery Ratio* It refers to the ratio of the count of packets successfully received in destination against the total number of packets sent.
- *Packet Drop Ratio* It refers to the ratio of difference present between the packet sent and packet received.
- *Delay* It refers to the time taken by a packet to travel from source to destination.
- *Energy Consumption* It refers average energy consumed by the packet to travel from source to destination.

5.4 Results and Discussion

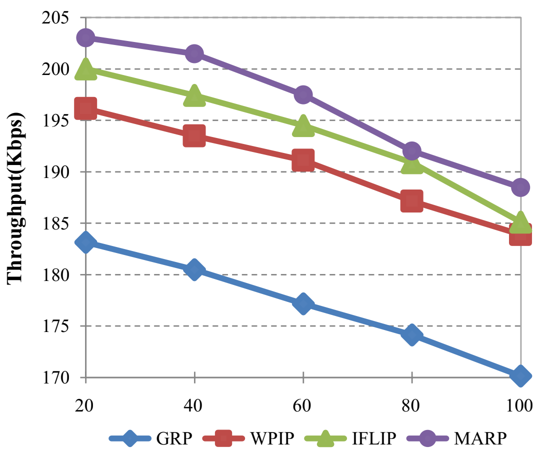
5.4.1 Throughput Analysis

In Fig. 1, the x-axis is marked with No. of Nodes and the y-axis is marked with Throughput in kbps. From Fig. 1, it is very clear to make an understanding that MARP outperforms GRP, WPIP and IFLIP and it is identified that throughput gets linearly decreased when the count of node gradually increases. The foraging behavior of MARP acts faster to find better routes than GRP, WPIP and IFLIP. Foraging behavior makes MARP achieve maximum throughput than other protocols. The average throughput achieved by MARP is 196.492 kbps, where GRP, WPIP and IFLIP have achieved average throughput as 177.019 kbps, 190.355 kbps and 193.587 kbps respectively.

5.4.2 Packet Delivery Ratio Analysis

In Fig. 2, x-axis is marked with No. of Nodes and y-axis is marked with Packet Delivery Ratio in percentage. It is very clear to make an understanding that MARP outperforms GRP, WPIP and IFLIP. From Fig. 2, it is identified that packet delivery ratio gets linearly decreased when the count of node gradually increase. Social behavior present in MARP

Fig. 1 MARP vs Throughput



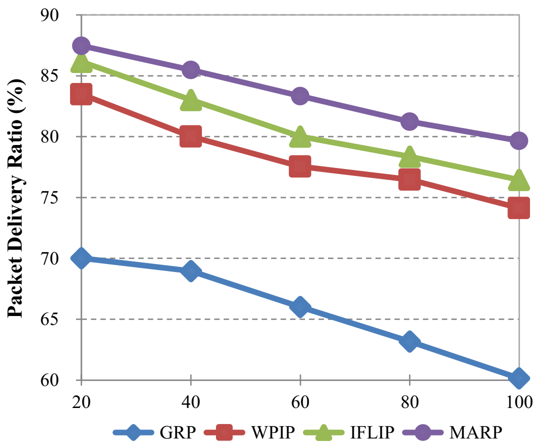


Fig. 2 MARP vs Packet Delivery Ratio

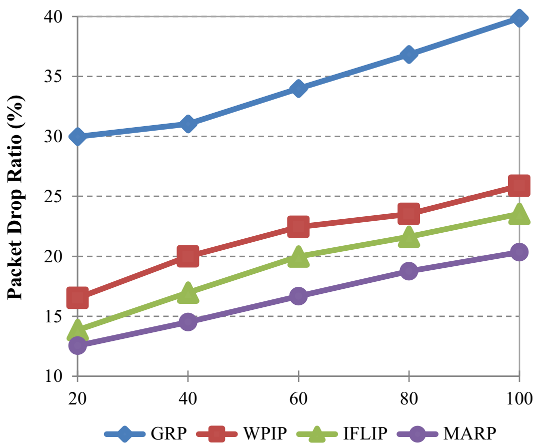


Fig. 3 MARP vs Packet Drop Ratio

makes nodes to share rouing information with other nodes which results in increased packet delivery ratio. Average packet delivery ratio achieved in MARP is 83.437%, where GRP, WPIP and IFLIP has achieved average packet delivery ratio as 65.659%, 78.331% and 80.8% respectively.

5.4.3 Packet Drop Ratio Analysis

In Fig. 3, x-axis is marked with No. of Nodes and y-axis is marked with Packet Drop Ratio in percentage. It is very clear to make an understanding that MARP outperforms GRP, WPIP and IFLIP. From Fig. 3, it is identified that packet drop ratio gets linearly increased when the count of node gradually increase. Follow-up behavior assist MARP to follow the successful routes which are shared previously by other nodes and this makes MARP to drop packet in a very low level when compared with other routing protocols. Average packet drop ratio of WPFSIP is 16.563%, where GRP, WPIP and IFLIP has average packet drop ratio as 34.341%, 21.669% and 19.200% respectively.

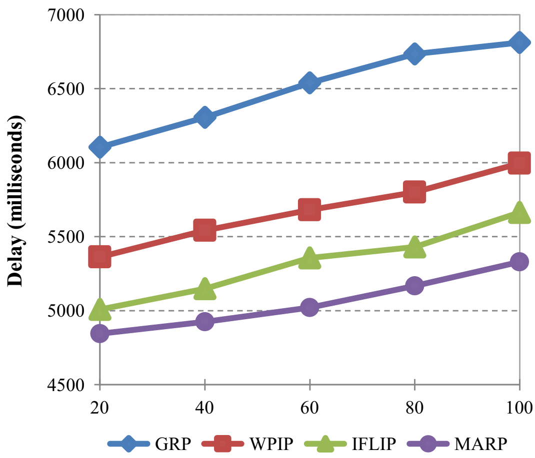


Fig. 4 MARP vs Delay

5.4.4 Delay Analysis

In Fig. 4, x-axis is marked with No. of Nodes and y-axis is marked with Delay in milliseconds. It is very clear to make an understanding that MARP outperforms GRP, WPIP and IFLIP. From Fig. 4, it is identified that delay faced by all protocols are high when minimum number of nodes are present, but the delay gets linearly decreased when the count of node gradually increase. Stochastic Behavior of MARP makes nodes to move in random direction and seek best route to destination which results in gathering of more number of new routes and face low delay than other protocols. Average delay of WPFSIP is 5057.4 ms, where GRP, WPIP and IFLIP has average delay as 6499.2 ms, 5676.2 ms and 5321.4 ms respectively.

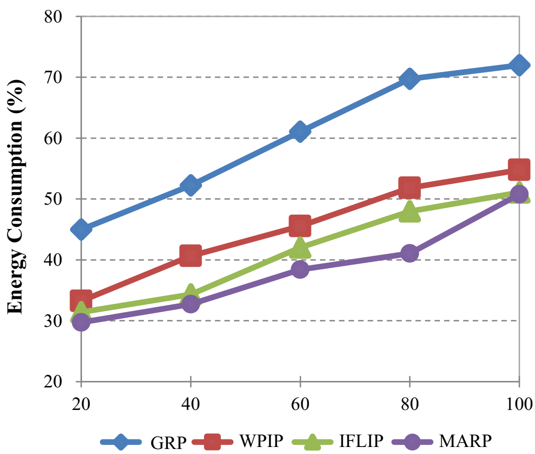


Fig. 5 MARP vs Energy Consumption

5.4.5 Energy Consumption Analysis

In Fig. 5. 10, x-axis is marked with No. of Nodes and y-axis is marked with Energy Consumption in percentage. It is evident that WPFSIP has consumed minimum energy than MARP outperforms GRP, WPIP and IFLIP. From Fig. 5. 10, it is identified that energy consumption of all protocols increases when count of node gets increased. Monitoring Board of MARP collects information from all nodes regarding routes and performs synchronization to give updated information to the nodes while sending data. This makes MARP to avoid lengthier routes and fault routes which consume more energy. Average energy consumption of WPFSIP is 38.531%, where the average energy consumption of GRP, WPIP and IFLIP is 60.002%, 45.202% and 41.369% consecutively. Corresponding numeric values of Fig. 5. 10 is provided in Table 5.6.

6 Conclusion

The primary issue present in IoT-CRMANET is increased delay and energy consumption. Exhaustive energy consumption leads reduced network lifetime. Multi-Adaptive Routing Protocol (MARP) has been proposed in this paper to overcome the barriers present in IoT-CRMANET. MARP is developed based on natural characteristics of fish towards searching its food. Foraging behavior assists nodes to dynamically find the best route to destination. Social Behavior and Follow-up Behavior assist nodes to share the gathered routing details and follow the best route. Stochastic Behavior makes nodes to move in random direction and seek best route to destination. Monitoring Board collects information from all nodes regarding routes and performs synchronization to give updated information to the nodes while sending data. NS3 simulator has been used to evaluate the performance of MARP against previous routing protocols with the parameter node count. Results makes an evident that MARP outperforms other routing protocol in terms of throughput, packet delivery ratio, packet drop ratio, delay and energy consumption. Future enhancement of this research work can be focused with applying machine learning algorithms to classify the routes for better results.

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Data availability This research work utilizes no data or dataset. This research work utilizes the randomly generated data by the simulator as input.

Code availability Custom code available on request due to privacy or other restrictions.

Declarations

Conflicts of interest The authors of this paper have no conflict of interest towards the publication of this research article.

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