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MODIFIED LEACH-R APPROACH WITH CACHE STRATEGY FOR MOBILE ROBOT SWARMS

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Abstract: As technology evolves, so does the demand for employing sophisticated mobile robots. Nevertheless, researchers confront two major obstacles when building automated mobile robots: energy efficiency and path planning. In this paper, an efficient and effective Fuzzy based mobile robot system is presented wherein works has been done on effective CH selection and relaying technique. The main objective of the proposed work is to reduce energy consumption of nodes while finding route for transmitting data to sink node. To achieve this objective, the proposed model utilizes Fuzzy Logic System (FLS) for selecting the appropriate and optimum cluster Heads. Three important factors i.e. Distance, connections and residual energy of a particular node are considered which serve as input to Fuzzy system. The fuzzy system analyzes these factors and generates a single output that determines the probability of node to become CH in the network. In addition to this, the suggested work employs a CH chaining-based relaying approach to lessen network complexity and increase network speed. The efficacy of the proposed approach is examined and validated by comparing it with traditional models in MATLAB software. The results were obtained in terms of Packet Delivery Ratio (PDR) and Lifetime for scenarios with varied packet size, BS speed, node speed, and network size. Results obtained simulated that proposed fuzzy model is showing more promising and effective results for all parameters.

I. INTRODUCTION

The present era is appropriately referred to as the "digital era." Digital communication devices have become considerably more popular than expected due to the significant developments and lower cost of advanced technologies. Mobile phones, personal digital assistants, and even desktop and laptop workstations are some of these digital platforms. These digital communication platforms are in higher demand due to their simple network accessibility, which is made possible via wireless interfaces. Mobile robot swarm communications do have a substantial impact on a number of wireless communication sectors. These industries include those that deal with drone swarms, disaster assistance, communication on the battlefields, and search and rescue [1]. The main aim of wireless communication system being to provide a seamless experience to the consumers, whenever any mobile node gets out of the range of the current connected base station it automatically gets connected to a new base station in the range. The automatic interconnection between the devices is carried out with the help of a wireless interfaces, wherein they self-organize themselves into ad-hoc networks. Ad-hoc networks can be defined as the wireless distributed networks that doesn’t need infrastructure for its functioning. Every node in an ad hoc network functions as a router for the node behind it, facilitating the passage of data packets as needed. This is the basic characteristic of an ad hoc network [2]. In practical MANET implementations, mobile robot swarms are typically clearly task-oriented due to which they exhibit Group movements. This mobility is basically relies upon grouping models like Reference Point Group Mobility (RPGM). Mobile robot swarms have a greater research value as a result of its increase in group mobility models. Nevertheless, for these task-oriented traits, the requirement for trustworthy communication channels and a bigger workspace arise [3–4]. Mobile robot swarms have a variety of uses and benefits, but they also have significant drawbacks. These restrictions include the fact that the base station must move in order to accomplish its goals, making it distinct from some stationary base stations, the need for effective energy-saving strategies due to the robot's mobility and constantly changing topology, and the fact that the communication radius of mobile robots cannot satisfy larger workspace requirements [5,6,7]. In addition to this, routing is among the biggest challenges faced by a MANET in the absence of a fixed infrastructure. This process involves selection of a path through which the data is to be transferred by the router. However, there are a variety of alternatives to these issues now thanks to technological advancements. Unmanned aerial vehicles, which offer several benefits over other networks due to their high mobility and considerable versatility, are one of them. Obtaining node mobility models, routing protocols, and energy management, among other things, on UAVs presents a variety of difficulties [8]. The mobile ad hoc network lacks base station assistance, and the wireless medium is used as their primary communication method. The wireless servers have a finite lifetime and are powered by a battery. The deployment, replacement, and maintenance of batteries may not always be possible, making it crucial that MANET has an efficient energy management system [9-10]. The issues mobile robot swarms encounter have been addressed in a variety of ways. The clustered routing protocol, relay selection, relay placement, relay trajectory optimization, and controllable mobility aided routing are just a few of the many ways that have been suggested to address these issues. Also, utilizing the MANETS routing protocols will further improve the performance of mobile robot swarms. The next section of this paper reviews some of the latest publications of various authors for solving problems of mobile robot communication models, followed by proposed Model and its Methodology. After that, the paper discusses the results obtained for proposed model under different situations like varying packet size, BS speed, Node speed and network size and finally conclusion of paper is written down.

Literature Survey

Over the years, a number of approaches were proposed by various scholars for addressing the challenges of mobile robot communication systems. Some of these are reviewed here in this section; Ying Zhang [11], presented the LEACH relay (LEACH-R) with caching approach that assured the stability of communication links against movable base station, saving energy and even for portable robot topologies that often changed, and also aided in meeting broader workplace demands. the results showcased that suggested scheme was outperforming all existing models in terms of efficacy. Xingjuan Cai [12], Suggested a Unified Heuristic Bat Algorithm (UHBA) suggested in this paper to enhance the process of cluster head selection. The suggested model elected CHs in a way that allowed both global and local searching to be openly transformed. Ji OuYang [13], introduced RONA, a clustering decision-making framework for solving the robotics swarm decision-making issue under local interaction, wherein they included Clustering and intracluster group decision-making models. Fei-Fei Li [14], presented a path planning and smoothing technique for mobile robots that combined the enhanced artificial fish swarm algorithm with continuous segmented Bézier curves. Moreover, they also used , plausible solutions and a range of step sizes, based on Dijkstra's algorithm to tackle the low accuracy difficulties, more inflection points, and relatively lengthy routes in the standard artificial fish swarm algorithm for path planning. JY Chang [15], proposed a unique and productive data selecting path planning strategy was provided for WSNs for decreasing moving distances and extending the lifespan of the mobile sinks. They designed an inner middle path planning method and also used back-routing avoidance mechanism for reducing mobile sink moving distance and solving moving path back propagation problem. W. Wen [16], provided an energy-aware path building (EAPC) method that identifies a suitable set of data collection points, builds a data collection path, and collects data from the databurdened points. The model calculated the path cost from its current data collecting point to the next point, as well as the forwarding load of each sensor node, in order to extend the network's lifetime. C-F Cheng [17], proposed a new mobile data gathering algorithm named as, Bounded relay combine-TSP-reduce was the name of the suggested algorithm (BR-CTR) with multi-hop transmission for reduction of data gathering delay time. Y. Li, et al. [18], presented MANET cooperation based on mobile agents to facilitate cooperation between mobile robots that perform a complex task or monitor an area. Rattrout, Amjad, et al. [19], created a unique QoS-aware routing technology to improve MANET QoS performance. The authors provided research gaps which was based on a study of all new ways of improving QoS. In addition to this, they also analyzed the difficulties and an efficient QAODV routing algorithm were proposed for solving those problems. A. Junnarkar et al. [20], presented a unique clustering technique that was based on Artificial Bee Colony (ABC) to find the Cluster Head (CH) in each cluster while taking into account a set of parameters in order to calculate the proposed fitness function and handle control traffic message. From the literature survey it is analyzed that mobile robot swarm-based communication is receiving and lot of attention from researchers as it acts like the basic block in domains like searching, field communication and other. Despite the fact that working with mobile robots is a crucial activity, there seem to be a handful of challenges that must be overcome if a reliable and strong infrastructure is to be attained in the field of mobile robotics. Moreover, it was observed that most of the researchers are considering only energy factor of neighboring nodes for selecting the CH in the network. However, we analyzed that there are number of other factors that play a crucial role in selecting the appropriate and optimal CH in the network. In addition to this, some researchers have also introduced the concept of relaying, but it is not efficiently implemented in the network. Because of this the time taken by the mobile robot for making decision enhances which ultimately leads to late data transmission. Furthermore, the fact that the sink node is mobile might have an impact on the transmission of the data. Keeping these facts in mind, a new and improved method will be proposed in this research that overcomes above given short-comings.

Present Work

In order to overcome the limitations of existing mobile robot communication systems, an improved and efficient model that is based on Fuzzy Logic System (FLS) is proposed in this paper. The main objective of the proposed strategy is to reduce energy consumption of nodes so that overall lifespan of network is enhanced. Basically, the proposed approach works improves the performance of mobile robot system at two stages, i.e. CH selection and relaying data from sensor nodes to sink node. For selecting the efficient CH in the network, the proposed model employs fuzzy logic system (FLS) which takes three inputs and generates a single outcome. The three important parameters used in FLS are Communication Distance between sensor and sink node (Dcomm), Connection requests (Creq) and residual energy of nodes (Eres) of the node. These models are processed by the knowledge base module and finally a single output “prob” is generated. One of the key goals of adopting fuzzy systems is to reduce the complexity brought on by the use of straightforward mathematical models. The block diagram of the proposed Fuzzy system is given in figure 1.

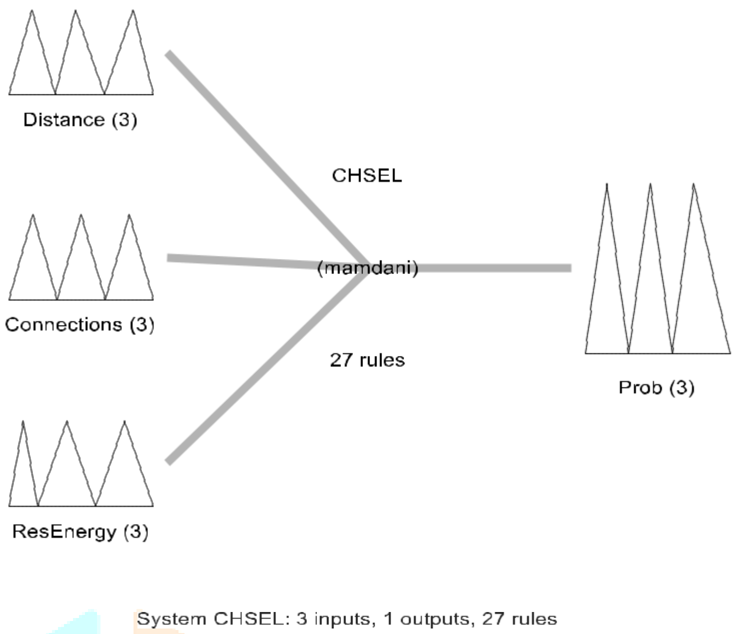
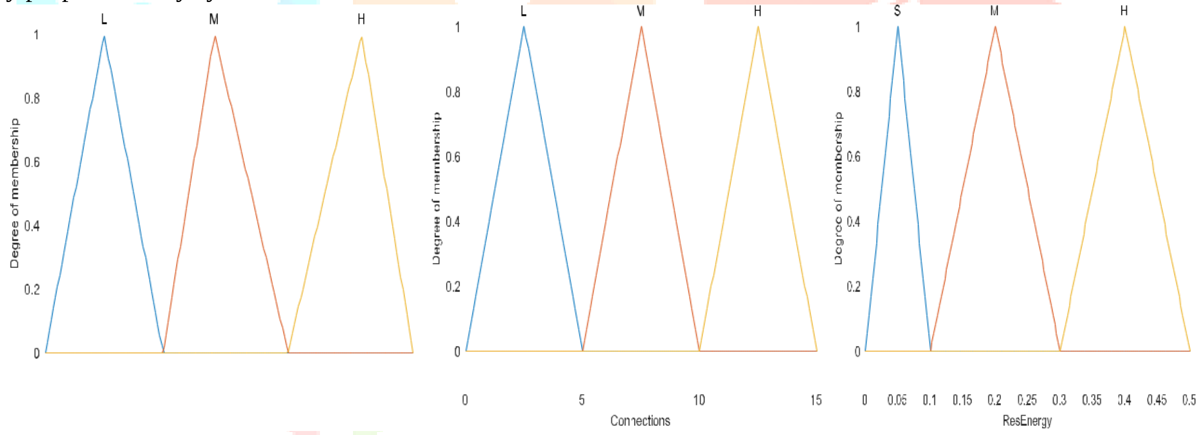


Figure 1. Proposed Fuzzy Logic System with three inputs

The above figure (figure 1) demonstrates the schematic diagram of proposed Fuzzy system in which i.e. Distance, connection and residual energy serve as three input parameters. These inputs are then processed by the Mamdani type of fuzzy system as per the 27 rules defined in it, to generate a single output "Prob" in model. Figure 2 shows the graphical representation of three inputs used by proposed fuzzy system



(a) (b) (c)

Figure 2. Three inputs of Proposed Fuzzy System

Figure 2 represents the graph for three inputs i.e. distance, connection and residual energy of nodes in (a, b & c). The distance and connection membership function have three variables of Low, medium and High whose range lies between 0 to 1 and 0 to 15 respectively. While as, residual energy function also has three variables of Small, medium and High with range 0 to 0.5. The Mamdani fuzzy system's rules analyze these three inputs, and the resultant output "Prob" calculates the possibility that a given node to become a CH. The graphical representation of the fuzzy output is depicted in figure 3.

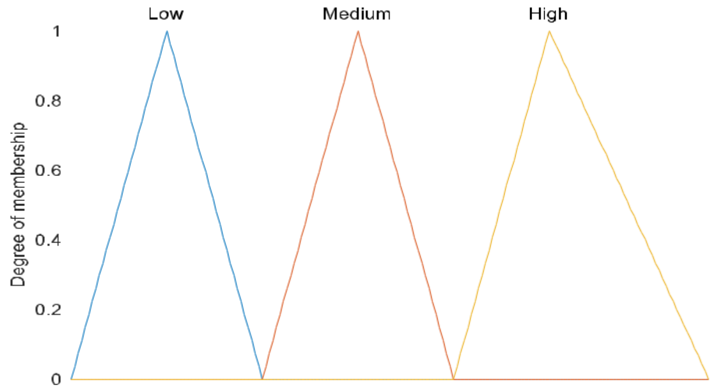


Figure 3. Output generated by proposed Fuzzy system

The output generated by the FLS depicts the probability of a node to become CH in the network and is shown in figure 3. The output function has three membership variables of Low, medium and High whose range starts from zero and ends at 1.

The relaying mechanism has been improved in the second phase of the suggested paradigm. The technique of transferring data from the sensor node to the sink node or BS is decided by the relaying procedure. In the proposed work, data is sent to the sink node via the CH node using the CH node relaying mechanism. This will make it easier for the proposed approach to choose the relaying path quickly so that the data can be delivered to the sink within its mobility step time. The detailed working of the proposed fuzzy based approach is depicted in Methodology section of the paper.

Methodology

The proposed fuzzy based mobile robot communication model undergoes through number of steps for achieving the desired results. Figure 4 depicts the flowchart of proposed fuzzy model, followed up by description of each stage.

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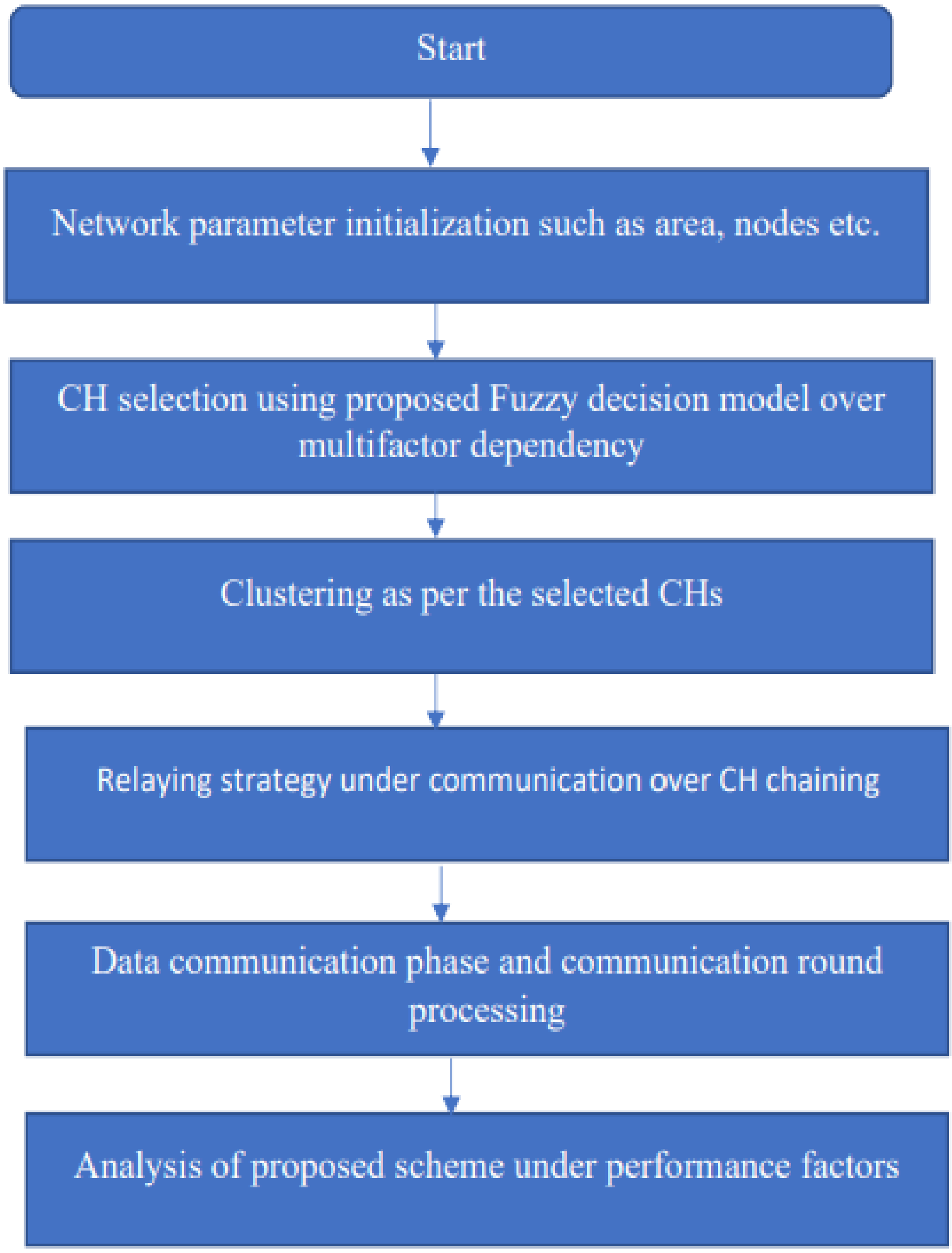

Step 1: Initially, mobile robot network is initialized in which various factors which included sensing region, nodes deployed, initial energy etc., are defined. Other than this, there are some other factors that are also defined in the network and are given in table 1.

Table 1: Network Initialization Parameters

Parameters	Values
Sensing region	$1000m^2$
Total no. of sensor nodes (N)	100
Initial Energy	0.5j
Protocol used	Wifi 802.11b
Communicating Radius	225m
Data Packet size	1500 bytes
Control packet size	300 bytes
Energy dissipation for transmitting or receiving 1-bit data	50 nJ/bit
Coefficient of energy dissipation in the free space ε	10 $pJ/bit/m^2$
Coefficient of energy dissipation in multi-path attenuation model ε	0.0013 $pJ/bit/m^4$

Step 2: After this, the nodes are deployed in the sensing region. In the proposed work, a total of 10 nodes are deployed in the sensing region and the location of BS is center.

Step 3: Once nodes are deployed in the region, the next stage is started in which CH are selected in the network. Three factors—distance, connection, and the remaining energy of a specific node— are taken into account to complete this operation. Following that, the fuzzy logic system processes these three variables in accordance with its predefined rules. The network chooses the node designated as CH whose residual energy is high, distance is short, and connections are stable.

Step 4: Once the CHs are selected in the network, it is time to form clusters in the network. For this, a particular CH is selected and distance from it to a specific node is calculated. The node whose distance to CH node is least are grouped together to form a cluster.

Step 5: Once the clusters are formed, the proposed CH chaining relaying technique is implemented that helps the nodes to easily find path for themselves for transferring the data to BS node.

Step 6: After this, communication phase starts wherein the CH nodes collect data from sensor nodes present in their cluster and sent it over to the sink node through a path defined by relaying technique in previous step

Step 7: Finally, the effectiveness of the suggested fuzzy-based strategy is evaluated for several situations, including changing packet counts, node speeds, and network sizes. The results obtained are discussed in the next section of this paper.

Results Obtained

In this section, the efficacy and effectiveness of proposed fuzzy based model is examined and validated by comparing it with conventional models in MATLAB software. The anticipated outcomes are assessed using variables such as packet deliver ratio (PDR), delay and lifetime evaluation for different packet size, BS speed, node speed, and network size under conditions of various packet sizes.

Performance Evaluation

The performance of the proposed fuzzy based approach is evaluated and later on compared with traditional LEACH-M, RoCoMAR, CORMAN, EEDDA, and LEACH-R models in terms of their PDR value with changing packet size. The comparison graph obtained for the same are shown in figure 5. After closely reviewing the graph, it is clear that the LEACH-M paradigm exhibits the worst PDR outcomes, starting with an initial PD ratio of 13 percent before falling to 12 percent at a packet size of 3000. Nevertheless, conventional RoCoMAR and CORMAN systems with maximum PDR of 20% and 30%, respectively, perform marginally better. The greatest PDR for conventional EEDDA and LEACH-R models when the packet size was 2000 and 1000, was 55 percent and 70 percent. In contrast, the proposed fuzzy model's PDR value was the best of all the systems, reaching a maximum of 92.6 percent when the packet size was 1500. Additionally, it was concluded that the proposed fuzzy model's PDR values don't fluctuate greatly because of the model's successful relaying strategy.

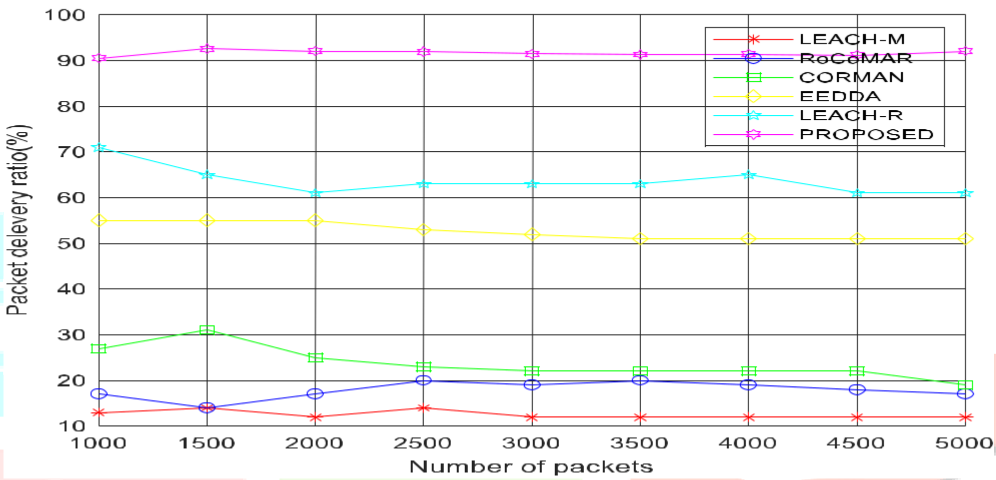

Figure 5. Comparison of PDR under changing packet size

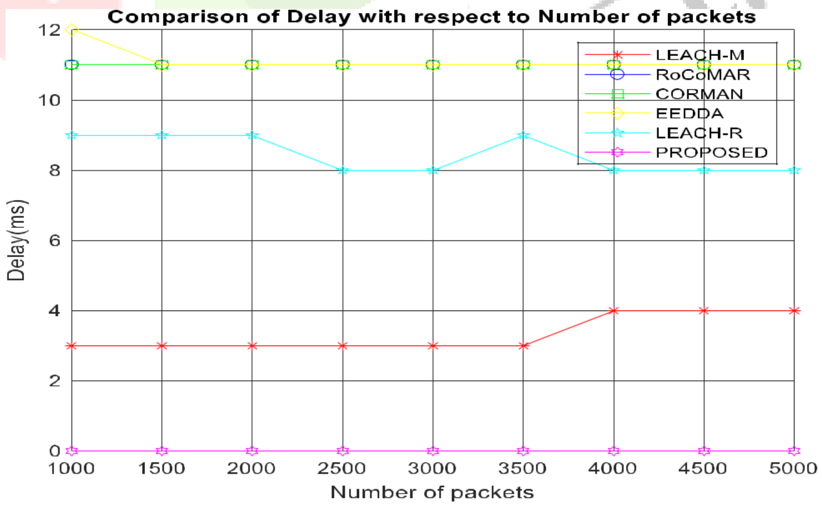

Figure 6. Delay comparison with varying packet sizes

Additionally, the efficiency of the suggested fuzzy technique under different packet sizes in terms of delay is examined and contrasted with standard methods. Figure 6 displays the comparison graph that was produced following the simulations. The simulations showed that the suggested fuzzy model's value for delay was 1.20E-05 at 1000 packet sizes, and that it continued to decrease with increasing packet sizes until it reached 7.20E-05 at 5000 packet sizes. On the other contrary, the classic EEDDA method showed the maximum delay of 12, when the packet size was 1000. The specific value obtained for PDR and delay in each model is depicted in table 2.

Table 2: Comparison values for PDR and Delay with varying packet size

Packet size	PDR value attained under varying packet size						Delay produced with varying packet size					
	LEACH-M	RoCoMARCORMANEEDDALEACH			-R	ProposedLEACH-M	LEACH-R	CORMANEEDDARoCoMARProposed				
1000	13	17	27	55	71	90.5271	3	9	11	12	11	1.20E-05
1500	14	14	31	55	65	92.6	3	9	11	11	11	7.30E-05
2000	12	17	25	55	61	92.05	3	9	11	11	11	7.20E-05
2500	14	20	23	53	63	91.92	3	8	11	11	11	7.60E-05
3000	12	19	22	52	63	91.4667	3	8	11	11	11	7.30E-05
3500	12	20	22	51	63	91.3429	3	9	11	11	11	8.00E-05
4000	12	19	22	51	65	91.425	4	8	11	11	11	7.00E-05
4500	12	18	22	51	61	91.2	4	8	11	11	11	7.40E-05
5000	12	17	19	51	61	92.05	4	8	11	11	11	7.20E-05

In addition to this, we analyzed the performance of proposed approach in terms of PDR and lifetime under changing BS speeds. The results of proposed approach are validated by comparing it with LEACH-M, RoCoMAR, CORMAN, EEDDA and LEACH-R models. The results obtained for the same are shown in Table 3.

Table 2: Comparison values for PDR and lifetime with varying BS speed

BS speed	PDR value attained under varying packet size						Lifetime with varying packet size					
	LEACH-M	RoCoMAR	CORMAN	EEDDA	LEACH-R	Propo-sed	LEACH-M	LEACH-R	CORMAN	EEDDA	RoCoMAR	Proposed
36	15.47	40.39	35.66	47.99	72.85	92.33	864	358.59	600.31	591.71	1289.6	1420
54	19.55	33.46	19.55	47.99	66.3	92.33	857.6	382.35	606.62	591.71	1310.4	1420
72	16.54	35.29	13	47.99	62.28	92.26	844.8	359.32	605.5	591.71	1414.4	1425
90	12.13	27.01	18.05	47.99	67.81	92.53	838.4	273.8	607.54	591.71	1310.4	1346
108	13.76	26.46	17.29	47.99	57.86	92.33	857.6	281.48	606.82	591.71	1305.6	1452
126	11.45	24.81	17.96	47.99	54.61	92.53	844.8	225.45	587.93	591.71	1481.6	1501
144	10.92	30.22	17.75	47.99	50.49	92.33	883.2	239.3	593.94	591.71	1427.2	1460

After closely scrutinizing the graph, it is shown that the PDR in the suggested model increases from 92.33 percent to 92.53 percent when the speed of the BS is altered from 37 km/h to 90 km/h. The PDR ratios stay the same for BS speeds of 108 km/h, 126 km/h, and 144 km/h. On the other side, we observed that conventional LEACH-M, RoCoMAR, CORMAN, and LEACH-R models' PDR values alter significantly with an increase in BS speed, whereas the standard EEDDA model's PDR value remains stable since its BS is stationary. Similarly, the lifetime evaluation values depict that the proposed fuzzy model outperforms existing models in terms of lifespan. It is evident that the proposed fuzzy model exceeds every other method currently in use in terms of lifespan. It was found that the lifetime of the presented approach can endure up to 1501 rounds at BS speeds of 126 km/h and a minimum of 1346 rounds at BS speeds of 90 km/h.

In the third scenario, the performance of the proposed fuzzy model is examined and validated by comparing it with conventional models in terms of their PDR and lifetime values under varying node speed. The results obtained for this case were depicted in table 3. The results revealed that proposed model PDR value doesn't fluctuate much and remains steady at 92.26 for most of node speed values. On contrary, when efficacy is analyzed in terms of lifetime we observed lifespan of prosed model is 1314 at a node speed of 36 km/h, rising to 1718 at a node speed of 72 km/h and 108 km/h. The lifetime of the suggested fuzzy model extends to 2028 when the node speed is raised to 144 km/h, demonstrating its applicability.

Table 3: Comparison values for PDR and lifetime with varying Node speed

Varying node speed	PDR value attained under varying packet size						Lifetime with varying packet size					
	LEACH-M	RoCoMAR	CORMAN	EEDDA	LEACH-R	Propo-sed	LEACH-M	LEACH-R	CORMAN	EEDDA	RoCoMAR	Proposed
36	15.52	44.08	14.91	52.17	69.97	92.33	889.2	411.31	620.42	772.35	1195.2	1314
54	21.72	28.13	14.82	46.95	72.89	92.26	889.6	366.37	639.59	583.7	1192	1293
72	16.54	35.29	13	47.99	62.28	92.33	844.8	359.32	605.5	591.71	1414.4	1718
90	14.97	26.9	21.74	39.02	64.74	92.33	883.2	327.21	597.83	513.54	1195	1389
108	15.1	46.01	13.47	50.45	54.36	92.33	857.6	309.78	626.72	449.62	1315.2	1718
126	19.18	31.34	19.35	44.95	67.79	92.26	838.4	264.46	589.9	387.3	1188.8	1198
144	14.92	29.66	27.34	39.74	64.81	92.33	864	235.33	570.49	408.9	1446.4	2028

Table 4: Comparison values for PDR and lifetime under different network size

Network size	PDR value attained under varying packet size						Lifetime with varying packet size					
	LEACH-M	RoCoMAR	CORMAN	EEDDA	LEACH-R	Propo-sed	LEACH-M	LEACH-R	CORMAN	EEDDA	RoCoMAR	Proposed
800*800	22.63	51.84	28.4	64.13	65.5	92.06	947.2	323.32	610.1	920.3	1294.4	1547
900*900	19.74	44.9	13.58	62.6	63.87	92.4	915.59	421.6	599.85	915.59	1361.6	1878
1000*1000	16.54	35.29	13	47.99	62.28	92.06	844.8	359.32	605.5	591.71	1414.4	1854
1100*1100	14.76	20.99	13.31	53.87	62.88	92.66	864	365.83	674.84	877.8	1216	1361
1200*1200	11.87	16.73	7.09	33.75	60.2	92.53	832	280.37	702.1	641.64	1457.6	1720

Last but not least, we compared the effectiveness of the suggested and conventional models in terms of PDR and lifetime values again, but this time we altered the network size. Table 4 displays the comparison resulting values obtained for each model. The results obtained showed that proposed model achieved highest PDR value of 92.66 when network size is 1100*1100, whereas, its PDR value came out to be least at 92.06% when network size is 900*900 and 800*800. On the other hand, we also analyzed that the highest PDR value in standard LEACH-M, RoCoMAR, CORMAN, EEDDA and LEACH-R models when network size was 800*800 and least PDR value was achieved when network size was 1200*1200 respectively. Likewise, the suggested fuzzy model clearly outperforms all other known models in terms of longevity, with a minimum lifespan of 1360 at a network size of 1100*1100 and a maximum lifespan of 1878 at a network size of 900*900, respectively.

From the above graphs and tables, it can be concluded that proposed fuzzy based mobile robot swarm method is generating more promising and effective results under all four scenarios to prove its superiority and dominancy over traditional approaches.

Conclusion

In this paper, an effective and efficient Fuzzy Logic based mobile robot swarm communication approach is presented. The productivity and usefulness of the suggested scheme is examined and analyzed in the MATLAB software under changing packet size, BS speed, Node speed and network size. The simulated results were attained in terms of Packet deliver Ratio (PDR) and lifetime evaluation. The results revealed that PDR value was highest at 92.6% when we varied data packet size. Additionally, in the second scenario with BS speeds ranging from 36 km/h to 9 km/h, the PDR value was achieved at 92.33 percent and 92.53 percent, correspondingly, while lifetime in the suggested model was found to be maximum at 126 km/h. The effectiveness of the suggested approach is further tested with varying node speeds, with PDR and Lifetime values showing 92.33 percent at various node speeds of 36 km/h, 72 km/h, 90 km/h, 108 km/h, and 144 km/h, respectively. While as, the network lifespan was increased from 1314 to 1718 when node speed was shifted from 36km/h to 72km/h, while as it came out to be 2028 at 144km/h. In addition to this, we also analyzed that proposed fuzzy model was attaining much better results in terms of PDR and network lifespan when network size was varying. These stats prove the efficacy and effectiveness of suggested fuzzy based mobile robot communication approach under all four scenarios.

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