# Authentication Function Optimization in Mobile AD-HOC Network

**Thesis**

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Degree of Doctor of Philosophy
Computer Science and Engineering
By

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# Declaration by the Scholar

I hereby declare that the work presented in this thesis entitled "**Authentication Function optimization in mobile AD-HOC Network**" in fulfillment of the requirements for the award of Degree of Doctor of Philosophy, submitted in the Maharishi School of **Engineering & Technology**, Maharishi University of Information Technology, Lucknow is an authentic record of my own research work carried out under the supervision of **Dr. Vaishali Singh** and co-supervision of **Dr. B.D.K. Patro** and **Dr. Himanshu Pandey**. I also declare that the work embodied in the present thesis-

i) is my original work and has not been copied from any journal/ thesis/ book; and

ii) has not been submitted by me for any other Degree or Diploma of any University/ Institution.

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## Supervisor's Certificate

This is to certify that **Ms. Pragya Kabra** has completed the necessary academic turn and the swirl presented by her is a faithful record is a bonafide original work under my guidance and supervision. She has worked on the topic "**Authentication Function optimization in mobile AD-HOC Network**" under the School of **Engineering & Technology**, Maharishi University of Information Technology, Lucknow.

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# ABSTRACT

Ad hoc Networks are a form of wireless network that is decentralized. Ad hoc networks, unlike wired networks, do not need pre-existing infrastructure.

Mobile Ad hoc Networks (MANETs) are composed of mobile devices that are capable of self- configuration and self-healing to form complex networks of mobile nodes. Each system in such networks communicates with another through peer-to-peer communication. Due to these characteristics, MANETs are often referred to as "on-the-fly" networks and have applications ranging from Army tactical MANETs to commonly used mobile phone Ad hoc networks. Minimal setup and rapid deployment are credited with the creation of MANETs as an effective network for situations involving emergency operations, such as those encountered during natural disasters or military operations. Routing protocols' complex existence often aids in the rapid establishment of ad hoc networks. The proliferation of smartphones, mobile phones, and standards such as 802.11 over the last decade has also fueled research in the field of MANETs. “Authentication Function Optimization in Mobile Ad - Hoc Networks.”

Considering the above, the following goals were identified:

Create a cumulative metric for testing MANET protocols.

Create parameters for node selection and apply them using fuzzy logic.

To implement an energy-efficient technique that prevents the same node from being used repeatedly as an intermediate node. This will help prevent the node from failing due to a lack of energy.

Utilize Ant Colony Optimization to develop an effective routing algorithm for exploring multiple paths between nodes in a Mobile Ad hoc network.

Thus, by considering all of the above, an effective protocol can be built. The trade-off in this process is that to minimize the path length between the source and destination, an effort has been made to use the same route between any two nodes for the transmission of distinct data packets. This type of repeated use of the nodes will deplete their energy reserves. As a result, energy is a significant constraint in Ad hoc networks that must be addressed.

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# LISTOFABBREVIATIONS

| Abbreviation | Description |
|---|---|
| MANETs | Mobile Ad hoc Networks |
| DSR | Dynamic Source Routing Protocol |
| DSDV | Destination Sequenced Distance Vector Routing |
| AODV | Ad hoc On- Demand Distance Vector Routing Protocol |
| AOMDV | Ad-hoc On-Demand Multi-Path Distance Vector |
| PDR | Packet Delivery Ratio |
| CI | Computational Intelligence |
| ANN | Artificial neural networks |
| ACO | Ant Colony Optimization |

# CHAPTER-1

# INTRODUCTION

Ad hoc Networks [**1**] are decentralized form of wireless networks. The pre- existing infrastructure is not indispensable to the Ad hoc networks like wired networks.

The Mobile Ad hoc Networks (MANETs) consist of mobile devices having the properties to self-configure and self-heal for the formation of dynamic networks of mobile nodes. Each device in such networks uses a peer-to-peer communication. Due to these properties, the MANETs are sometimes known as „on the fly" networks and find their applicability in variety of fields ranging from Army tactical MANETs [**2**] to widely used smart phone Ad hoc networks. The features like minimal configuration and quick deployment are attributed towards development of MANETs as an appropriate network for situation requiring emergency operations as is observed in natural disasters or military operations. The dynamic nature of routing protocols also helps in quick establishment of Ad hoc networks. The growth of laptops, smart phones and the standards like 802.11 in the last decade has also been the motivating factors toward research in the field of MANETs. [**2**]

Routing is the process of selecting a path for transmitting data packets with in a network. In general, routing is the process to identify the best or optimal path in a network. The process for selection of suitable routing protocol is controlled by a number of parameters such as hop count, overhead and delays involved. The focus of present thesis is on optimizing the routing mechanism in MANETs. While optimizing a routing mechanism, it is required to give a due consideration to the following issues:

- Various factors related to routing in MANETs.
- The type of routing.
- The technique to be used for making routing decisions.
- The way for information management in the network.

The rest of the chapter focuses on these areas leading to the problem formulation and the objective of the work carried out.

## 1.1 FACTORS AFFECTING ROUTING IN MANETs

The MANETs being the dynamic networks are affected by a number of factors. If two nodes are trying to communicate with each other and are located very close to each other, then there is no significant difference between different routing strategies. On the other hand, if the number of mobile nodes is more than two, then the decision regarding selection of route becomes critical. The decision regarding using any particular route from source to destination depends upon various parameters of mobile nodes. For example, the energy consumption is one such parameter. Moreover, it is also desirable to select a route with minimal delay and hop count along with least energy consumption. In addition to delay, each transmission, reception and processing of packets also consume energy.

The factors which affect the selection of a protocol for MANETs are as follows [**3**] [**4**]:

- **Multicast**: The ability to transmit the data packets to multiple nodes at a time is multicasting.

- **Loop Freedom**: Bandwidth is an important resource in MANETs. Thus, preventing transmission of packets through same node twice before it reaches the destined node becomes important.

- **Unidirectional link support**: In addition to the use of bidirectional links, unidirectional links are also required to be used effectively to improve the performance of routing protocol.

- **Multiple routes**: Multiple routes assure the availability of route even if one route gets stale due to some problem. Thus, protocols with multiple routes are more robust to link failures.

  **(a) Distributed Operation**: The distribution of operations helps in decentralization of control. The decentralization is desirable in the sense that it reduces the dependency on a single node thereby reducing chances of single point of failure.

  **(b) Reactive or Proactive**: In Reactive protocols, the routes are discovered between the nodes only when the requirement for a route to a particular node arises. In contrast to the reactive routing protocols, proactive protocols maintain routes to various nodes without waiting for their requirements.

**(c) Power Conservation**: Energy is an important resource in the MANETs. The nodes are mobile and hence the level of Energy in the mobile node decides the participation of a particular node in the network.

**(d) Security:** The radio environment is always vulnerable to security breaches. Thus preventing any such unwanted behavior is very important in these networks.

**(e) Quality of service support:** The quality of services offered by a protocol is related to the application for which the network will be used.

## 1.2 ROUTING PROTOCOL STRATEGIES

The Dynamic nature of MANETs is responsible for introducing lots of challenges in the process of designing protocols for such networks. Considerable amount of research in this area have resulted in the development of various strategies.

These Ad hoc routing strategies can be categorized as table driven or proactive routing strategies, demand-driven or reactive strategies and hybrid strategies. The hybrid strategies have been developed to use the best features from both strategies i.e. table driven as well as the reactive strategies.

### 1.2.1 Proactive strategies [5]

In proactive routing strategies, a node maintains complete routing information about all the nodes available in the network. Thus, delays involved due to the process of discovery of routes are minimized due to availability of the route. However, in an environment with high mobility, the proactive strategies consume large amount of bandwidth due to larger communication overhead.

The beacons messages are used for maintaining the updated information about different nodes in the network. Destination Sequenced Distance Vector (DSDV) routing protocol is an important example of this strategy.

### 1.2.2 Reactive strategies [6]

In reactive routing strategies, nodes are required to find the route, as and when there is a requirement for a route to the destination arises. The communication overhead involved in the proactive strategies due to the presence of beacon messages has been reduced at the cost of delays introduced by the process of route discovery. These strategies also contribute towards the energy conservation by preventing the exchange of beacons. The Dynamic Source Routing Protocol (DSR) and Ad hoc On-Demand Distance Vector Routing Protocol (AODV) are prime examples of reactive strategies.

### 1.2.3 Hybrid strategies [7]

The hybrid routing strategies are aimed at utilizing the best features of both proactive and the reactive routing protocols. Both proactive and reactive routing strategies have their own advantages and limitations. Thus, an optimum combination of both can be used for the large and scalable networks due to the need of partitioning the network. Example of Hybrid routing strategy includes Zone Routing Protocol (ZRP).

## 1.3 METRICs FOR EVALUATION

The measurement is always important to carry the qualitative analysis of any product. The process of measuring the performances of routing protocols in MANETs is done on the basis of following metrics [**8**]:

- **Packet Delivery Ratio** (**PDR**): It is the ratio of the number of data packets reaching some destined node to the number of data packets that were originated from the source. Higher PDR signifies better quality of routing strategy.

- **Throughput:** Throughput refers to the number of bits successfully received at the destination. It is measured in kilobits per second (Kbps).

- **End-to-End delay:** This refers to the average amount of time elapsed in successfully transmitting the data packets comprising the message across the network i.e. between any pair of nodes.

- **Average Energy Consumption**: Energy or the battery life is an important resource in mobile networks. The energy is consumed for each transmission and reception of packets. The average energy consumption is the average amount of energy consumed by each node of the network.

## 1.4 UNIPATH ROUTING MECHANISM

The routing protocols in MANETs may use either unipath routing or multipath routing. The Unipath routing protocols use single path from source to destination. Examples of unipath routing protocols include DSDV [**5**], DSR [**9**] and AODV [**10**]. This section describes the basic functioning of all these protocols.

### 1.4.1 DSDV

DSDV [**5**] is a hop-by-hop distance vector routing protocol. The basic feature of this routing protocol is that, at each node a routing table is maintained for all reachable nodes. The nodes are also responsible for maintaining information such as next hop for transmitting the data as well as the number of hops required to reach a particular destination. The key feature of DSDV over other distance vector protocols is the capability to provide loop free paths. This loop freedom is attributed to the use of sequence numbers. The sequence number also relates to the freshness of the route. Higher sequence number represents a more favorable route than the route with lower sequence number.

The DSDV maintains an updated record of topological changes by the use of regular update messages. To control the information content of these updates, two ways have been specified to transmit the messages. The comprehensive update message comprising of all the fields in the table is known as full dump and information comprising of the fields in the table that has gone through the change since last full dump is known as incremental dump.

DSDV is dependent upon the periodic messages or broadcasts to maintain updated routing information. In MANETs, the topology is dynamic in nature and thus periodic broadcasts also contribute towards a larger overhead in the network.

### 1.4.2 DSR

Dynamic Source Routing [**11**] uses a reactive strategy. Source routing is a distinguished feature of DSR. In source routing, each packet header maintains a sequential list of nodes through which the data packets must be transmitted between any pair of nodes. Thus, unlike DSDV, intermediate nodes are not required to be aware about the information related to topological changes. Hence, no periodic update messages are required. This also contributes toward the energy conservation in the network as substantial amount of energy can be conserved due to the absence of the periodic update messages. Moreover, the overhead is also controlled due to the absence of periodical updates. The DSR works in two phases i.e. route discovery and route maintenance.

A node initiates the Route discovery process by broadcasting route request messages consisting of the desired destination node. The DSR maintains all the routes in the route caches of nodes. Every node receiving the route request searches its cache for finding the possible route to the desired node. In case of absence of such route, request packet is forwarded from the current node after appending its address to it. This packet moves through the network till it reaches the destination or some destination aware node. In case of successful reception of request packet by the node, the route reply packet is generated and is sent back towards the source node along the reverse path of the route request packet by using the information stored in the packet.

The Route maintenance phase uses the route error packets. These packets are destined towards the source from the node that detects the problem. On receiving the route error message, the erroneous node is deleted from the route cache and all routes with this node are also truncated.

The major limitation with this protocol is the absence of mechanism for repairing of a damaged link in route maintenance phase. Moreover, an inconsistency in the information stored in the route caches is also an area of concern. Other limitations include delay due to route discovery and route setup phase, degradation in performance in high mobility environment, and routing overhead due to the use of source routing.

### 1.4.3 AODV

AODV [**10**] is a distance vector-based protocol like DSDV. The major difference amongst these two protocols is in the type of routing strategy. AODV utilizes a reactive strategy in comparison to Proactive strategy of DSDV. The route in AODV is requested only when there is a need for such route. The nodes that are not participating in the communication are free from maintaining information to destination node. The AODV maintains the destination sequence numbers. AODV also has route discovery phase that is followed by a maintenance phase.

The Route Discovery is initiated at the source as and when the requirement of route to some particular node arises. In such a case, the node firstly checks its own routing table. In case of absence of the route or the presence of an expired route in the routing table, route request messages are broadcasted to all neighbors. The route request propagates through the various nodes in the network till it reaches the destination or a node with latest route to the desired node. After reaching such a node, a route reply message is sent back to the source node. The hello messages are exchanged periodically among the neighboring nodes to assure the presence of node in the neighborhood.

The information for maintaining an updated routing table includes:

- Destination node IP address
- Destination Sequence number
- Number of required Hops for reaching some destination i.e. Hop Count
- Next Hop Address.
- Life time or the validity period for any route
- List of active neighbors
- Request buffer.

In Route maintenance phase, a node on detecting a broken link to a neighbor removes the entry corresponding to that link and a route error message is propagated towards every source node using that link. Each intermediate node receiving this message deletes the route entry corresponding to the stale link and then message is forwarded to the next node towards the source. This process is repeated by every node receiving the message till the route error message reaches the source node. The source node then reinitiates the route discovery on the basis of its requirement.

AODV uses a combination of distance vector along with a reactive approach and succeeds in reducing the number of routing messages. However, a single route is maintained corresponding to each destination. This single route may become invalid with the time. In such a case, the protocol will initiate a new route request. This situation can be easily avoided by the use of multiple routes for each destination.

## 1.5 MULTIPATH ROUTING IN MANETs: ISSUES AND CHALLENGES

Traditionally, the routing protocols in wireless Ad hoc networks such as MANETs were limited to single path between any pair of nodes. Multipath Routing [**12**] consists of finding the multiple number of routes amongst a pair of nodes. These multiple routes can be used to control the uncertainties associated with Mobile Ad hoc Networks due to dynamic nature of the network topology.

The multiple routes so discovered can add variety of features to the process of routing. Some of the features include load balancing, fault tolerance and higher bandwidth utilization. For achieving load balancing, the traffic can be distributed among multiple routes and hence also leading to the effective use of network resources. Since the bandwidth is a limited resource in MANETs, the routing along a single path may not provide enough bandwidth for a connection. Moreover, the throughput achievable in case of multipath routing protocols is also much better as compared to unipath routing protocols.

The Multipath routing consists of mainly three components [**12**]:

- Route Discovery Mechanism
- Route Maintenance Mechanism
- Traffic Allocation Mechanism

The purpose of using Route discovery mechanism and the maintenance mechanisms is same as in the unipath routing protocols. The distinguishing feature of multipath routing protocol is the use of traffic allocation mechanism. Once a source has discovered a number of paths to any other node, it can begin the process of sending the data along these paths. The traffic allocation strategy deals with the process of distributing the data amongst the various available routes.

## 1.6 MOTIVATING FACTORS FOR MULTIPATH ROUTING IN MANETs

The traditional routing protocols were mainly based on the use of single path and hence are unipath routing protocols. Examples are, DSR, AODV etc. These routing protocols select best route for transmission of data from source to the destination. The route selected is usually the shortest one among various other possible routes. Some limitations of using these protocols are slow convergence rate, congestion along a single route and link failures. These protocols consider the shortest route as the only criteria. The other important factor that needs to be considered in the MANETs is Energy. The Battery or the energy available at each node is limited. The Energy is consumed for every packet that is received, processed and transmitted by the node. In case of unipath routing, only one route is used repeatedly and hence the energy of the nodes along that particular route depletes with time. This kind of depletion in the energy level of the nodes along a particular route may lead to failure of the nodes i.e. the link failures.

Thus, multipath routing definitely extends the benefit of having multiple routes in case of link failure. Moreover, it also prevents the node or the link failure by preventing over utilization of a route. Delays occurring due to link failure and process of discovering new route in case of failure can also be controlled by using multipath routing protocols.

Traditional approaches based on multipath routing have produced good results. But, in order to regulate the use of different paths in such protocols to increase the efficiency of such routing protocols, the computational intelligence can be used along with multipath routing.

A brief overview of the concept of computational intelligence along with the techniques is discussed as follows.

## 1.7 COMPUTATIONAL INTELLIGENCE

**Computational Intelligence (CI) or Soft Computing** comprises a number of natures inspired computational techniques, which can be used for problem solving in complex, uncertain and stochastic real world problems and are unsolvable by traditional approaches [**13**] [**14**]. Computational intelligence mainly uses approximate calculations for providing near optimal solutions for complex problems. This technique is mainly used to provide solution for the problems that either consume more time to solve with hard computation or are unsolvable. Computational Intelligence is an extension of natural heuristics and it does not require strict mathematical distinctions and definitions. Hence it is capable of dealing with complex systems. In order to attain solution with minimal cost, robustness and tractability, computational intelligence is tolerant to uncertainty, imprecision and partial truth. In fact, the main role model of computational intelligence is natural and artificial ideas. Solutions obtained by soft computing techniques are not very strict, but they usually provide more efficient and effective near optimal solution. The methods that mainly constitute CI are as follows:

- Fuzzy logic techniques that can be used to deal with uncertainties.
- Artificial neural networks add the data learning capability, thus operating like the biological one.
- Evolutionary computing incorporates the phenomena of natural selection.
- Based on the prior knowledge, Probabilistic reasoning techniques use logic and probability concepts to provide feasible solution to a reasoning problem.
- Learning theory techniques work on experience and acquired knowledge for providing solutions.

### 1.7.1 Fuzzy Logic

Fuzzy logic is a generalized form of Boolean logic that was presented by Zadeh [**15**]. The important feature of Fuzzy logic is that it can be used to deal with the varying number of situations beside true or false, for example, partially true or partially false. These logics are most suitable for uncertain situations. In such situations, it is usually difficult to predict about the sequence of events. So, Fuzzy logic can be considered as a good technique to deal with random uncertainties. In MANETs, because of limitations associated with infrastructure and high mobility of the nodes, wireless links are more likely to get stale. Hence, routing in MANETs is a critical task as a result of extremely dynamic environment. Therefore, Fuzzy logic can be applied to manage the routing policies and to achieve Quality of service. In case of MANETs, degree of membership function can be mapped to various parameters like bandwidth, mobility, signal power and packet forwarding ratio (PFR) for providing due consideration to each factor.

### 1.7.2 Artificial Neural Network

Artificial neural networks (ANN) [**16**] have been developed as an inspiration from biological neural networks. Like the human brain neurons, ANNs also consist of artificial neurons. The neural network is a system that comprises of different machine learning algorithms to work in a coherent way to deal with complex inputs. The important feature of this type of networks is the process of learning. These systems do not work on predefined set of rules. Instead, they rely on the process of learning to perform any task. The artificial neurons, just like the biological counterparts, are capable of passing the signal from one neuron to another. An artificial neuron after receiving the input signal is required to firstly process it and then pass it to other connected neurons. The development of ANNs was mainly inspired with an idea to deal with complex problems in a similar way as is done by the human mind. Today, ANNs find their application in various fields and tasks, i.e. computerized vision, system identification, pattern recognition, facial recognition, machine translation, data filtering, gaming, diagnosis of complex medical conditions such as cancer and even in the areas that were traditionally limited to human beings such as painting etc.

### 1.7.3 Evolutionary Computation

Evolutionary computation (EC) [**14**] is based on the evolutionary concepts like survival of fittest, theory of natural selection and reproduction. Most commonly used evolutionary algorithm is Genetic Algorithm. Others include Swarm intelligence, Ant Colony Optimization and Particle swarm intelligence. A brief about these algorithms is as follows:

#### (a) Genetic Algorithm (GA)

GA proposed by Holland [**17**] is an optimization technique that performs the global search based on the concept of natural selection and genetics [**18**]. GA works on strings of fixed length comprising the population. These strings are similar to chromosomes in case of genetics. Chromosomes are the combination of genes. Each gene has an associated value known as allele. Each chromosome is evaluated on the basis of a fitness value calculated by using the fitness function. The basic operations performed in a genetic algorithm are: Initialization, Selection, Reproduction and Replacement of initial population with offspring‟s. Firstly, a suitable encoding scheme is used for encoding the initial population. Then selection operator is applied to the initial population to select individual for further processing. In the next step, selected individual is used to perform the reproduction operation. The last step involves the replacement process. In this process, the existing individuals are replaced with newly produced individuals. The process is repeated for a fixed number of generations.

**(b) Swarm Intelligence**

Swarm Intelligence [**19**] proposed by Beni and Wang in 1989 is the study of combined behavior of decentralized, self-organizing natural systems. Swarm intelligence generally consists of a number of individual agents involved in an interaction with each other and also with the environment. The individual agents in such systems are required to be controlled by a set of rules without the presence of any controlling center to guide the movement. This interaction of these agents leads to the intelligent formations to which these agents are unaware. Most commonly observed examples of Swarm intelligence are Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO).

**(c) Ant Colony Optimization**

Ant Colony Algorithms [**20**] are based on the natural foraging behavior of ants. Real ants usually exploit the pheromones information to search the minimal path from their present location to the food without the aid of any visible queues. During movement, ants' secrets biological chemical known as pheromone and follow the path based on the pheromone secreted by another ant. As shorter path is travelled faster by the ants, so pheromone deposit on that path will be more. After a period of time, the difference in the amount of pheromone on both the paths is adequately large and is substantial to guide the new ants entering the system. The new ants will most likely follow the path with larger amount of pheromone. As a result of this, all subsequent ants will be using this path.

**(a) Particle Swarm Optimization:**

PSO proposed by Eberhart and Kennedy [**21**] is an evolutionary technique that uses swarm intelligence. This approach is focused on obtaining a global search solution by using a number of individual particles in parallel that investigate their local search space. Position of each particle can be mapped to a local or a candidate solution. PSO uses both the globally optimum solution as well as the local or candidate solution corresponding to each particle within its search space. Although, the movement of each individual particle is carried out as per the local solution, but this movement is also influenced by the discovery of other best solution i.e. as and when such solution is updated by other particles. The important features of PSO include its easy understandability and implementation. Moreover, it can also be applied to solve other optimization problems such as in neural network training.

### 1.7.4 Probabilistic Methods

The probabilistic method [**22**] by Paul Erdos, uses a non-constructive approach, mainly applied in combinatorics to prove the existence of a combinatorial object with certain properties. It demonstrates that if someone randomly selects objects from a given class, then the probability of selecting an element with desired properties is more than zero. The probabilistic approach has been strikingly successful in various areas including Graph Theory, Combinatorial Number Theory, Optimization, Theoretical Computer Science and Information Theory.

### 1.7.5 Learning Theory

Learning theory is a subfield of Artificial Intelligence. It is a way to develop the reasoning similar to human beings. According to Psychology, learning is the process to utilize the cognitive thinking, emotions, environmental effect and past experiences to modify knowledgebase, skill set and values [**14**]. On the basis of the acquired knowledge, learning theories help in making predictions or decisions.

## 1.8 PROBLEM FORMULATION

### 1.8.1 Computational Intelligence in Network Routing

In recent years, computational intelligence has also seen a substantial growth in the field of MANETs. Solution to various complex problems, such as selecting the route by using more than one parameter for determining the optimum route and controlling the network while not allowing the overhead to increase, can be attained by using computational intelligence techniques. The other major issue with the MANETs is that it needs constant updating of various parameters stored on the mobile nodes so as to achieve dynamic routes in the networks. Different computational intelligence techniques have been used to optimize Ad hoc routing related problems, yet ACO in combination with Fuzzy logic have been perceived as one of the most appropriate techniques for exploring multipath routing. A fair number of research contributions in the direction of ACO based routing have been figured out in literature with diverse perspectives [**20**] [**23**]. Fuzzy logic helps in dealing with the uncertainties and hence is an appropriate tool to deal with the different parameters in the process of route selection by correctly assigning the membership to different parameters. Thus, Fuzzy logic can help in developing the selection criteria for selecting the optimum path to the destination on the basis of various important parameters. In Ant Colony based routing algorithms, a set of artificial ants start exploration from a source to the destination. While exploring, they develop solutions and update the problem by utilizing the collected information and thus finding the optimum solution. The ACO approach, by using the nature inspired learning behavior, and also considering the environment factor by incorporating the evaporation phenomena in the network, brings dynamism in the parameters of the MANETs. An important ACO based approach, AntHocNet [**24**] algorithm, utilizes only the hop time to decide the best route for selecting the route, while utilizing pheromone updating mechanisms to constantly update the probabilities of the route selection of various routes.

### 1.8.2 Traditional Routing Mechanism Vs ACO Approach

- Traditional routing protocols in case of MANETs were focused only on finding the path with shortest hop length or the hop time. There are a number of different parameters that need to be considered while deciding the optimum route. The topologies in the MANETs are dynamic and hence the need of a nature inspired technique increases. A nature inspired technique such as ACO can sense the topology of the network and based on the various sensed parameters, can update the pheromone content and hence the probability of particular route selection.

- Traditional protocols did not focus on the parameters like energy. Energy being the limited resource needs a focused approach, which can incorporate it as a parameter in controlling the network. ACO approach by introducing it as a parameter in the phenomena like evaporation can be healthy in increasing the life of the network.

- ACO can help in developing the topology aware dynamic network and unlike traditional protocols, can also prevent the over utilization of single route.

Thus, an optimum utilization of nature inspired technique such as ACO can prove to be beneficial in finding the solution to the complexities of Ad hoc networks.

## 1.9 OBJECTIVES

Keeping in view the above considerations, following objectives were perceived:

- Design a cumulative metric for evaluating protocols in MANETs.
- Design node selection criteria and implement it using Fuzzy logic.
- To introduce an energy efficient strategy that can prevent the repeated use of same node as an intermediate node. This can prevent the node failure due to limited energy.
- Design an efficient routing algorithm for exploring multiple paths between nodes in a Mobile Ad hoc network using Ant Colony Optimiza th5yuiotion.

Thus, by taking all of the above points into consideration, an efficient protocol can be designed. However, the tradeoff involved in this process is that, in order to reduce the route length between the source and the destination, attempt has been made to use same route between any two nodes for the transmission of different data packets. This kind of repeated use of the nodes can decrease the energy levels of those nodes. Hence energy is one of the important constraints in Ad hoc networks which needs to be dealt with.

The complex and challenging issue of multipath routing in Ad hoc networks is the thrust of the research study. This thesis comprehends the following contributions:

- **Identification of multiple paths** from a source to a destination following ACO Approach
- **Implementing the designed node selection criteria using Fuzzy logic** through Fuzzy rules and the membership function
- **Predicting the Energy state of Ad hoc network to prevent node failure** and thus developing an intelligent network.
- **Formulating an adaptive load balancing criteria for optimal use of multiple paths.**

In particular, a significant contribution has been made in formulating an efficient and intelligent approach for exploring and exploiting multipath routing in an Ad hoc network using ACO and Fuzzy logic.

## 1.10 ADOPTED METHODOLOGY

The following track has been accorded to accomplish the objectives: -

- A detailed investigation of the traditional routing protocols and the performance metrics.
- A detailed investigation of pertinent literature related to multipath routing.
- A detailed investigation of literature related to the application of nature inspired learning i.e. Ant Colony Optimization and Fuzzy logic to multipath routing.
- Designing a cumulative metric and analyzing its efficiency using NS2.
- Realization of multiple paths in a network adopting proficiencies of Ant Colony Optimization approach.
- Implementation of the conceived approach using NS2.

The Fuzzy logic methodology is implemented using MATLAB Fuzzy logic toolbox as follows:

- Fuzzification of crisp values using membership function and linguistic variable into Fuzzy input.
- Computation of Fuzzy output using Fuzzy rule base.
- Defuzzification of Fuzzy output into crisp values.

Fuzzy based control methodology has been adopted to deal with the uncertainties and high variability of parameters affecting the performance of a network. Hence, overall network performance is anticipated to improve. The selection of the Fuzzy logic approach rationalizes on its simplicity and cogent inference rules leading to a robust routing methodology. It can be modified and tweaked easily to improve the performance.

## 1.11 LAYOUT OF THE THESIS

The thesis consists of nine chapters inclusive of **chapter 1** that provides a rationale for the work carried out. Starting with an introduction to routing and its types, multipath routing and computational intelligence, the chapter concludes on the problem formulation and objectives of the thesis.

**Chapter 2** focuses on relevant literature survey related to multipath routing. It introduces the motives behind multipath routing as well as its design issues. The survey is supported by observations and inferences that have given directives to the problem formulation for the proposed work.

**Chapter 3** delineates literature survey in the context of Ant Colony Optimization as well as its variants. Literature related to various protocols in Mobile Ad hoc Network i.e. ACO- AOMDV, ABEAR, ANTHOCNET etc. have been outlined. The chapter concludes with the cognition of the reviews and the motivations derived from them.

**Chapter 4** describes the concept of Fuzzy logic and its associated notions required to model an application system. Fuzzy logic has been used in the present work for implementing the node selection criteria. Literature related to the use of Fuzzy logic in routing has also been outlined in the chapter.

**Chapter 5** explores the different areas for exploitation in Mobile Ad hoc Networks. For this purpose, a new cumulative metric has been designed.

Further, various existing multipath and unipath routing protocols have been compared using this metric. The analysis proves the scope of work that can be done in the field of energy.

**Chapter 6** presents the node selection criterion that has been designed for selection of next node on the basis of various factors. Further this criterion has been implemented using the Fuzzy logic tool of MATLAB.

A multipath routing strategy referred as Ant Colony Based Energy Efficient Multipath Routing (ACBEEMR) has been proposed in

**Chapter7**. The design of the algorithm along with data structures is delineated in the chapter along with an illustration of the functionality of the strategy on an example network.

**Chapter 8** presents the implementation of ACBEEMR and its variants in NS2. The results are interpreted for verification of the correctness of the strategy.

**Chapter 9** is a compilation of conclusion. The scope for further investigation is also summarized in this chapter.

# CHAPTER 2

## A REVIEW OF THE LITERATURE ON MULTIPATH ROUTING

In the field of routing, multipath routing has been implemented in a variety of ways. An example of multipath routing applied in classic circuit switched telephone networks is an alternative path- based technique. There are a variety of alternate routes between any two nodes that can be discovered using alternate path routing. The alternate path strategy selects an alternate way from the collection of possible options in the event that the shortest route is unavailable.

The introduction of quality-of-service support can be linked to multipath routing. The best path can be followed until it reaches its final destination. After then, you can take any of the alternate routes. Since its inception, it has only been used in connection-oriented networks. Congestion control in packet-oriented networks can also be achieved by employing this technique.

MANETs had traditionally used unipath routing protocols, which only allowed for the discovery of a single path between two nodes, as their standard operating procedure. Continuous mobility of nodes may lead to the formation of stale routes in MANETs. The Multipath technique, on the other hand, seeks to find many pathways between any two nodes. The stale route problem can be efficiently addressed by the Multipath strategy, which makes use of many paths to connect two nodes. When a route fails, data can be transmitted via any of the other accessible routes. It is thus possible to manage the dynamism and unpredictability of MANETs by employing numerous pathways.

According to numerous parameters, the performance of MANET protocols can be affected by a variety of factors such as scalability and network speeds of mobile devices as well as the number of routes available. The packet delivery ratio, energy consumption, and network throughput can all be significantly impacted by the limitations on the speed of mobile nodes in MANETs. Multiple pathways provided by multipath routing protocols can be beneficial in MANETs, which is why they are commonly used.

The remainder of the chapter is devoted to a survey of significant literature on multi-path routing in MANETs, which has guided the thesis's research. Multipath routing is also influenced by design considerations that are outlined in the chapter. There are various criteria, observations, and conclusions made in the literature study with the goal of determining a direction for developing an issue in the thesis.

## 2.1 The EFFICIENCY OF MANET-WIDE MULTIPATH ROUTING:

Numerous factors affect the performance of protocols in MANETs. The following are the primary areas of concern:

**(a) Uncertain surroundings:**

Nodes in MANETs can be put in any environment, including adverse conditions and hostile situations that could impair nodes' operation. As a result, node failures are quite prevalent.

**(b) Wireless medium's unreliability:**

MANETs communicate between mobile nodes over a wireless channel. Variable environmental circumstances may impair the wireless medium's quality. Thus, the quality of connectivity may vary in MANETs.

**(c) Restrictive Resources:**

MANET nodes use energy, e.g., batteries. Additionally, storage and processing capacity are constrained. These constraints further emphasize the importance of developing energy-efficient algorithms with low processing and storage requirements.

**(d) Changes in Topology:**

The topology of MANETs is very dynamic and changes at an alarming rate due to node migration. This may result in failures along a number of the links. As a result, the algorithm must be capable of dealing with dynamic topologies.

A variety of defects may occur in MANETs as a result of various difficulties with MANETs. The following are the various types of faults that can arise in MANETs:

**(i) Errors in transmission:**

In MANETs, the unreliable and unpredictable wireless medium of transmission may result in packet errors.

**(ii) Failures of nodes:**

MANET nodes are also susceptible to failure owing to varying environmental conditions. They may choose to leave MANETs freely or as a result of energy depletion.

**(iii) Failures of links:**

Links may become non-operational due to node failures and environmental variables.

**(iv) Breakdowns in the route:**

Existing routes may become invalid due to topological changes, such as node migration.

**(v) Nodes or links that are congested:**

Certain nodes or lines may get overcrowded as a result of the routing protocol's scheme. This can result in increased delays and packet loss.

The following benefits may accrue from multipath routing.

**(a) Tolerance for**

Due to the mobility of errors:nodes in MANETs, link failure is a very typical occurrence. The path that existed at one point in time may be interrupted as a result of the node's mobility. Multipath routing establishes many pathways between two nodes and thus readily handles faults caused by link failures.

**(b) Balanced load:**

Energy is a scarce resource in MANETs, and excessive consumption of any path may result in depletion of the energy levels of nodes along that path. This can be avoided by implementing a multipath routing approach.

**(c) Aggregation of bandwidth:**

In MANETs, bandwidth is viewed as a precious resource that must be carefully controlled. Bandwidth control is made simple by separating data packets into distinct routes.

**(d) Decreased delay:**

The maintenance of several pathways ensures that the route is always available and thereby reduces delays.

## 2.2 COMPONENTS OF MANET-WIDE MULTIPATH ROUTING:

The following are the design difficulties that arise when developing Multipath protocols for MANETs.

**(a) Calculation of the path:**

Paths can be computed in a variety of ways, including source routing, hop by hop routing, and so on.

**(b) Metrics for routes:**

These are the performance measurement parameters. End-to-end delay, throughput, path length, and energy consumption are all examples of routing metrics.

**(c) Load balancing mechanism:**

To spread the load throughout the network's different available pathways.

**(d) Paths chosen in total:**

Multipath routing cannot be applied on all accessible paths. There are only a limited amount of paths used.

**(e) Utilization of various paths:**

Numerous pathways can be utilized concurrently or as alternates.

Multipath routing consists of three components, namely a process for discovering routes, a phase for maintaining existing routes, and a mechanism for allocating data traffic among available paths. These critical components are explained in the following sections:

### 2.2.1 Route Identification and Maintenance:

The route discovery method is concerned with determining multiple pathways between two nodes. Multiple paths discovered can be disjoint or non-disjoint. The disjunction of routes can be determined based on shared nodes or linkages. Disjoint pathways between nodes are also referred to as total disjoint paths. They are characterized by the absence of any common node. Link disjoint pathways, on the other hand, are associated with the absence of a shared link. However, the discontinuous pathways that connect them may share nodes. Non-disjoint routes may share both a node and a connection. The primary advantage of discontinuous pathways is that they maximize resource availability. Non-disjoint pathways consume fewer aggregate resources due to the use of shared nodes and links.

Disjoint pathways offer a higher level of fault tolerance. If a link or node fails, no other disjoint nodes or links are affected. However, if a node fails in a link-disjoint route, numerous routes that share that node may fail as well.

Due to the ease with which non-disjoint routes may be discovered, they are more preferred. Without limitations, non-disjoint pathways can proliferate. In multipath routing protocols, route discovery is launched even if a single route fails, as a delay in initiating the route discovery may damage the quality-of-service support.

### 2.2.2 Data Traffic Allocation:

Granularity is defined as the smallest unit of information that can be sent along each path. Granularity on a per-connection basis refers to the allocation of complete traffic for a single connection to a single path. By contrast, per-packet granularity is intended to distribute packets from numerous connections down distinct pathways. A per-packet granularity improves performance by allowing for more control over network resources. To distribute traffic, a round robin technique might be utilized. The primary challenge with multipath routing is the sequencing of packets in order to retrieve useful info rmation.

## 2.3 IN MANETS, MULTIPATH ROUTING PROTOCOLS:

This section discusses the various multipath routing protocols that are available in MANETs. Numerous Multipath variations of AODV and DSR exist, some of which are given below:

### (a) Routing using Multipath Sources (MSR):

MSR is a protocol extension for the DSR protocol. The route finding and maintenance phases of DSR have been updated to generate a large number of pathways with the node-disjoint property. Additionally, it provides a system for allocating load across multiple alternative paths using the round robin scheduling technique. It determines numerous routes between two nodes. Additionally, MSR makes use of source routing. By using source routing, it is possible to store routes identified in route caches by assigning a unique route index to each route. MSR selects disconnected pathways with a high degree of path independence. This enables the attainment of numerous routes. The concept of node disjoint Ness is undoubtedly beneficial when it comes to constructing various pathways. It was one of the first forays into multipath routing. The increased overhead associated with the process was undoubtedly an issue. Additionally, the system lacked principles such as optimal energy usage and waste control.

**(b) SMR is a term that refers to split multipath routing:**

SMR is an on-demand protocol that utilizes multipathing and source routing. SMR creates pathways that are as discontinuous as possible. SMR is based on DSR, however unlike DSR, no intermediary nodes store route caches. As a result, route answers from intermediate nodes are likewise not possible. This enables the destination to be aware of all alternative routes, allowing for the selection of the most discontinuous routes conceivable. Routes that are maximally disjoint define an upper bound on the number of possible common links or nodes. The proposed route selection algorithm selected only two routes. However, the number of available routes can be increased. The destination creates a response solely in response to the initial request, as specified in the method. The least delay path is the one that corresponds to the first response.

Additionally, as more requests are received, a maximally discontinuous path is chosen from the shortest latency paths. If more than one maximal disjoint path is available, the path with the lowest Hop Count is chosen. If the Hop Count is also the same, the path associated with the earliest request is chosen. Finally, the destination generates a response message in response to the source's request message. Route error messages from upstream are used for route maintenance purposes. The strategy is effective in steering the course toward the generation of multiple routes. However, it is less adaptive to the network's current condition.

**(c) Ad-hoc On-Demand Multi-Path Distance Vector (AOMDV):**

AOMDV is a multipath-extended form of the AODV reactive unipath protocol. AOMDV has the advantage of generating discontinuous pathways. The increased fault tolerance in AOMDV due to frequent connection failures is also due to the availability of fragmented pathways. Additionally, the pathways exhibit the property of loop freedom. Each node's routing table stores the following data for each destination, namely a list of the next hop and the hop count. The path is tracked using the sequence number. Additionally, an advertised hop count is recorded for each destination. It specifies the maximum number of hops required to reach the target sequence number specified in the initial advertisement. Additionally, route advertisement messages are constrained by the announced hop count required to reach a specified destination. Receipt of duplicate advertisement indicates the presence of several paths to the destination node. When the destination node receives numerous request messages, it is obligated to respond to each route request in accordance with the principle of disjoint ness and independence from loops. The existence of a loop is determined by comparing the lengths of several available pathways to the claimed hop count. The shorter path length in comparison to the reported hop count indicates the presence of loop-free connectivity. The advertised hop count remains constant as long as no advertisement with a higher sequence number is received for a particular destination. The presence of an advertisement message with a higher sequence number may cause the next node and advertised hop count to change. The primary advantage of AOMDV is that it reduces route discovery while increasing the availability of alternate routes. However, there is potential for resolving the route cutoff problem, and load balancing AOMDV is another critical issue that must be solved if full multipath routing benefits are to be realized.

**(d) AOMDV that has been modified:**

The improved AOMDV idea makes route selection possible by utilizing the residual energy associated with each node along the path. To begin, this algorithm computes the remaining energy of nodes along each path. All pathways are ranked according to their cumulative residual energy in decreasing order. The route with the highest cumulative residual energy is utilized for packet transmission. This method of utilizing residual energy substantially improves energy usage and so increases the network's life. The steps are as follows:

- Calculation of each node's residual energy along all pathways.
- Calculation of each node's residual energy along all pathways. Calculate the cumulative residual energy along all possible paths and then find the path with the lowest residual energy.
- Sorting all routes according to their cumulative residual energy in decreasing order.
- The path with the highest residual energy is chosen for data packet delivery.

However, the primary disadvantage of this strategy is that it uses solely energy as a route selection criterion. Additionally, there are elements such as traffic congestion and route length that affect the routing selection.

**(e) Secure Multipath AODV with Low Energy Consumption (EESM-AODV):**

EESM-AODV is an AODV variation with multiple paths. The usual protocol has been expanded in such a way that several pathways can be generated. It has been changed to transmit data in an energy-efficient manner. The route discovery procedure of the conventional protocol has been adjusted so that a destination is obligated to generate reply packets in response to each request packet received. Even if the packets have the same sequence number, replies are generated. After receiving a list of paths, the sender is needed to sort them by hop count. The table is used to pick the three best pathways. If the data is sufficiently substantial to be disseminated across multiple paths, it is distributed across multiple paths. Otherwise, the shortest path is chosen to ensure complete data delivery. This procedure assists in avoiding route breaking that occurs with typical protocol. Even if one route fails, data can still be transferred over the alternate path. Additionally, the approach improves energy efficiency by distributing the packet among numerous pathways, avoiding excessive energy use along a single line. The RATE LIMIT option is used to limit the number of route requests accepted and processed by the algorithm. Each node keeps track of the requests it receives from each source. If this number is smaller than the value specified by the RATE LIMIT option, the packet is processed normally. The BLACKLIST LIMIT argument is used to specify the node's malicious activities. If the number of requests exceeds this value, it can be concluded that the node is acting maliciously. If the number of requests exceeds either of these two limits, the requests can be added to the wait queue. Utilizing an upper limit on the number of queries is undoubtedly a better strategy for reducing energy consumption. However, the technique should be more adaptable and include more characteristics rather than relying solely on route requests.

**(f) SMORT is an acronym for Scalable Multipath On-Demand Routing:**

SMORT is another AODV multipath variation. The purpose of this protocol is to decrease network overhead. Instead of employing discontinuous paths, the so-called "fail-safe multiple paths" are used. A path is considered fail-safe if it has at least one node that is distinct from the primary path, i.e. it contains a bypass to at least one primary path node between the source and destination, as seen in Figure 2.1.

The source node initiates the route discovery process by flooding the network with request packets. In SMORT, request packets do not contain the entire path, as big packets may result in an increase in collisions. Each intermediate node checks for an entry of a route corresponding to the destination upon receipt of request packets. If such a route is accessible, a reply for the source node is generated. Alternatively, the request packet is routed to the next node. When the destination node receives the request packets, it is bound to create a reply packet. The method of fail-safe multiple pathways is ensured by the fact that each node has several copies of route requests. As a result, the destination sends several route reply packets to the source node. The intermediate nodes, on the other hand, send only the first reply packet and discard the others after noting the secondary pathways. SMORT maintains a dedicated routing table for the purpose of storing route reply packets. Additionally, the source node is designed to initiate data transmission upon receipt of the first reply packet along the received path to the destination. The phase of discovery is followed by the phase of upkeep. The following are the critical tasks related with this phase:

- Re-establishment of a connection between two nodes, the source and destination nodes, if the whole route becomes invalid during processing.
- Stale routes are completely removed from the routing table.

Although SMORT is an excellent method for increasing the network's scalability, when computing fail-safe pathways, it ignores elements such as the alternate nodes' available energy level and traffic conditions, as well as the overhead associated with the process.

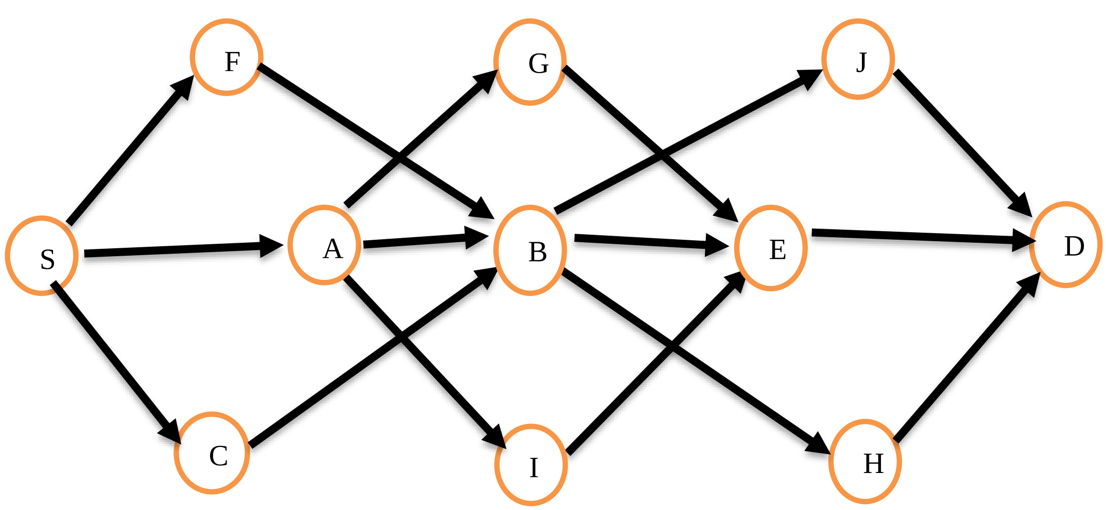


**Figure 2.1: Fall Safe Path**

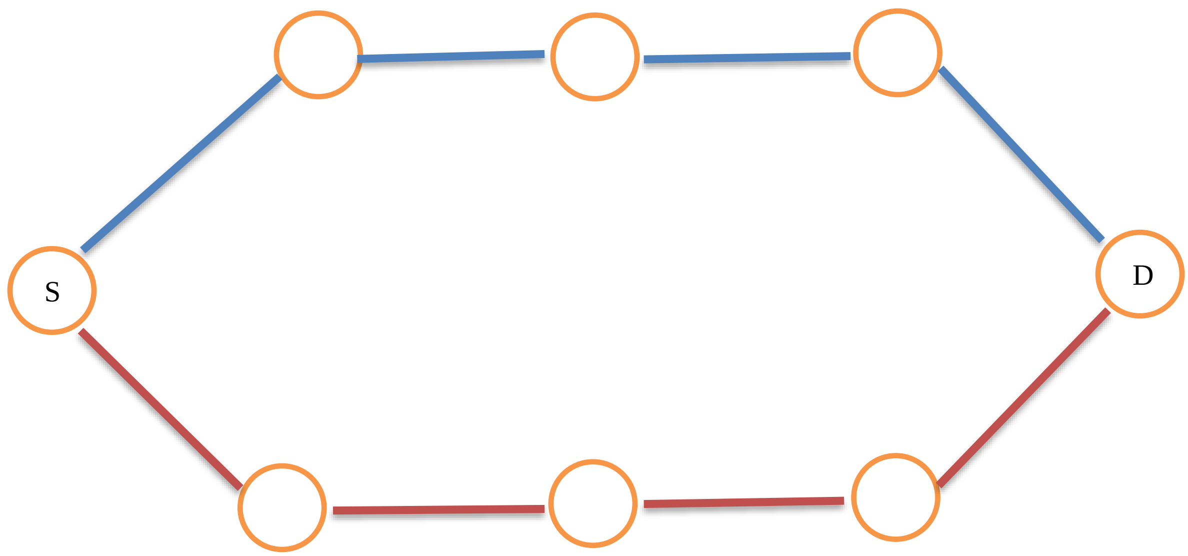


**Figure 2.2 Node Disjoint Path**

**(g) MNL-AODV: AODV with Multipath Node-disjoint AODV:**

MNL-AODV also makes use of AODV's features. Its objective is to generate two node is joint pathways between two nodes, as seen in Figure 2.2. Additionally, the routing table is changed to include a route entry giving information on the primary and backup routes. In the route discovery process, a flag "F" is utilized to distinguish between the two types of routes. MNL-AODV employs a backup route in place of the failing primary route in order to minimize transmission delays. During the discovery phase, route requests come from the source node. To commence route discovery, the flag "F" is set to "zero." After receiving the route request packet, the destination sends a reply to the source in order to create a primary path. Additionally, a new request is generated with "F" and "D" values of "1". The request packet's route is copied to the new request packet. The source is notified of the new request packet. The following request packets are dropped at the destination. The backup path finding process is initiated by the new request packet generated from the destination. This creates a reversal of the source-to-destination path. The backup path discovery method compares the address of the visiting node to the cached route. The existence of a match between the two indicates that the node is associated with the major path. Otherwise, the reverse path is recorded as a backup route to the target.

HELLO messages are tasked with locating the broken link. Route Error packets are used to maintain routes. When an intermediate node detects a broken link, it is responsible for sending an error message to the source. After receiving these signals, the source node is responsible for invalidating all failed routes associated with the error messages. The technique is advantageous for generating various pathways between two nodes. However, the procedure's primary constraint is the overhead associated with doing the discovery process from both ends.

**(h) AODV-MAP is an abbreviation for AODV Multiple Alternative Paths:**

Additionally, AODV-MAP enhances the capabilities of AODV. Its computations are aimed at producing node disjoint pathways that are also fail-safe. Using a shared node or a link, fail-safe pathways can be created. It generates more alternate paths than either a node-based or a link- based disjoint multipath generating technique. Each node maintains a route table and a neighbor table to hold routing information. The AODV-MAP uses the same control messages as AODV, namely route request, route reply, and route error. The process of discovering routes is initiated by a source node sending request packets containing the destination sequence number, the route request identifier, and the source address. After receiving the request message, an intermediate node checks to see if this is the first time the route request has been received. When the node receives the first request, it attempts to determine the reverse route to the source. If such a route does not exist, a new one is built. Duplicate request packets may be forwarded from the intermediate node if they meet the AODV-MAP criteria for hop count and neighbor node. Even though an intermediary node is aware of the route, it is not responsible for sending the route response. This aids in the establishment of several paths to the destination. The destination's primary path must possess features such as node disjointedness and fail-safety. When a destination node receives a request packet, it is responsible for replicating it and preparing a response for the source. If multiple route requests are received, the destination node must compare the route request's route to the route table's route. Additionally, the destination packet contains a label matching to the Node-disjoint or Fail-safe path entry. Finally, the response packet is routed back to the source.

When a broken or stale connection is identified, the detection process is immediately followed by the recovery process. HELLO messages are used to determine if a link is broken. Route error packets are used to relay information about broken connections between the source and destination nodes. All routes with broken links have been invalidated. Node may re-initiate the route request after a specified number of paths has been exhausted or after all paths have been exhausted.

**(i) AOMRLM is an acronym for ad hoc on-demand multipath routing with lifespan maximization:**

Smail et al. suggested AOMR-LM with the goal of developing a multipath protocol with an emphasis on energy conservation. The fundamental concept of AOMR-LM is to balance and control the operation of nodes in order to reduce energy consumption and extend the network's overall life. The residual energies of mobile nodes were also used to allocate the appropriate energy levels in AOMR LM. The energy levels assist in classifying pathways appropriately based on their residual or remaining energy. Equation 2.1 specifies the energy s,d level e n at node n between source s and destination d.

$$(e)^{s,d}(n) = \frac{e(n)}{\left(\mathrm{e(averageNet)P(s,d)}\right)} \qquad (2.1)$$

Additionally, the categorized nodes are utilized to classify the pathways into three categories. The path between two nodes is chosen based on their energy levels. To begin, high-class pathways are chosen. All packets travelling to a certain destination use the same path. The designated path is utilized to transmit the packets until they fail. The pathways of the high class are used indefinitely till the class is not empty. The roads with an empty high class give way to those with an average class. Similarly, the defunct average class gives way to the defunct low class. Paths from low class are chosen only when the average class is empty. The discovery process is launched only if no path exists between two nodes. While classifying nodes aids in limiting energy usage, additional criteria like as hop count, traffic condition, and so on must be given sufficient weightage during this process. Additionally, it lacks a mechanism for balancing network traffic, which means that nodes in the high class are likely to get congested.

**(j) Ad Hoc On-Demand Load Balancing Multipath Distance Vector (LBAOMDV):**

Saleh et al. proposed LBAOMDV to address a critical issue in multipath routing protocols: traffic allocation. Traffic allocation must be done in such a way that the load is spread uniformly and coherently across all feasible routes in the network. A load distribution method that is efficient may also result in optimal energy use in the network. This may extend the network's total lifetime and hence result in more efficient use of the network's limited resources.

Another critical aspect of LBAOMDV's design is its bandwidth. Thus, the main purpose of this protocol is to build one that maximizes bandwidth consumption while also exhibiting energy-conscious behavior. Additionally, the simulation results demonstrate the protocol's effectiveness. LBAOMDV is an AOMDV version. The procedure for discovering routes is identical for both procedures. The primary distinction is in the process of selecting data transmission paths. The routes are chosen based on their overall energy use.

The collection of paths so generated through energy effectiveness analysis is then subjected to a selection process based on average unutilized bandwidth. The full message is transmitted in discrete bits of fixed size. While this strategy is effective at balancing the load, it should be more flexible to the network's current status.

**(k) Routing scheme with several paths and mobility awareness (MBMA-OLSR):**

Jabbar et al. suggested MBMA-OLSR in order to design a strategy based on two factors: the movement of nodes, or mobility, and the restricted energy resource. As a result, the technique has been dubbed Multipath Battery and Mobility Aware Routing. The mobility factor adapts the protocol to the changing nature of mobile ad hoc network topologies. As a result, it also aids in preventing packet loss caused by topological changes. The second issue to consider is energy. Thus, the strategy is focused on developing a Multi-Criteria Node Rank (MCNR) measure based on these two parameters. The protocol's simulation also demonstrates the benefits of the strategy in coping with stale routes caused by node migration. Additionally, the technique attempts to balance data traffic among accessible routes. Another objective of the strategy is to establish stable routes. This was accomplished by providing the lowest priority to nodes with better mobility and low energy use. The establishment of reliable pathways leads in a significant reduction in the number of packets discarded. MBMA OLSR, on the other hand, concentrates exclusively on environments with high mobility and load characteristics.

**(l) AOMDV with Traffic-Aware Load Balancing (TALB-AOMDV):**

The TALB-AOMDV routing scheme is an illustration of a load balanced multipath routing strategy. Pathak et al. proposed the technique as a means of balancing load across the many possible channels as a result of the AOMDV. The shortcoming of AOMDV is that it uses a single path for packet delivery even when many paths between two nodes are available. TALB- AOMDV has taken use of this constraint. Overuse of a single path may result in overexploitation of the resources along that road. TALB-AOMDV considers both the queue length and the hop count when selecting a route. The primary use of this technique is to prohibit the path from being used repeatedly. The strategy is an effective method of uniformly distributing traffic. However, it uses traffic as a criterion for judging the route's quality. Additionally, other elements like as energy, bandwidth, and mobility must be taken into account while spreading load across the network.

Souihli et al. suggested a method that is primarily concerned with the network's centrality. Route selection based on criteria such as the shortest way may result in a path carrying a high volume of traffic. Thus, the authors concentrated on dispersing traffic in such a way that it was pushed away from the network center, i.e. on lowering the route's average centrality. This prevents overexploitation along a single path.

## 2.4 COMPARISON OF UNIPATH AND MULTIPATH ROUTING PROTOCOLS BASED ON SIMULATION:

The literature on multipath protocols demonstrates the critical nature of a multipath method. This section includes a simulation-based comparison between a unipath protocol and its multipath equivalent. AOMDV is a multipath variation of AODV, which is an on-demand protocol. Both protocols were examined using network simulator 2, abbreviated as NS2. Due to the availability of models such as an energy model and a mobility model, the NS2 enables the modelling of MANETs. As a result, is a critical tool for simulating the complicated scenarios associated with MANETs. This section analyses AODV and AOMDV using simulations for a variety of performance metrics and a variety of node counts and speeds.

| Routing Protocols | AODV, AOMDV |
|---|---|
| Network size | 1000 * 1000 |
| MAC Type | 802.11 |
| Max. IFQ | 50 |
| Number of Nodes | 10, 30, 50 |
| Max Simulation time | 50 s |
| Speed of nodes in m/s | 0.5, 1.0, 1.5, 2.0 |
| Pause time | 0.25s |
| Traffic type | CBR |

**Table 2.1 Parameters for Simulation**

Table 2.1 summarizes the various simulation parameters employed during the simulation procedure. The CBR traffic was used, and protocols were simulated at rates of 0.5, 1.0, 1.5, and 2.0 m/s. The simulation also includes a 0.25-second pause. The entire simulation has been separated into four scenarios based on the measure being evaluated.

**Case I Variation in energy consumption as a function of the number of nodes and their speeds:**

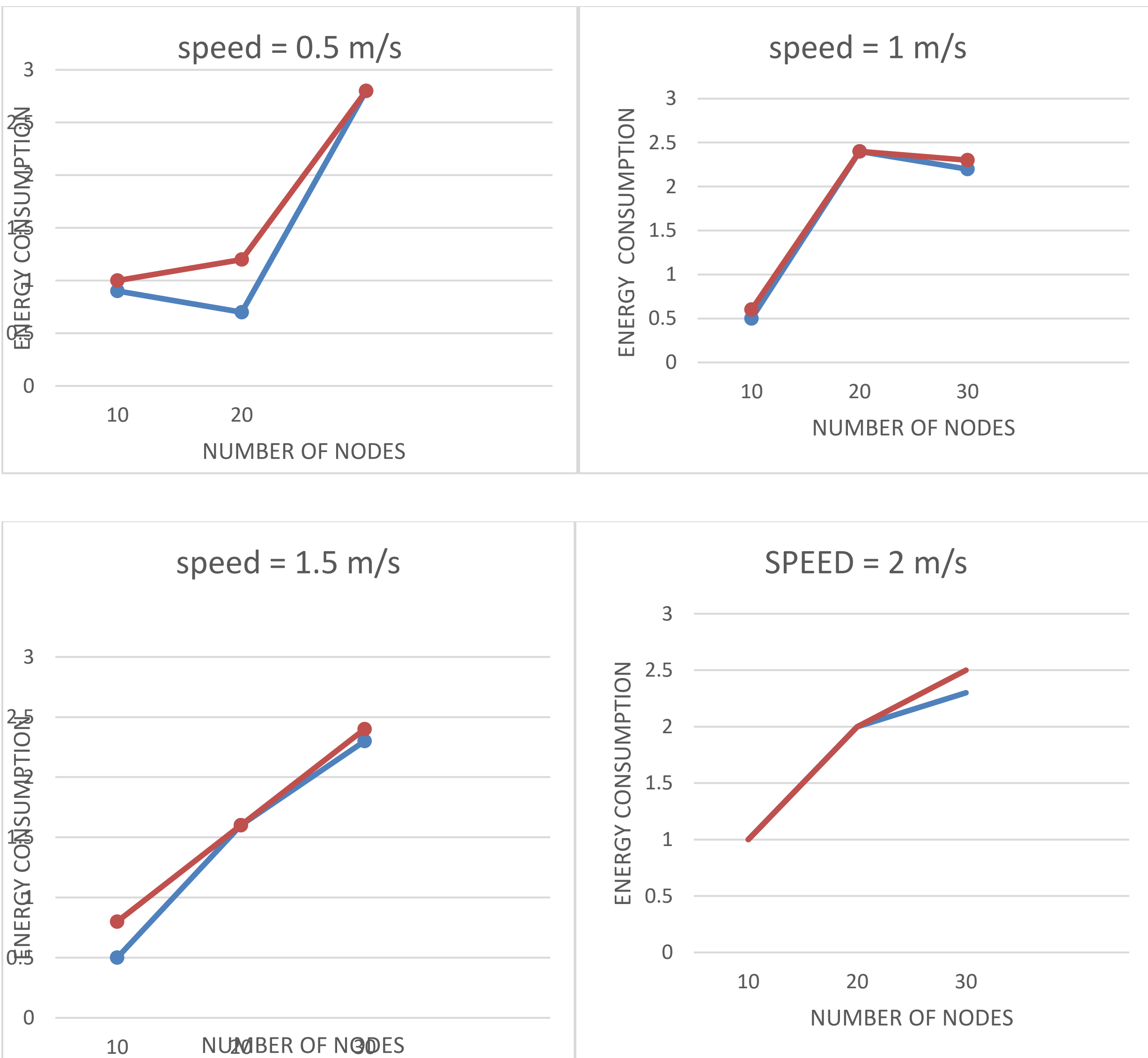


**Figure 2.3 Variation in Energy Consumption as a Function of Node Count and Speed**

Both routing methods were evaluated for average energy consumption over the entire simulation duration for nodes with a count of 10, 30, and 50 travelling at various speeds of 0.5, 1.0, 1.5, and 2.0 m/s. The resulting results are depicted in Figure 2.3. As a multipath routing protocol, AOMDV consumes somewhat more energy on average than AODV.

However, AODV may be preferable to AOMDV due to its lower speeds and fewer nodes. As illustrated in Figure 2.3 for speeds of 0.5, 1.0, and 1.5 m/s, AOMDV consumes more energy. Although both methods produce nearly identical results with nodes moving at 2.0 m/s, they waste more energy as the network's scalability increases. This also demonstrates the potential for improvement in the area of energy usage, which may be used to further improve the quality of multipath routing.

**Case II Variation in Packet Delivery Ratio (PDR) as a function of node count and speed:**

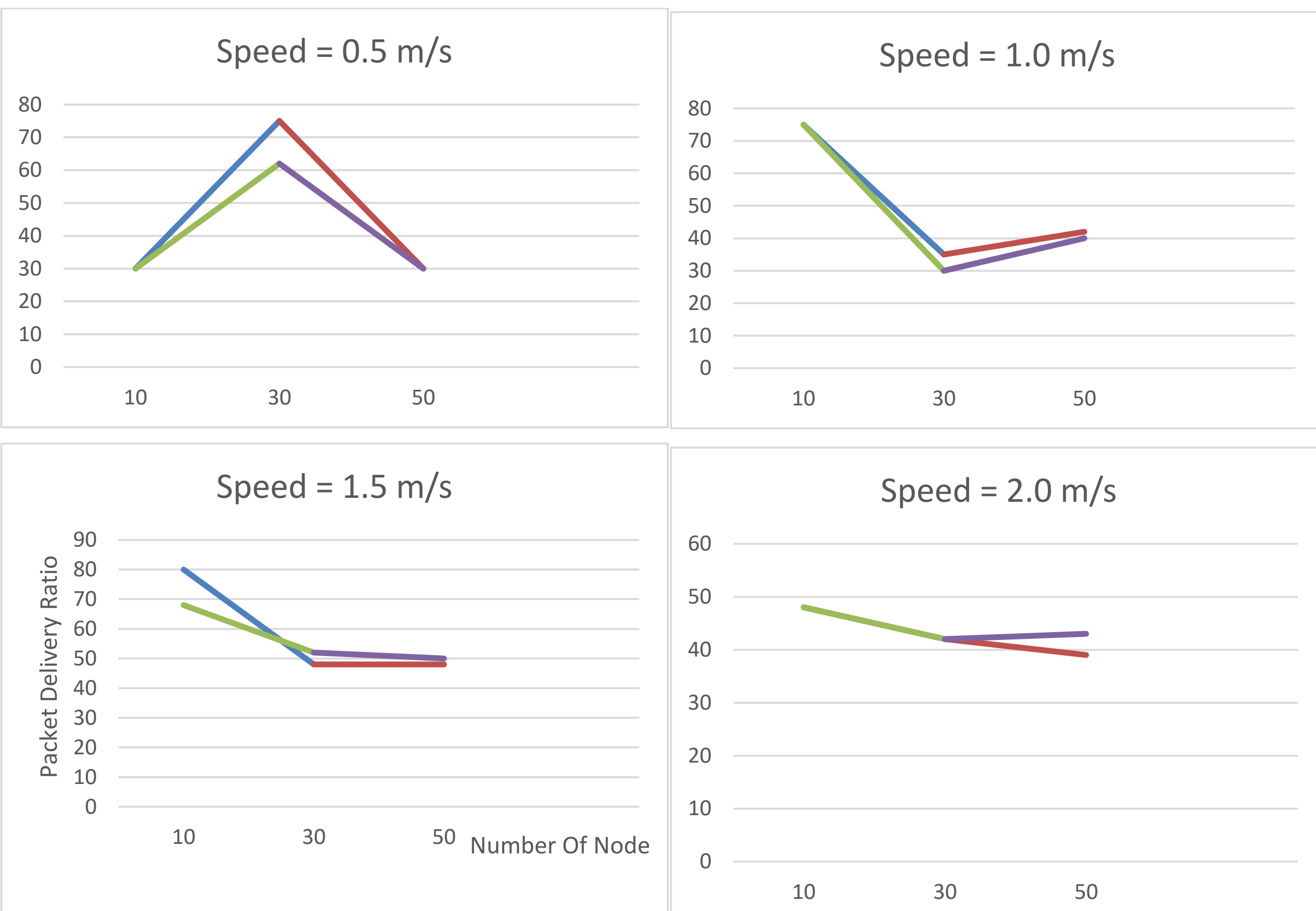


**Figure 2.4 Variation of PDR with Node Count and Speed**

In Figure 2.4, the PDR is expressed as a percentage. The overhead associated with multipath routing protocols is typically greater than that associated with unipath routing protocols. As a result, AOMDV is projected to have a lower PDR than AODV. Figure 2.4 further demonstrates this, as AOMDV has a smaller PDR than AODV at a lower speed, 0.5 m/s. However, it is worth noting that as node speeds improve, PDR produces findings that are essentially identical in both protocols.

**Case III: Variation in throughput as a function of the number of nodes operating at varied speeds:**

Figure 2.5 illustrates the results for altering the number of nodes at various speeds. The results demonstrate the evident advantage of multipath routing in terms of bits received per unit time. This is due to the fact that numerous pathways exist between two nodes. In every circumstance, AOMDV outperforms AODV in terms of throughput. However, the results demonstrate that the benefits of multipath routing become apparent only as the number of nodes is increased. As can be shown, with a number of nodes equal to 10, the throughput is nearly identical at all speeds.

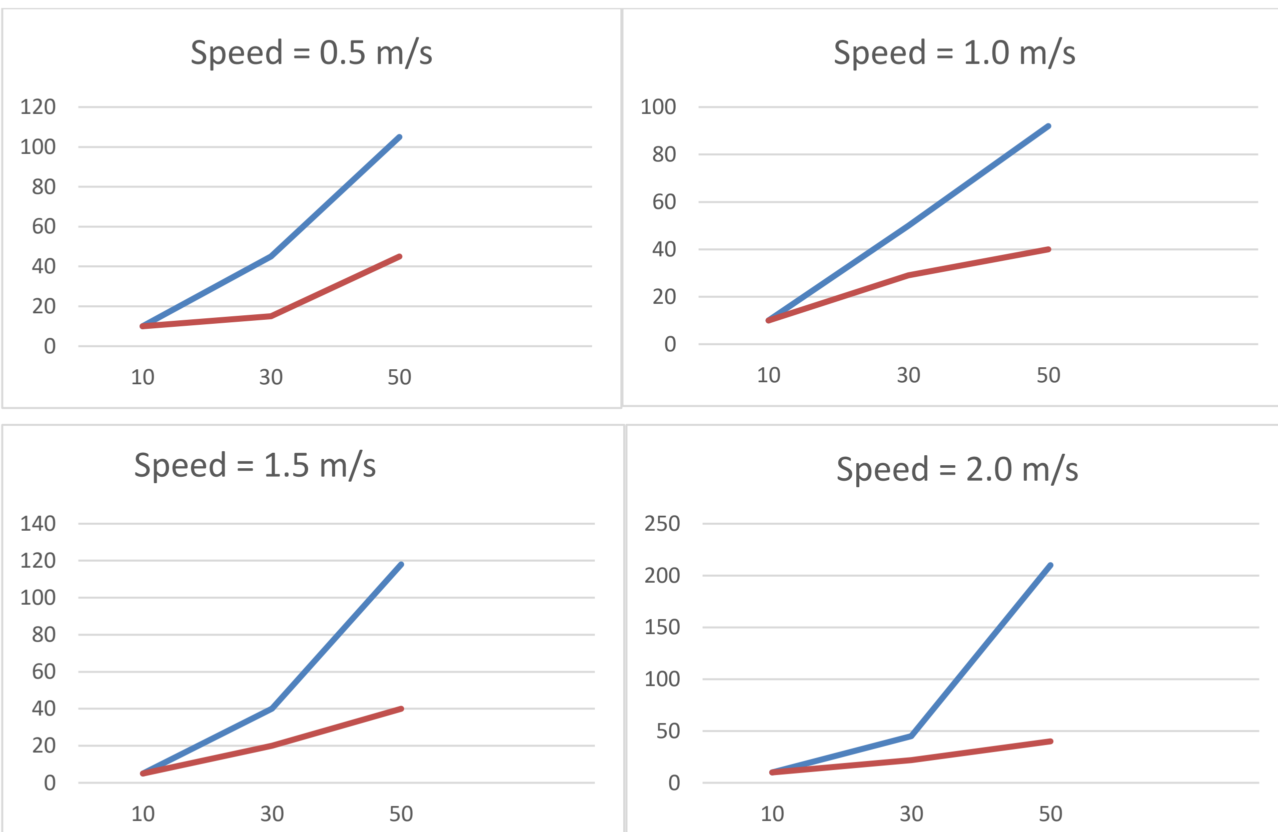


**Figure 2.5 Variation in Throughput as a Function of Node Count at Various Speeds**

However, as the number of nodes increases, the performance of AOMDV improves. As can be observed, the results of AOMDV are much better than those of AODV as the number of nodes is increased. This could be explained by the existence of many pathways.

**Case IV End-to-End Variation Delay as a function of the number of nodes operating at varied speeds:**

Multiple pathways may contribute to the benefit obtained in terms of End-to-End delay (s). The results of Figure 2.6 demonstrate that AOMDV is more effective than AODV. AOMDV's End- to-End latency are much lower than those of AODV when the number of nodes and their speeds fluctuate.

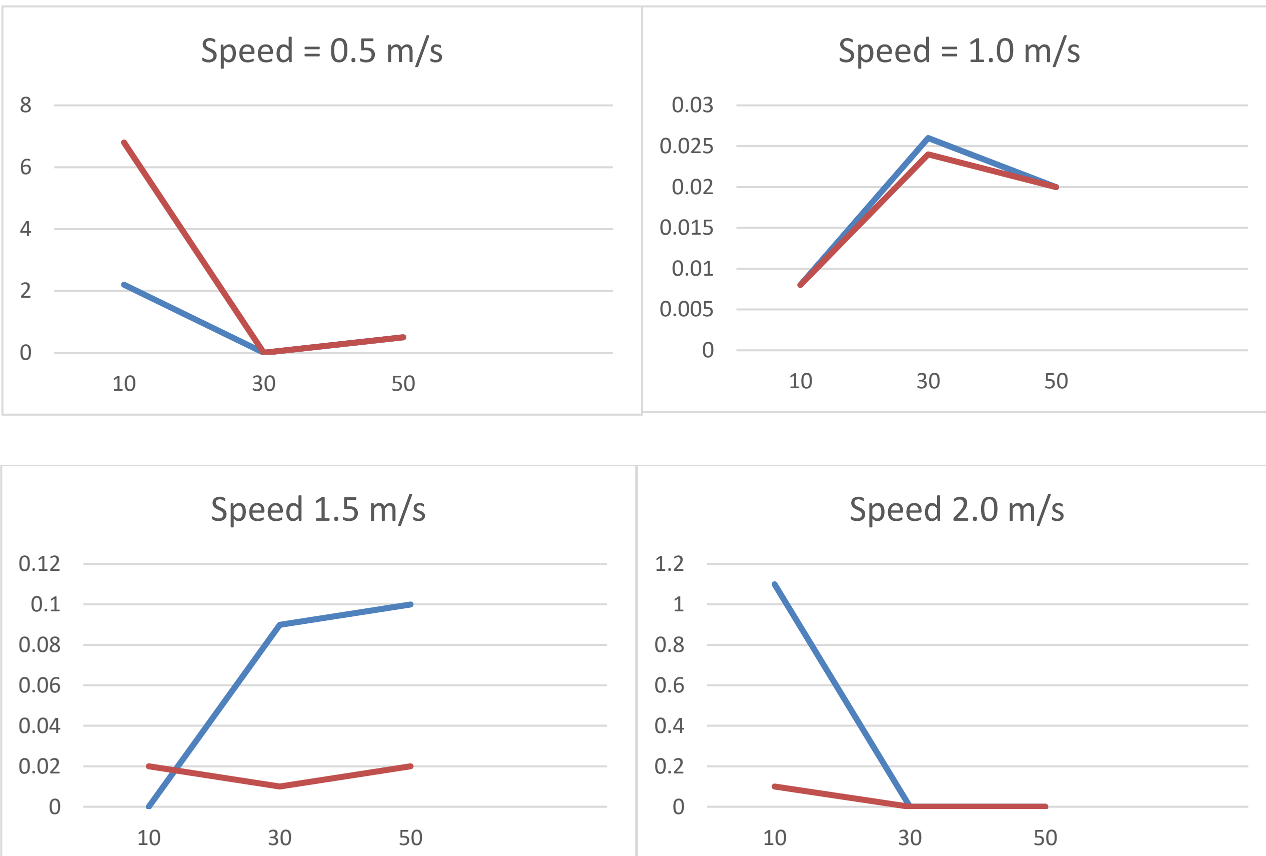


**Figure 2.6 Variation in end-to-end delay as a function of the number of nodes operating at varying speeds**

Taking all scenarios into account, it can be concluded that AOMDV surpasses AODV in terms of End-to-End Delay and Throughput. However, being a multipath routing technology, AOMDV has inherent restrictions. This is seen in the Packet Delivery Ratio and Energy Consumption figures. AOMDV PDR, on the other hand, is essentially identical to AODV at greater speeds. Thus, an area that requires further attention is energy saving when several pathways are used.

Given the requirement to control average energy use, there are two viable avenues for research in this area:

- By imposing a threshold restriction on the node's energy usage, the average energy consumption of the node can be reduced. This can be used to disable the node's participation in packet transmission if the limit is reached.

- The load can be allocated proportionately to the remaining energy along each path, so that the path with the most energy receives more packets. Additionally, this load distribution may result in a reduction in average energy use.

## 2.5 SUMMARY:

This chapter discussed the rationale behind multipath routing as well as the associated design problems. On the basis of this, a survey of multipath routing was conducted. Observations from various multipath routing protocols, together with simulation studies, stimulate study in the topic of multipath routing. The literature review's conclusions have provided a positive path for problem conceptualization.

Multipath routing is defined as computationally intelligence but it is further explained with different parameters as:

1. Review of Ad-Hoc Single path routing protocol
2. Extensions of Ad Hoc Single-Path routing protocols
3. Other Ad Hoc multiple routing protocols

# CHAPTER 3

## OPTIMIZATION OF ANT COLONY

In the absence of any fixed infrastructure, mobile ad hoc networks (MANETs) are generated when a number of mobile nodes connect with one another. Due to the dynamic nature of MANETs, their limited bandwidths, and energy limits, the routing process is complex and challenging. All of these variables can be regulated exclusively through the use of learning, adaptive, behavioral, and nature-inspired routing protocols. As a result, it is critical to construct intelligent networks. Nature-inspired techniques include swarm intelligence techniques such as Ant Colony Optimization (ACO) and its derivatives.

Swarm intelligence techniques entail evaluating the combined behavior of individual agents interacting locally in a distributed environment in order to solve problems on a global scale. ACO is an example of a method known as swarm intelligence. As a nature-inspired method, ant colony optimization (ACO) can easily map the intricacies of the real world. As a result, it is the most appropriate technique for creating routing protocols for MANETs.

ACO was proposed by Marco Dorigo. The ACO algorithm is inspired by the foraging behavior of biological ants. ACO seeks the shortest route between their nest and food sources. Ants communicate in an indirect manner, with engagement occurring through their environment. Ants accomplish this by depositing a chemical called pheromone along the way to food. The popularity of Ant-based routing algorithms in the field of research is due to their inherent features of flexibility, resilience, scalability, and self-organizing nature.

ACO has been successfully used to a variety of combinatorial optimization issues, including the following:

- Traveling salesman
- Assignment problems
- Scheduling problems
- Load balancing
- Sequential ordering problem

- Industrial applications\

The scope of ACO in MANETs is discussed in this chapter. ACO is used in ad hoc networks to simulate network traffic using artificial ants, pheromones, and data structures.

### 3.1 OPTIMIZATION OF ANT COLONY:

In the actual world, biological ants initiate the process of food searching by randomly moving from nests to food sources. They achieve this by leaving traces of a chemical molecule called pheromone. They return along the same path they used to lay down the pheromone while seeking for food. When the other ants locate food, they follow the trail with the highest concentration of pheromones to the colony. This type of indirect communication between ants via their environment is referred to as staggery.

The ACO results in a short path since it is traversed more quickly than other paths. This results in a higher concentration of pheromones being redeposited along the shorter path compared to other routes. However, the pheromone trail will continue to grow in size as time passes along a given route. Thus, each ant will take the same path. However, as time passes, pheromone evaporation begins, resulting in a decrease in pheromone content. Evaporation is exactly proportionate to the time required for ants to journey to and return from food.

Additionally, the evaporation process precludes convergence to a locally optimal solution. Without evaporation, the course chosen by the first ant will be followed by the remaining ants. As a result, exploration will be limited. The Ant Colony algorithms are designed to mimic the foraging behavior of biological ants using artificial ants to model the problem.

The ACO technique is described in Figure 3.1. The procedure is as follows:

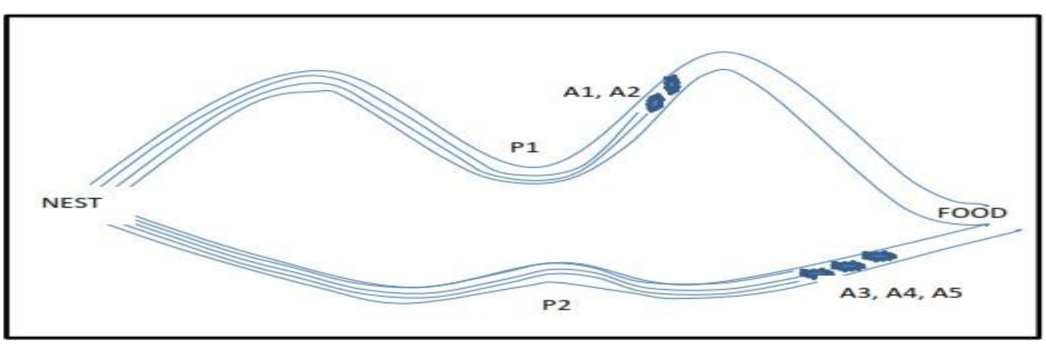


**Figure 3.1 Solution by the Ants**

Solution by the Ants Five biological ants are moving toward a food source from their nest on two paths, P1 and P2. P1 is longer than P2. All of the ants shown as A1, A2, A3, A4 and A5 are at their NEST. They have to choose between P1 and P2 to get to the food source shown as FOOD in Figure 3.1.

- At NEST, all the ants don't know where food is. There are two paths that they can choose from: P1 and P2. So, they start by choosing any one of them. Then, let's say that A1 and A2 are moving along P1; then, A3, A4 and A5 are moving along P2.

- The ants move along paths P1 and P2 and leave behind some pheromone. This can be written as PH1 and PH2. At NEST, all the ants don't know where food is. There are two paths that they can choose from: P1 and P2. So, they start by choosing any one of them. Then, let's say that A1 and A2 are moving along P1; then, A3, A4 and A5 are moving along P2.

- Path P2 is shorter than Path P1, so the ants labelled as A3, A4 and A5 will get to the FOOD before the ants on Path P1 i.e. A1 and A2.

- People A3, A4, and A5 need to choose between P1 and P2. They need to go back to the nest from the source of food. Path P2 has more pheromone than Path P1, because A1 and A2 haven't found food yet. So, A3, A4 and A5 will go down the path P2 instead.

- You'll see this happen when A3, A4 and then A5 go back to P2. The pheromone on path P2 will go up. Thus, when A1 and A2 reach the food source, they are more likely to choose path P2 to return to the NEST.

There is a problem with ACO algorithms that don't change. As shown in, there are many ways to deal with this problem. Evaporation, Aging, Limiting, and Pheromone heuristic control are some ways to control stagnation. According to, controlling pheromones can be done by finding ways to make people want to try new things and lessen the impact of their past experiences.

**(a) Evaporation:** This method can be used to control the effects of past experiences. When making ACO, it can be used. An important goal for the process of Evaporation is to make sure that the concentration of pheromones on any given path isn't too high.

**(b) Age:** The pheromones that an ant puts out as it gets older are related to how many nodes it has been to. The process of ageing is based on the idea that older ants can't find the best way to get there. This is because an older ant will take longer to find its way to the next place.

**(c) Limiting:** Limiting works by setting a limit on the amount of pheromone that can be in the air at once. A pheromone can only be spread so far along a path when it is limited. This helps to reduce and control the stagnation by limiting the amount of pheromone that can be spread. This limit on how much pheromone can be in the air stops the dominant path from being made.

**(d) Pheromone-Heuristic Control:** It tries to keep things moving by making it easier for people to lay special pheromones. It's called this strategy because one group of ants is given more attention than another group of ants. This means that these special ants will deposit more pheromone than other ants do. This can cut the time it takes for things to come together a lot.

### 3.2 ACO's SCOPE AND CHALLENGES IN MANETs:

Because ACO-based algorithms can deal with the real world's problems, they are very good at routing in complex networks like MANETs, which are very hard to set up. The properties of ACO-based algorithms that make ACO good for MANETs are shown in the table below.

**(a) Dynamic Structure:** By utilizing autonomous agent systems such as artificial ants, MANETs may quickly adapt to their present topology.

**(b) Local Work:** Unlike standard algorithms, ACO-based algorithms make use of local information. This also reduces the overhead associated with routing table or other message transfer to other nodes.

**(c) Link Quality:** The pheromone concentration along a specific link can be adjusted based on the link's quality and condition.

**(d) Support for many paths:** Nodes must store a routing table in addition to the pheromone concentration in order to communicate with all of their neighbors. Thus, may choose any node based on the pheromone concentration. This fact argues in favor of using ACO for multi-path routing.

## 3.3 IN MANETS, VARIOUS ACO ALGORITHMS:

Numerous techniques based on the concept of Ant Colony Optimization have been introduced in MANETs. This Section discusses such algorithms in detail. Due to the adaptability of ant colony optimization and the usage of autonomous agents such as artificial ants, it can be utilized in conjunction with the various routing schemes outlined in Chapter 1. Thus, Ant Colony routing protocols in MANETs can be characterized as proactive, reactive, or hybrid.

### 3.3.1 Routing Protocols Based on Proactive Ants:

Several notable instances of proactive or table-driven routing methods based on ACOs include the following:

**(a) ABC (Ant-Based Control):**

The first algorithm in the realm of network routing to be inspired by ant colonies was Ant Based Control (ABC). ABC was developed by Schoonderwoerd et al. for use in telephone networks. This technique makes use of ants, which are mobile routing agents. These ants wander aimlessly through the network. The routing tables are updated based on the current status of the network.

ABC employs ants that are exploratory. These ants are generated at random locations from each source node. On each node in the network, the routing table is kept. The routing table is made up of rows and columns that reflect neighbor and destination pairs. The routing table entry represents the pheromone for a particular link through a certain neighbor to a particular destination. It is used to pick the link based on the routing table's probabilities. The ant arriving at a node updates the table entries according to the following equation (3.1).

$$P = (P_{old} + \Delta \mathrm{p})/(1 + \Delta \mathrm{p} \qquad (3.1)$$

Here, P denotes the updated probability and X denotes the probability change. Other entries are decremented in accordance with the evaporation process (3.2).

$$P = (P_{old})/(1 + \Delta \mathrm{p}) \qquad (3.2)$$

Additionally, ABC developed the concept of ant ageing and postponing. Artificial delay can be used to introduce delay. Ants delayed forwarding results in a decrease in flow rates.

**(b) AntNet:**

In 1998, Di Caro and Dorigo created the Ant Net framework. AntNet is a network optimization approach based on ant colony optimization. AntNet is applicable to telecommunications networks, optical packet switching, and wavelength-routed optical networks. Initially, AntNet's routing measure was based on the delay produced by each node. However, in circuit switching networks, the concept of delays is irrelevant, and hence the routing statistic is dependent on the number of hops.

DiCaro and Dorigo's AntNet algorithm is as follows:

- At regular intervals of time, forward Ants to a certain destination are originated from the source node.
- The next Forward Ant node is chosen based on probability. The probability is determined by the length of the output queue.
- If the next node determined in the previous phase is not a destination node, Forward Ants scan the buffer to avoid the same node being repeated. This ensures that Forward Ants do not travel in loops.
- When the Forward Ant reaches the destination, it is turned into a Backward Ant, and the information contained in the buffer is used to return to the source.
- On each node, the Backward Ant pops the stack to learn about the next node while retracing the Forward Ant's path.
- The Backward Ants are also responsible for updating the probability in the routing table using a reinforcement factor on intermediate nodes toward the source. The reinforcement factor reflects the network's quality, congestion, and dynamics.

**(c) PAR (Potentiality Ant Routing):**

Probabilistic ant routing makes use of two distinct sorts of ants: Forward Ants and Backward Ants. FA represents forward ants, which are probabilistic in nature. They are used to do network traffic analysis. Priority queues are used for routing. When the Forward Ants reach their destination, they are killed, and the Backward Ants, or BA, copy the stack from the Forward Ants. The Backward Ants' approach is deterministic. The BA are distributed through a high-priority queue. The Backward Ants go the opposite path as the FA. Additionally, the BA is responsible for maintaining the routing tables.

The neighbor list is constructed using Hello messages with a hop count of one. At each node, the routing table is initialized by assigning a probability of 1/N to each node. Here, N is the number of neighbors a node has. When the FAs arrive at their destination, they are meant to transmit all stored data to the equivalent BAs produced at the destination. After conveying this information, the FAs perish.

### 3.3.2 Routing Protocols Based on Reactive Ants:

#### (a) Algorithm for routing based on ant colonies (ARA):

The ant colony-based routing algorithm (ARA) is a reactive routing protocol for MANETs. The agents known as ants are transmitted only when a route is required. The network is saturated by these ants. Instead of using probabilities, the routing table entries employ pheromone concentrations. The pheromone concentrations can then be converted to probability. The entirety of ARA's functioning can be separated into three phases:

- **Route Discovery:** This technique involves broadcasting Forward Ants, or FAs, from sender nodes to their neighbors. Each FA is uniquely recognized by a sequence number. When a node receives an FA, it saves the record that includes the destination address, the next hop, and the pheromone value. After analyzing the data, the node distributes the FA to its neighbors. The method is repeated for each node. When the destination node receives the FA, it destroys it and creates a Backward Ant, or BA. After then, this BA is returned to the source node.

- **Route maintenance:** Paths are maintained only through the use of data packets. As a result, no overhead is created. When a data packet is transmitted to a neighbor node, the pheromone value associated with that entry is enhanced. Evaporation is introduced by reducing the pheromone value on a regular basis.

- Route failure handling: When a missed acknowledgement is detected, the link is killed by setting the link's pheromone value to 0. After that, the alternate path is attempted. The ARA does not begin route discovery until the source node does not get a route error report.


- **Route failure handling:** When a missed acknowledgement is detected, the link is killed by setting the link's pheromone value to 0. After that, the alternate path is attempted. The ARA does not begin route discovery until the source node does not get a route error report.


The on-demand or reactive behavior is unquestionably beneficial in terms of controlling overhead. However, ARA's primary shortcoming is its inability to adapt to the dynamic topological conditions found in MANETs.

**(b) Algorithm for Probabilistic Emergent Routing (PERA):**

The probabilistic emergent routing algorithm was proposed by Baras and Mehta. (PERA). The algorithm keeps a routing table in order to store the probability distributions associated with surrounding nodes. This probability is analogous to the probability of each neighbor acting as a forwarding node and ultimately delivering the packet to the target node.

The route discovery process employs two distinct types of ants, the Forward Ant and the Backward Ant. If no route exists that corresponds to a destination, Forward Ants are formed and regularly transmitted throughout the network until the required route becomes available. A Forward Ant stores information such as the Source IP address, the Destination IP address, a sequence number, a hop count, and a stack. The stack is composed of visited nodes and their associated timestamp values.

The Backward Ant is formed from the destination by utilizing the Forward Ant's information. Backward Ants are in charge of updating the probabilities along their path to the source. The primary disadvantage of this protocol is that, unlike other protocols, it broadcasts Backward Ants. This results in increased overhead due to the vast number of redundant ants. The Forward and Backward Ants' broadcasts generate various pathways.

However, the technique has the disadvantage of utilizing only the path with the highest probability.

**(c) Ant Dynamic Source Routing:**

Ant Dynamic Source Routing (ADSR) provides support for quality-of-service factors like as latency, jitter, and energy consumption. The ADSR protocol is an asynchronous protocol. It does so use source routing. Route caches containing source routes are stored on mobile nodes. The route caches are updated on a regular basis to ensure that the information regarding new routes is always current. The route discovery phase employs Forward Ant, i.e. FA, as the route request packet and Backward Ant, i.e. BA, as the route reply packet of the DSR protocol, whereas the route maintenance phase employs route error packets and acknowledgements. Constant acknowledgements are used to ensure that the links are functioning properly. As a result, there is an increase in control overhead.

**(d) PACONET: An Improved Ant Colony Optimization Algorithm for MANETs:**

PACONET, developed by Osagie et al., employs two agents, Forward Ants and Backward Ants, denoted by FA and BA. FAs are broadcast in a regulated manner in order to discover new paths. BAs are used to configure the path based on data received from FAs. The agents deposit the pheromone when their leave from a node. FAs are designed to travel through undiscovered nodes or along the path with the highest pheromone concentration. The data packets are routed to their destination along the path with the highest pheromone value. At each node, the routing table is composed of rows representing neighbor nodes and columns representing all network nodes. The table's (row, column) pair stores two values that represent the following information:

- Indicates the visitor's state, e.g. Visited or Unvisited
- Pheromone associated with the pair of nodes.

The approach's primary disadvantage is that it results in the construction of a single path between two nodes at the expense of increased overhead.

**(e) ACO-AOMDV:**

Multipath routing has a lot of advantages, including increased performance metrics.

However, increased overhead and other related difficulties are some of the performance bottlenecks in multipath protocols. The AOMDV protocol is a leading example of a multipath protocol. Wang et al. suggested a variation of AOMDV using Ant Colony Optimization. ACO-AOMDV is the name given to this variation. The ACOAOMDV is designed to store a variable amount of pheromone based on a variety of various circumstances. Each path is determined by a variety of criteria, including the average number of links, the load condition along the path, the number of hops, and the quantity of pheromone. Different weights are assigned to various factors when the pheromone table is updated. The selection of the data transmission path based on the updated quantity of pheromone and the current network conditions can significantly improve the routing protocol's performance.

Additionally, simulation of ACO-AOMDV demonstrates the protocol's effectiveness in terms of higher Packet Delivery Ratio, lower End-to-End delay, and decreased route discovery frequencies when compared to other protocols such as ARA and AOMDV. This protocol is an excellent illustration of a strategy that combines the on-demand multipath technology with Ant Colony Optimization inspired by nature.

Similar to AOMDV, the routing algorithm consists of three phases: route discovery, route maintenance, and route failure handling. The method is intended to produce more stable pathways. It does, however, have an increased overhead issue in both low and high dynamic circumstances.

### 3.3.3 Routing Protocols Based on Hybrid Ants:

**(a) Ant-AODV**:

Ant-AODV was created to circumvent the AODV's limitations. Ant-AODV is a protocol that combines several protocols. It tries to reduce the discovery process's end-to-end delays and latencies. Additionally, it results in increased connectivity between nodes. It makes use of the on-demand behavior to discover a route to the target node, i.e. route discovery is performed in the absence of a recent route. Ants contribute to improved connectivity by increasing the number of active links to the destination. This results in a reduction in the number of route discovery packets. This connectedness results in a greater likelihood of receiving prompt responses from neighbors in response to route requests. Additionally, the AntAODV approach makes use of error packets to provide information regarding connection failure. This is accomplished in a manner similar to that used by AODV. The primary disadvantage of this strategy is the increased frequency of route mistakes.

**(b) AntHocNet:**

Caro et al. pioneered the use of the AntHocNet Algorithm in MANETs. It makes use of the Ant Colony Optimization component inspired by nature. AntHocNet is a hybrid protocol that employs a reactive approach for route configuration and a proactive procedure for route management. Additionally, the node contains two types of pheromones, namely ordinary and virtual pheromones. The Reactive Backward Ants deposit the standard pheromone. Only the Forward Proactive Ants employ the virtual pheromone. The Reactive Forward and Backward Ants are used to build routes, while the Proactive Forward and Backward Ants are employed to maintain them. Maintenance is a continuous procedure that occurs during the duration of the session. Route maintenance is a critical activity that is responsible for keeping the network's status current. Apart from keeping the network's state current, it also aids in the exploration of new routes. A node initiates the route discovery process by transmitting the Forward Ants. When the intermediate node receives the Forward Ant, it is necessary to unicast the ants if it knows the pathways to the destination. In the absence of this, the Forward Ant is transmitted. If a number of known neighbors exist that correspond to a path to destination d, they are chosen according to equation (3.4).

Taraka et al. compared AntHocNet to established protocols such as AODV and DSR using simulations. In comparison to the other two protocols, the simulation demonstrates AntHocNet's appropriateness for highly scalable networks. Additionally, AntHocNet is a faster protocol at large data rate. However, with low data rates and a small number of nodes, conventional protocols are preferable than AntHocNet. Additionally, AntHocNet is a protocol that is well-suited for large-scale networks and networks with relatively high data rates. The quality of AODV and DSR degrades as the number of nodes increases, whereas AntHocNets perform better as the number of mobile nodes increases. Additionally, due to its hybrid character, AntHocNet is better suited to dealing with network dynamism than standard protocols. However, the primary difficulty with this protocol is the added overhead. Due to the fact that this is a multipath protocol and the usage of reactive setup in conjunction with continual proactive maintenance, the overhead is quite substantial with this protocol.

**(c) Ant Routing Algorithm for Adaptive MANETs (ARAAI):**

Both typical strategies, proactive and reactive, are not completely strong. Proactive systems are not ideal for dynamic networks due to the significant overhead associated with updating the routing tables. Reactive schemes, on the other hand, suffer from route setup delays. ARAAI combines the finest characteristics of both methods to create a multipath scheme. Additionally, this technique benefits from adaptive control.

Two distinct sorts of tables are maintained by the method. The first table has entries for three fields: "initial node" for storing the starting node of ant generation, "last node" for storing the last visited node, and "heuristic value" for storing information about the energy associated with the local node. The second routing table is used to keep track of neighbors and represents the connection between the current node and other nodes. This table has entries for the following fields: neighbor node, time to monitor and check connectivity with neighbors via broadcasting the welcome message, and the final entry for the "„pheromone value, which holds information about the current connection's quality. Thus, by analyzing the quality of the relationship via the pheromone value, ARAAI aids in the introduction of adaptive behavior. The disadvantage of this technique is the delay connected with the discovery procedure.

**(d) MAARA (Multi-Agent Ant-Based Routing Algorithm):**

MAARA is a hybrid strategy that combines the best elements of reactive and proactive treatments. MAARA establishes a multi-agent system by utilizing the characteristics of the ant-based approach. The source generates paths to a certain destination only when there is a need for such a route. This feature enhances the protocol's reactive behavior. Additionally, the protocol manages the routing tables on each node. The nodes retain the routing tables till the session ends. Five phases comprise the routing technique. These phases are critical for discovering routes, updating routes, routing data packets, maintaining routes, and dealing with route failures.

**(e) HopNet:**

For MANETs, Wang et al. suggested the HOPNET routing protocol. HOPNET's fundamental technique makes use of Ant Colony Optimization characteristics. Additionally, the topography is separated into zones. Ants scurry from one zone to the next. Scalability of topology also contributes to the HOPNET's capacity to support high-quality services. The HOPNET algorithm employs proactive behavior when it comes to determining the route from the neighborhood and reactive behavior when it comes to determining the path via various zones. Zones are created based on the nodes' proximity. Thus, the neighborhood nodes constitute a zone. A routing zone may also have a radius length expressed in terms of hops. Additionally, a node can be shared between different zones. A node can be classified as an interior or a peripheral node based on its location within a zone. Each node maintains two types of routing tables: intra zone routing tables, which are used for communication inside a zone, and inter zone routing tables, which are used for communication between zones. However, the primary limitation of this strategy is its inability to scale to bigger networks.

**(f) Ant-Based Energy-Aware Routing Protocol (ABEAR):**

The ABEAR protocol was proposed by Ren et al. ABEAR is an example of a protocol that combines conventional routing with Ant Colony Optimization. ABEAR establishes the route in a reactive manner and maintains the updated list of neighbors in a proactive manner. As such, it an illustration of a hybrid method. Additionally, it employs a route maintenance phase to fix the routes.

The critical element of ABEAR is its energy-conscious nature. By focusing on energy, ABEAR aims to extend the network's total life. This is a defining characteristic of ABEAR in comparison to other ant-based routing protocols currently in use. Additionally, excessive consumption of scarce resources such as bandwidth and energy results in network congestion. The majority of existing energy-aware methods ignore network quality and congestion metrics. However, the energy state of the network is dependent on these variables. ABEAR examines all factors of routing, including the quantity of pheromone, the quality of the network, the congestion meter, and the following node's residual energy. Utilizing all of these variables in a cumulative analysis enables the selection of a node with a stable energy state. This also contributes to the reduction of dropped packets. This also results in a decrease in energy loss due to packet retransmissions, which lessens network congestion. Thus, ABEAR is an energy-efficient technique with an enhanced energy state and an increased overall life duration.

Additionally, the simulation of ABEAR demonstrates its usefulness in achieving a higher energy state and increased life time, as well as a higher packet delivery ratio and decreased average End-to-End delay. ABEAR is even more effective in larger networks and under conditions of heavy load.

However, its priorities the node with the highest energy level, while the node with the lowest energy level receives less attention. Additionally, it employs a form of alternate routing. Thus, a correct system for properly distributing the load across all nodes, together with the flexibility to respond to changes in the network state, may prove to be more useful.

**(g) ACO based Routing Algorithm (ANTALG):**

ANTALG replaces the typical routing table with a pheromone table by the employment of artificial ants. The values of pheromone tables are determined by the pheromone's concentration. The procedure begins with the production of Forward Ants from the source. Following that, a random source node is chosen from a collection of nodes to send Forward Ants to random locations. This assists in informing nodes about the topology via updated pheromone tables. The utilization of various sources enables comprehensive coverage of the topology in a short period of time. Additionally, the method employs proactive ants that are generated at a pace slower than the rate of data packets for route maintenance. Additionally, the algorithm includes a route recovery phase to address the circumstance of route failure caused by an identified invalid route. Apart from focusing on the quickest route, ANTALG considers the quality of the links that comprise the route.

Table 3.1 compares various ant-based protocols, where FA and BA denote Forward and Backward Ants, respectively.

| ***Algorithm*** | ***Routing Approach*** | ***Ant Type*** | ***Energy Awareness*** | ***Problem*** | ***Path Type*** |
|---|---|---|---|---|---|
| ABC | Table driven | Exploratory Ants | - | Congestion along the Best Route | Unipath |
| AntNet | Table driven | FA, BA | - | Longer Delays in Propagation of routing informations | Unipath |
| ARA | On demand | FA, BA | - | Polluted Cache | Multipath |
| Ant AODV | Hybrid | FA, BA | - | Frequent Route fault | Unipath |
| PERA | On demand | FA, BA | - | Greater Overhead | Multipath |
| AntHocNet | Hybrid | FA, BA | - | Increased Overhead | Multipath |

| | | | | | |
|---|---|---|---|---|---|
| ARAAI | Hybrid | FA, BA | Present | Delays due to Route discoveries | Multipath |
| MAARA | Hybrid | FA, BA, Reactive FA & Route repair Ants | - | Decreased packet delivery ratio with increased pause time | Multipath |
| ACO-AOMDV | On demand | FA, BA | - | Increased Overhead | Multipath |
| ADSR | On demand | FA, BA | Present | More Control overhead is required for consistent monitoring of paths | Unipath |
| HOPNET | Hybrid | Intra_zone FA &BA and Inter_Zone FA &BA | - | Scalability to larger networks | Multipath |
| PACONET | On demand | FA, BA | - | Increased Overhead | Unipath |
| PAR | Table driven | FA, BA | - | Overhead in Smaller networks | Unipath |
| ABEAR | Hybrid | FA, BA | Present | More overhead & Adaptation | Multipath |
| ANTALG | Hybrid | FA, BA, Proactive FA, notification ants & error ants | - | Overhead | Multipath |

**Table 3.1 Comparative Analysis of Several ACO-based Techniques**

### 3.4 OBSERVATION AND PURPOSE:

The biological nature of ants enables us to build a strategy capable of dealing with numerous challenges connected with dynamic networks, such as traffic distribution and route creation. Additionally, ant colony optimization can be utilized to imbue the network with learning and adaptive behavior. This can undoubtedly aid in controlling topology's dynamic character.

- ACO-based algorithms such as ABC and AntNet demonstrated the utility of ideas such as ageing, postponing, evaporation, and heuristic function in dynamic networks such as MANETs. This can undoubtedly add adaptive behavior into the routing process in these networks.

- The concept of evaporation is beneficial when dealing with problems such as stale route development over time.

- In protocols like as PAR and ADSR, the usage of continual acknowledgements or Hello messages enables the development of a network state aware routing strategy.

- ACO-AOMDV is an excellent illustration of how to combine the ACO technique with a standard multipath routing protocol such as AOMDV. Thus, demonstrating the ACO approach's relevance to MANETS routing.

- The adoption of a hybrid approach, such as Ant Hoc Net, demonstrates the ideal way to combine the probabilistic behavior of reactive ants with the deterministic behavior of proactive ants to maximize network resource use.

- ABEAR is an excellent example of a method that utilizes many parameters. Additionally, it serves as a catalyst for the development of energy-aware routing strategies for energy-constrained networks such as MANETs.

- The concept of regular and virtual pheromones, i.e. two distinct types of pheromones corresponding to two distinct types of Ants Hoc Net discoveries, may prove effective for mapping the diverse conditions of diverse networks, such as MANETs.

Thus, based on the foregoing discussion of Ant Colony Optimization and its application to MANETs, it can be inferred that ACO may be utilized successfully to optimize the routing mechanism and increase adaptability to the dynamic conditions of MANETs.

## 3.5 SUMMARY:

Traditional MANET routing has a number of drawbacks, including node or connection failures, sluggish response times, and a high overhead. As a nature-inspired technique, ACO is capable of dealing with the intricacies of MANETs. As a result, it outperforms existing procedures. This chapter provides an overview of various ACO-based algorithms. It is possible to conclude that a hybrid approach that leverages the efficacy of both reactive and proactive tactics may yield superior results. Thus, the implementation of ACO enables us to optimize the protocols in MANETs.

## Chapter 4

## AN APPLICATION OF FUZZY LOGIC TO MANET ROUTING PROTOCOLS

### 4.1 INTRODUCTION TO FUZZY LOGIC:

The term "fuzzy" refers to things that are imprecise, unclear, or ambiguous. There are instances in the real world where the state of various entities cannot be predicted precisely. Classical set theory holds true in deterministic situations. The classical view classifies states as true or untrue. Because fuzzy set theory operates between true and false, the state can be partially true or partially false, partially true or partially false, or partially true and partially false. Boolean logic is based on set theory. While in Boolean logic, absolute truth is represented by 1 and absolute falsity by 0, in Fuzzy logic, there is no idea of absolute truth or falsehood. Fuzzy focuses on the values that exist between absolute truth and absolute falsehood.

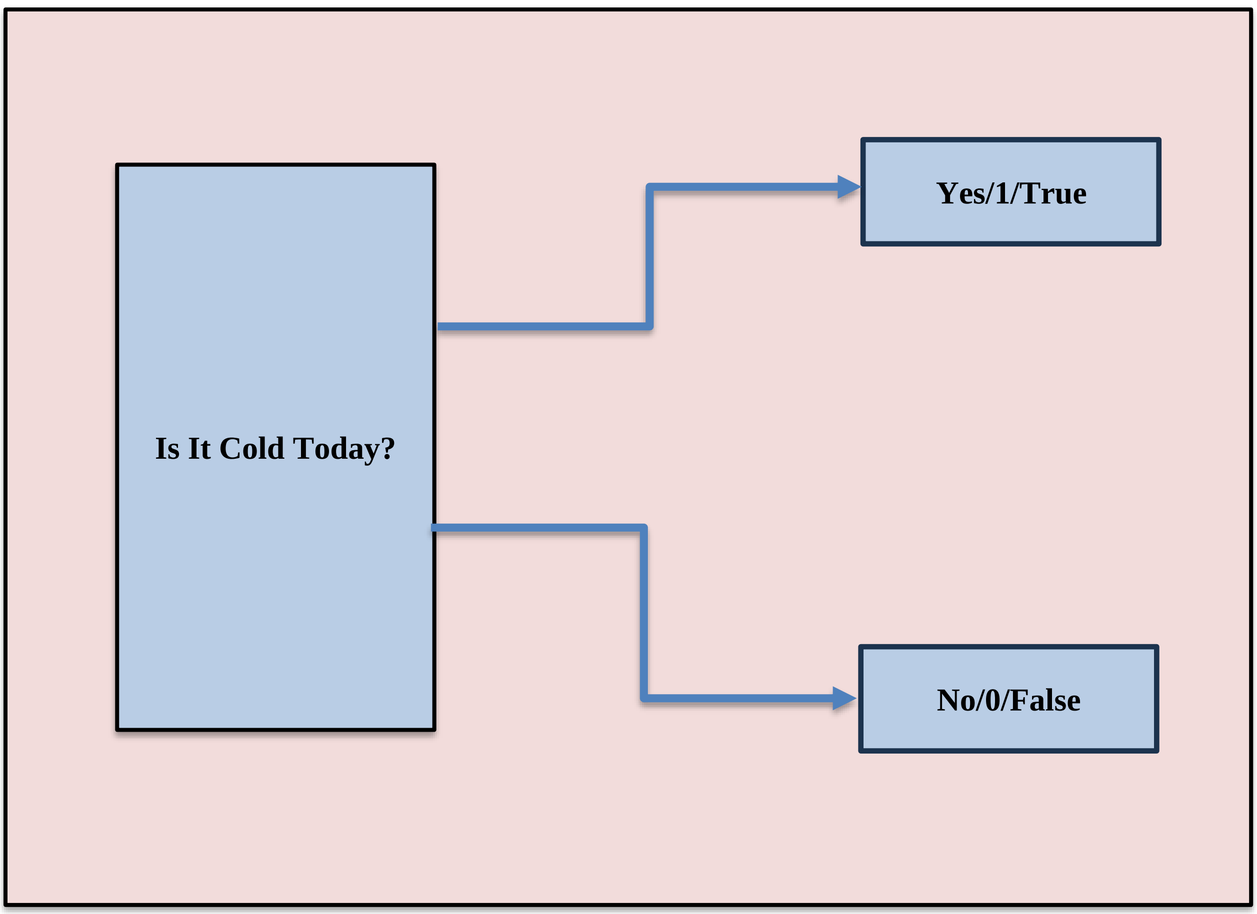


**Figure 4.1 Logic Boolean or Bi-Valued**

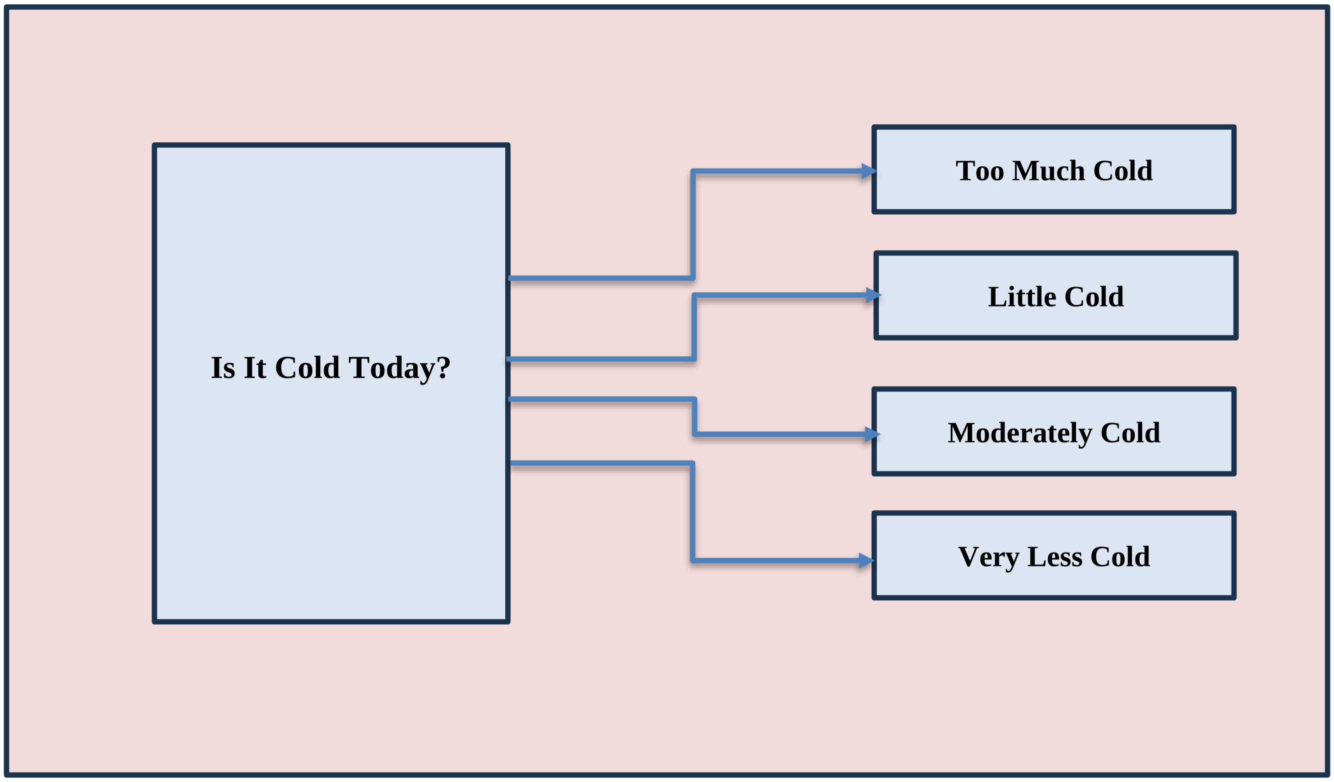


**Figure 4.2 Concept of fuzzy logic**

MANETs are the most susceptible network type. The dynamic nature of ad hoc networks keeps the network's nodes moving. Continuous node movement consumes a significant amount of resources. Constraints on resources are an issue that must always be addressed. Routing protocols are a set of rules that regulate how routes between source and destination nodes are discovered. Routing protocols are responsible for determining a healthy route. There are numerous routing protocols described in the literature. Routing protocols are classified into two groups, proactive and reactive. Routing protocols that are proactive maintain routing tables at each network node. They store routes in advance of a route discovery request, whereas reactive routing protocols always commence route discovery only when a route discovery request is received.

Hybrid routing protocols combine the advantages of reactive and proactive routing protocols. Generally, routing protocols are concerned with determining the shortest path to the destination node. Routing protocols should not be limited to determining the shortest route, as the shortest route is not always the optimal route. Routing protocols must strive to discover the shortest path. The optimal route is one that is stable, reliable, energy efficient, and scalable.

Changes in the placements of mobile nodes introduce uncertainty into the network. Because mobile nodes are battery-powered, they require energy to remain active in the network. Due to the network's changing topology, routes may become unstable at any time. That is why a dynamic routing system is necessary that can discover a steady and dependable path for continuous data packet transfer. Multiple aspects must be considered in order to find a stable approach, including network bandwidth, node energy levels, node mobility, and remaining battery power. Fuzzy logic enables the exact handling of all these imprecise elements and uncertainties associated with ad hoc networks. Fuzzy logic is a problem-solving technique that generates exact and decisive output from imprecise, unclear, and uncertain input. Fuzzy logic was inspired by the way a human being thinks and makes accurate decisions when confronted with an unusual and inaccurate amount of information.

Fuzzy logic is a multi-valued logic that is well-suited for dealing with the uncertainties inherent in MANET. Fuzzy logic is built around the concept of If-then rules. The precision and accuracy of the logic are dependent on the strength of the Fuzzy rules. To begin, relevant input parameters are picked based on the network's requirements. Fuzzification is done to the input parameters, converting them from their crisp values to Fuzzy ones. Then, fuzzy rules play a role in the selection process as a deciding factor. Fuzzy rules are If then statements that are used to create decisions based on the conditions given to the input parameters. These conditions are entirely created by humans. That is how Fuzzy is able to simulate the human mind. Fuzzy rules are created in the same way that human's reason. A fuzzy logic system is a mathematical instrument that successfully models several input and output variables in accordance with the limitations and conditions of the environment.

## 4.2 FUZZY SETS AND MEMBERSHIP FUNCTIONS:

Lotfi Zadeh's 1965 research on "Fuzzy sets" resulted in the establishment of fuzzy logic theory. Aristotle pioneered the concept of bivalued reasoning. However, the origins of fuzzy logic may be traced all the way back to Plato's time. Lukasiewicz hypothesized the presence of a third value in modern times, which he dubbed "possible." It is assigned a numeric value between false and true. This resulted in the growth of research in the field of multivalued logic, specifically four- and five-valued logic. This resulted in the conclusion that an infinite number of options exist between true and false. In principle, the concept of infinite valued logic was likewise recognized. Fuzzy logic is used to model situations that are inherently imprecise. Fuzzy is a technique for approximation reasoning that can be used to assist with decision-making.

Fuzzy set can be thought of as a subset of crisp set. The distinction between the two is in the type of membership each organization supports. A crisp set can have either a complete or a null membership. Additionally, the fuzzy set supports partial membership, which enables it to deal effectively with ambiguous conditions. A characteristic function (y) is used in a crisp set to describe the membership or non-membership of an element y in set B. The membership of element y is described by equation (4.1).

**Where,**

$$\mu a(y) = 1 \quad if \quad y = B \qquad (4.1)$$

and

$$\mu a\,(y) = 0 \quad if \quad y \neq B \qquad (4.1)$$

In this case, B denotes a Fuzzy set. The membership function is denoted by (y) and has a range of possible values between [0, 1]. Fuzzy set theory is capable of accurately representing imprecise linguistic labels such as rapid, slow, low, moderate, and high. The Fuzzy set theory does not impose a restriction on an element's membership in a single Fuzzy set at a time.

Equation illustrates the ordered pair form of B. (4.2). The ordered pair is composed of a standard element y with a value equal to the membership function's value. V is the discourse universe.

$$B = \{(y, \mu B\,(y)) \mid y = V\} \qquad (4.2)$$

In fuzzy set theory, the membership function is represented graphically as a curve that describes the mapping of input values to corresponding membership values ranging from 0 to 1. Different sorts of membership functions are utilized to map crisp data to their corresponding Fuzzy values. Triangular, trapezoidal, bell-shaped, Gaussian, polynomial, and sigmoidal functions are only a few examples.

## 4.3 FUZZY LOGIC SYSTEM:

Fuzzy logic systems are mostly used to approximate functions. All continuous functions or systems can be modelled using fuzzy systems. The general operation of a fuzzy system is depicted in Figure 4.3.

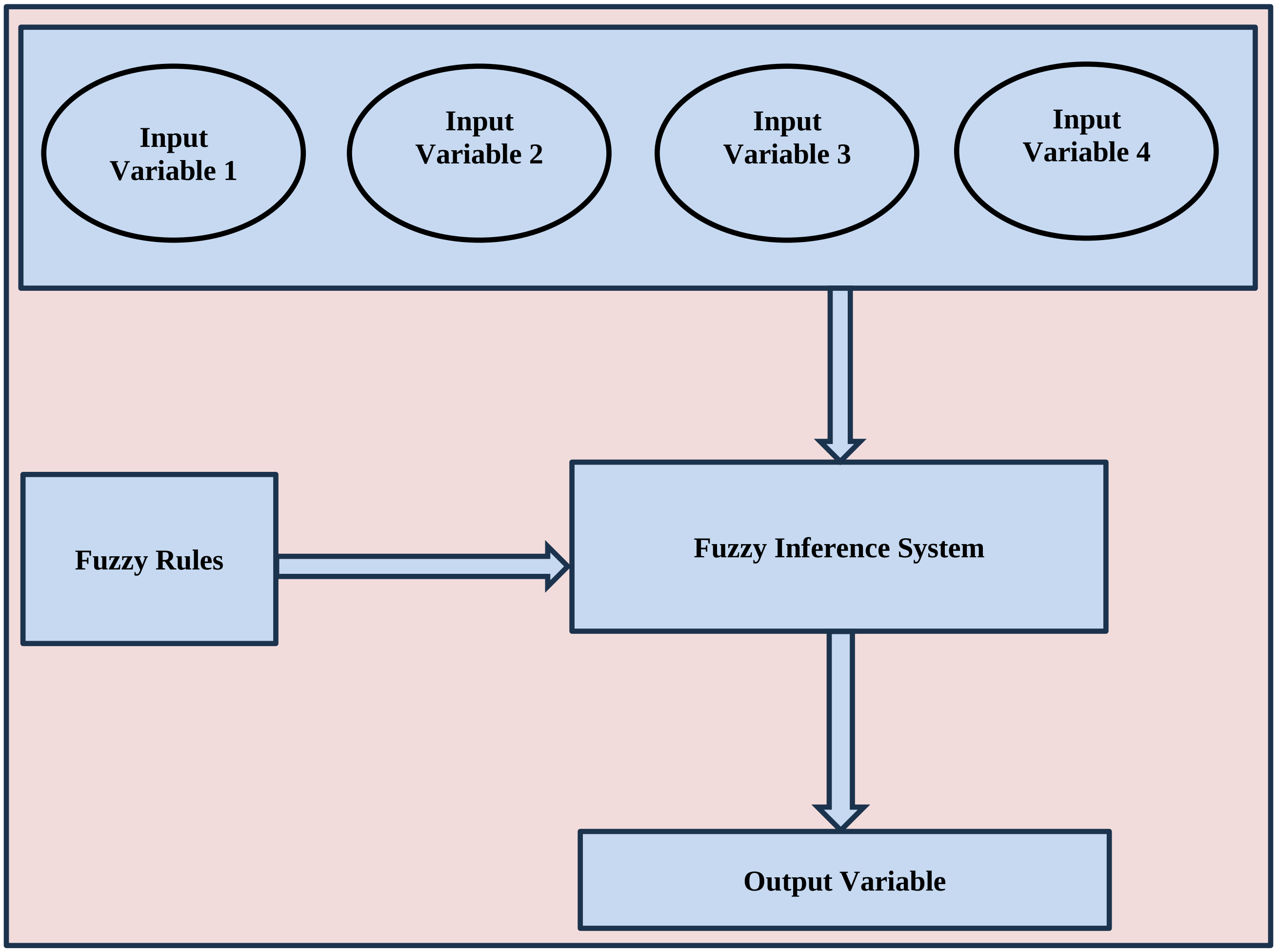


**Figure 4.3 System of Fuzzy Logic in General**

The set of Fuzzy rules developed determines the qualitative component of Fuzzy logic approximation. The outcome of the fuzzy logic system is always an approximation to an unknown non-linear function that changes over time. In general, fuzzy logic is a concept for modelling the linguistic variable in such a way that it models the imprecise rules in real time. The entire approximation process in fuzzy logic systems is dependent on the application of If- then rules. These rules aid in the conversion of an input to an output. The fuzzy inference system is the primary component of the fuzzy logic system that is in charge of the decision-making process. The following are the several processes that occur in the fuzzy inference system:

#### 4.3.1 Fuzzification:

The process of fuzzifying variables is taking input in the form of crisp values and associating them with a suitable Fuzzy set using a membership function. Thus, fuzzification is a procedure that converts crisp input data to fuzzy input data represented by linguistic variables. The membership function is used to translate the crisp input to the fuzzy input. The membership function quantifies how much an input variable belongs to the Fuzzy set.

#### 4.3.2 Application of Fuzzy Operator:

Following fuzzification, it is straightforward to determine the degree of satisfaction of each antecedent component corresponding to each rule. If a rule has more than one antecedent, the Fuzzy operator is used to calculate the rule's resultant antecedent value. The AND and OR fuzzy operators are frequently employed in the fuzzification process. The fuzzy operator accepts two or more membership values for the Fuzzy input variables and outputs a single truth value.

#### 4.3.3 Application of Implication Method:

The fuzzy rule base is made up of a diverse set of validated and finite-number Fuzzy rules. These rules are predicated on the ability to reason. If-then rules are constructed in such a way that they can imitate the thoughts, restrictions, and logic of the human mind. Each rule carries a distinct weight (i.e. from 0 to 1). This weight is typically set to 1 and has no effect on the inference process. Thus, in order to mitigate the effect of a particular rule, we can reduce its weight. Following the weight assignment, the implication process is carried out for each rule. This procedure accepts a single number as input and produces a Fuzzy set as output.

#### 4.3.4 Aggregation:

Aggregation is another operation that the inference system performs. Aggregation is the process of combining or aggregating the Fuzzy sets corresponding to the output of all the rules into a single Fuzzy set. Aggregation is performed once for all output variables, before to the final defuzzification step. The aggregating procedure requires as inputs a list of the outcomes obtained from each rule. Aggregation produces a single Fuzzy set as a result.

#### 4.3.5 Defuzzification:

Defuzzification is the technique of extracting precise values from Fuzzy output values. This procedure takes a Fuzzy set as input and outputs a single crisp value. The output of the defuzzifier can be denormalized to values acceptable in the actual world, however this step is optional. Numerous defuzzification strategies exist in fuzzy set theory, including the centroid approach, the bisector method, the smallest of maximum method, the average of maximum method, and the largest of maximum method. Among the six approaches discussed previously, the centroid (or) center of gravity method is the simplest and most used.

## 4.4 FUZZY LOGIC APPLICATIONS IN MANETS:

Due to the lack of infrastructure, MANETs face resource constraints. Routing efficiently and effectively allocating resources across nodes is a difficult problem that must be addressed. Peer-to-peer communication is used in Mobile Ad hoc Networks, which enables each node to operate as a receiver and forwarder of packets for the network's other nodes. Thus, a path between two points may contain a number of intermediate nodes. Additionally, because MANETs are wireless networks, they have lower capacity, longer distances, and less consistent connectivity.

Due to the presence of such variable factors, MANETs are an ideal environment for implementing fuzzy logic. As an illustration, Venkateswaran suggested a mobility metric and implemented it in MANETs using the fuzzy logic idea. Additionally, this metric was used to generate clusters in the algorithm. Additionally, the metric created in this manner resulted in stable cluster formation.

Shangchao et al. demonstrated that the Fuzzy scheduler may be used to process many input variables to produce a single output variable. Shangchao et al. demonstrated that multiple uncertain parameters such as expiry time, data packet rate, and queue length on each node can simply be handled as input to a fuzzy scheduler to produce a stable output in the form of some priority index. Fuzzy logic's effectiveness is based on its capacity to deal with uncertainty. Thus, fuzzy logic may be employed efficiently in MANETs to control a variety of uncertain aspects.

The incorporation of fuzzy logic ideas into MANET routing protocols indicates the extent of work that may be done in this field to improve the dependability and control of such networks' uncertainties. The work on fuzzy logic in the realm of MANETs has been investigated and summarized in Table 4.1. Thus, fuzzy logic can be employed to increase the protocol's efficiency.

| S. No. | Routing Protocol | Input Parameter Used | Output Parameter Used | Support for Multipath | Remarks |
|---|---|---|---|---|---|
| 1. | Fuzzy Ant Colony Based Routing Protocol. [61] | Remaining Battery Power, Buffer Occupancy, Signal Stability | Fuzzy cost (Representing Cost of Node Participating in Routing | No | PDR has been improved, reduction in delays and less Number of Route Discovery |
| 2. | Reliable Routing Algorithm Based on Fuzzy Logic (RRAF) [62] | Trust Value, Energy | Reliability Value | No | Better PDR as compared to AODV but high End-to-End Delay |
| 3. | Fuzzy Controllers Based Multipath Routing Algorithm in MANET [60] | Expiry Time, Rate of data packet and Queues Length maintained at nodes | Priority Index | Yes | Higher PDR, lower number of routing packets, lesser end to end delay |
| 4. | Fuzzy Logic Stable Backbone Based Multipath Routing Protocol. (FLSBMRP). [63] | Unutilized Bandwidth, Remaining Energy, Nodes Mobility, Links Quality and Reputation Index | Combined Score (CS) is calculated. Based on CS Candidate Node is detected | Yes | Reduces Drop Rate and increases PDR as compared to EDRP |
| 5. | Fuzzy Logic Based Clusterhead Selection Protocol [64] | Level of Competence Mobility and Goodness Function, and Mobility | Clusterhead Selection | No | Better selection of Clusterhead and minimization of Overhead. |
| 6. | Fuzzy Logic based Stable on Demand Multipath Routing Protocol (FLSMORP) [65] | Mobility, Energy | Link Stability | Yes | Minimized Overhead, Minimized Delay |
| 7. | Fuzzy Based Energy efficient multicast Routing for Ad-hoc Networks. (FBEEMR) [66] | Number of Hop. Number of Packet transmitted and Remaining Energy | Route Lifetime | No | Increase in Route Lifetime |
| 8. | Uncertain Rule Based Fuzzy Logic QoS Trust Model in MANETS [67] | Energy, Bandwidth and Link Stability | Node Trust value | No | Better End- to- End delays and throughput |
| 9. | Fuzzy Based Trust Model for Detection of Selfish Nodes [68] | Percentage of Dropped packet, Percentage of Dropped TC Packet, Percentage of TC Packet Generated. | Trust | No | Increase in PDR as compared to SLCR |
| 10. | A Fuzzy Priority Based Congestion Control Scheme. [69] | Average Queue Size, difference between avg. queue size and instantaneous queue size | Max. Drop Probability | No | Decreased packet loss, End-to-End delay and energy consumption |

**Table 4.1 Fuzzy logic in MANETs**

## 4.5 SUMMARY:

This chapter taught the fundamental concept of fuzzy logic. The phrase "fuzzy" refers to imprecision, uncertainty, and vagueness. The capacity of fuzzy set theory to cope with possible outcomes of two distinct situations has constantly aided researchers in achieving accurate and exact conclusions from imprecise input values. The focus of this research is mostly on optimizing the routing mechanism of MANETs. MANETs are networks with a high degree of dynamic behavior. A sufficient battery charge is essential for mobile nodes to stay functioning over time in the network. After a period of time, the network's dynamic topology may cause some of the routes to become unstable. As a result, dynamic routing protocols must make suitable decisions based on available resources and circumstances when selecting nodes or paths. By utilizing fuzzy logic, it is able to precisely handle all of the imprecision factors and uncertainties associated with ad hoc networks. It has the potential to be a very useful tool for dealing with MANETs that have extremely high degrees of uncertainty due to node mobility.

This chapter serves as a foundation for the subsequent work in Chapter 6, which calculates Node Selection Probability by fuzzifying Next Node Probability (NNP) and proportionate Energy Change (PEC) as input parameters. This will also be used to make a decision regarding the next intermediate node to be selected from a list of numerous available nodes.

# CHAPTER 5

# COLLECTIVE USE OF INFLUENCING PARAMETERS IN MANET ROUTING PROTOCOL ANALYSIS

This chapter proposes a novel approach for evaluating routing protocols in MANETs. After modelling a protocol, it is critical to conduct evaluation and analysis. A protocol's effectiveness and scope are determined by its evaluation procedure. This chapter defines a metric for evaluating routing protocols. The proposed metric is called "NET." The purpose of developing this statistic is to identify critical areas for optimizing routing protocol performance.

Numerous factors affect routing protocol performance in MANETs. These numerous elements also contribute to the breadth of possible research in the field of routing in MANETs. The performance of protocols associated with a given factor can be evaluated using the performance metrics discussed in Chapter 1. Performance metrics are critical tools for evaluating results related to packet delivery, latency, bandwidth use, and energy efficiency. However, none of them truly informs us about a particular location among the numerous alternatives for further optimizing a given technique.

The proposed metric intends to investigate the various options for selecting a potential exploitation location.

## 5.1 FORMULATION OF THE PROBLEM:

Each routing protocol in MANETs has a unique purpose. Numerous indicators are available for analyzing the properties of these regimens. The chapter discusses the measurements, which include energy consumption, end-to-end delays, packet delivery ratio, and throughput.

A protocol may perform admirably in one metric but fall short in another. This topic is best illustrated through the use of a real-world example. For instance, an automobile may have the fastest top speed but poor fuel efficiency. Thus, a complete inference about a car can be reached only after thoroughly comparing both of its aspects. Both components may be assigned a positive and negative value on a particular scale for this purpose. The cumulative value obtained as a result of both criteria may determine whether the car is a good or a terrible buy.

Similarly, a cumulative metric is required to assess the overall quality of protocols. This measure must be capable of analyzing a protocol in its entirety. Certain trade-offs inherent in the existing metric system also require thorough consideration. These trade-offs can be mitigated by allocating appropriate weights to protocols based on their performance on various criteria. Thus, the task can be characterized as developing a cumulative metric that takes multiple elements of protocols into account.

The following procedures have been taken to process a cumulative metric.

- All aspects that contribute to a protocol's performance improvement are studied.
- Additionally, the aspects that contribute to the protocol's degraded performance are studied.
- Each factor's proportionate value is determined for each increase or reduction in each metric.
- Different elements may be weighted differently depending on the level of service support.
- The cumulative value so obtained provides a holistic picture of the nature and scope of future work that can be accomplished.

## 5.2 COMPARISON OF PROTOCOLS BASED ON SIMULATION USING A TRADITIONAL APPROACH:

In MANETs, protocols may use a single or several pathways between the source and destination. As a result, they can be classified as unipath or multipath routing protocols. As discussed in Chapter 1, DSDV and AODV are instances of unipath routing protocols. As discussed in Chapter 2, AOMDV is an example of a multipath routing protocol, in that disconnected pathways can be specified. Historically, the following metrics have been used to evaluate the performance of routing protocols in MANETs:

- Packet Delivery Ratio (PDR)

- Throughput
- End-to-End delay
- Energy Consumption

The Network simulator (NS2) is an event-driven simulator for simulating and analyzing a variety of MANET protocols. Three protocols, AODV, DSDV, and AOMDV, were compared in this article using Network Simulator 2. The best examples of proactive and reactive unipath routing protocols, respectively, are DSDV and AODV, whereas AOMDV is a prominent example of multipath routing protocols.

| | |
|---|---|
| *Routing Protocol* | *AODV, AOMDV, DSDV* |
| *Network topology* | *1000 * 1000* |
| *MAC Type* | *802.11* |
| *Traffic Type* | *TCP* |
| *Max. Packet in IFQ* | *50* |
| *Radio propagation model* | *Two ray ground* |
| *Number of Nodes* | *20,40,60,80,100* |
| *Packet size* | *1500 byte* |
| *Max. Simulation time* | *50 s* |
| *Initial Energy* | *100 joule* |

**Table 5.1 Simulation Parameters**

Table 5.1 contains a list of several simulation settings for DSDV, AODV, and AOMDV simulations. A 1000 X 1000 node network topology has been chosen. The simulation is run for several node counts, namely 20, 40, 60, 80, and 100, for a total of 50 seconds. To investigate the network's energy usage, the energy model has been included in the relevant protocol's TCL scripts. Initially, each node was allotted 100 joules of energy.

Table 5.2 contains the results of protocol simulations using the settings specified in Table 5.1.

| Nodes | Energy | End-to-End Delay (ms) | PDR | Throughput |
|---|---|---|---|---|
| ***AODV*** | | | | |
| ***20*** | *48.25* | *170.58* | *90.58* | *51.62* |
| ***40*** | *49.22* | *175.64* | *95.97* | *73.73* |
| ***60*** | *49.28* | *249.44* | *90.64* | *97.97* |
| ***80*** | *49.27* | *290.97* | *84.66* | *206.3* |
| ***100*** | *49.08* | *313.02* | *81.54* | *372.7* |
| ***AOMDV*** | | | | |
| ***20*** | *49.98* | *175.12* | *90.38* | *72.17* |
| ***40*** | *49.94* | *277.63* | *81.33* | *110.11* |
| ***60*** | *49.99* | *255.94* | *92.08* | *161.84* |
| ***80*** | *49.98* | *343.64* | *87.06* | *276.63* |
| ***100*** | *49.99* | *309.62* | *87.64* | *419.96* |
| ***DSDV*** | | | | |
| ***20*** | *49.88* | *166.09* | *94.98* | *47.69* |
| ***40*** | *49.61* | *255.25* | *94.95* | *58.71* |
| ***60*** | *49.8* | *244.7* | *95.56* | *78.27* |
| ***80*** | *49.92* | *305.14* | *92.55* | *104.54* |
| ***100*** | *49.98* | *284.71* | *96.42* | *142.84* |

**Table 5.2 Comparative Analysis of Various Protocols Using NS2 Simulation**

Several key observations from the simulations include the following:

AOMDV achieves a throughput of 72.17 when the number of nodes is equal to twenty. This is significantly better than the throughput values for DSDV and AODV, which are 47.69 and 51.62, respectively. However, in terms of end-to-end delay, AOMDV outperforms both DSDV and AODV, with end-to-end delays of 175.12, 166.09, and 170.58 for the same number of nodes using AOMDV, DSDV, and AODV, respectively.

In terms of Packet Delivery Ratio for 20 nodes, DSDV outperforms AODV and AOMDV PDR. The results indicate that DSDV has a PDR of 94.98 percent, whereas AODV and AOMDV have PDRs of 90.58 and 90.38 percent, respectively.

Additionally, the data demonstrate a tendency toward increased energy consumption in multipath routing protocols, with AOMDV requiring more energy regardless of the number of nodes. AOMDV consumes 49.99 joules of energy per 100 nodes, compared to 49.08 joules for AODV and 49.98 for DSDV.

In comparison to energy, the results for throughput demonstrate that a multipath routing protocol has a higher throughput than a unipath routing system for the same number of nodes. Specifically, 419.96 for AOMDV versus 372.7 and 142.84 for AODV and DSDV for 100 nodes, respectively.

These observations from the simulation of three protocols are really intriguing and may serve as the foundation for future work aimed at increasing the efficiency of the analysis process. The next part examines the primary shortcomings of the traditional evaluation system and the recommended remedy for increasing the effectiveness of the evaluation process.

## 5.3 IMPROVE YOUR EVALUATION STRATEGY:

Two sections have been segregated into the process of optimizing the evaluation strategy. The first section discusses the shortcomings of the conventional technique, while the second portion specifies the cumulative metric.

### 5.3.1 Constraints with the Existing Approach:

The following limitations can be deduced from the simulation analysis presented in the preceding section:

- For 100 nodes, we can see that AOMDV consumes around 0.91 joules more energy than AODV but has a significantly higher throughput. As a result, it is necessary to determine whether this 0.91 joule may be sacrificed in exchange for improved throughput.

- The conventional metrics provide findings in a variety of units. As a result, there is no way to compare the findings for each metric. As a result, we cannot compare the worst energy consumption statistics for AOMDV to the best throughput values.

- The traditional system does not provide weights to metrics that match to the user's requirements.

Thus, a cumulative metric is required that takes multiple aspects into account with appropriate weighting for each factor. By utilizing this measure, the performance of various protocols can be easily compared on a variety of different dimensions, and a holistic perspective of the protocol's performance in relation to the user demand can also be deduced.

### 5.3.2 A Cumulative Performance Metric:

To develop a cumulative metric, it is necessary to consider a variety of factors, including the following:

All aspects that contribute to a protocol's performance improvement are studied. For instance, Packet Delivery Ratio and Throughput both contribute to the protocol's performance improvement. The higher the packet delivery ratio and throughput, the more efficient the protocol.

Additionally, the elements that contribute to the protocol's degraded performance are studied, such as energy consumption and end-to-end delays. The more energy consumed and the longer the end-to-end delay, the lower the performance.

Each factor's proportionate value is determined for each increase or reduction in each metric. This means that if a given protocol achieves better outcomes in a certain metric, the number of times they achieve better results than the worst possible result in the protocols being compared must be calculated.

To arrive at an aggregate value, or cumulative value, weights are allocated to several elements based on the quality-of-service assistance. For instance, if we want to improve the Packet Delivery Ratio, we might give it a higher weight than other criteria.

The cumulative value so obtained provides a holistic picture of the protocol's nature and extent of applicability.

NET has been developed in the following manner to account for the aforementioned factors.

$$\mathrm{NET_i} = \alpha \mathrm{E}_i + \beta \mathrm{P}_i + \gamma \mathrm{T}_i + \delta \mathrm{D}_i \tag{5.1}$$

$$\mathrm{E_i} = [((\mathrm{E_c} - \mathrm{E_{min}}) - (\mathrm{E_{max}} - \mathrm{E_C}))/\mathrm{E_{min}}] \tag{5.2}$$

$$P_i = [((P_c - P_{min}) - (P_{max} - P_C))/P_{min}] \tag{5.3}$$

$$T_i = [((T_c - T_{min}) - (T_{max} - T_C))/T_{min}] \tag{5.4}$$

$$D_i = [((D_c - D_{min}) - (D_{max} - D_C))/D_{min}] \tag{5.5}$$

Additionally, NET is a versatile statistic in that it allows for the addition of new factors as well as the elimination of current factors, depending on the comparative scenario.

## 5.4 ANALYSIS IMPLEMENTED WITH A CUMULATIVE METRIC:

The NET measure developed in the preceding section was used to evaluate the performance of the identical protocols that were simulated in Section 5.2 using the old approach. The weights, i.e., and have been assumed to be equal to one. The above-mentioned protocols' simulation results have been examined using the NET metric in Table 5.3.

| Nodes | Energy | End-to-End Delay (ms) | PDR | Throughput | Energy Factor | Delay Factor | PDR Factor | Throughput Factor | NET |
|---|---|---|---|---|---|---|---|---|---|
| **AODV** | | | | | | | | | |
| **20** | 48.25 | 170.58 | 90.58 | 51.62 | 0.04 | 0.00 | -0.05 | -0.35 | -0.36 |
| **40** | 49.22 | 175.64 | 95.97 | 73.73 | 0.01 | 0.70 | 0.18 | -0.36 | 0.54 |
| **60** | 49.28 | 249.44 | 90.64 | 97.97 | 0.01 | 0.01 | -0.05 | -0.56 | -0.60 |
| **80** | 49.27 | 290.97 | 84.66 | 206.3 | 0.01 | 0.22 | -0.09 | 0.30 | 0.44 |
| **100** | 49.08 | 313.02 | 81.54 | 372.7 | 0.02 | -0.10 | -0.18 | 1.28 | 1.01 |
| **AOMDV** | | | | | | | | | |
| **20** | 49.98 | 175.12 | 90.38 | 72.17 | -0.04 | -0.05 | -0.05 | 0.51 | 0.37 |
| **40** | 49.94 | 277.63 | 81.33 | 110.11 | -0.01 | -0.11 | -0.18 | 0.88 | 0.57 |
| **60** | 49.99 | 255.94 | 92.08 | 161.84 | -0.01 | -0.05 | -0.02 | 1.07 | 0.98 |
| **80** | 49.98 | 343.64 | 87.06 | 276.63 | -0.01 | -0.13 | -0.04 | 1.65 | 1.47 |
| **100** | 49.99 | 309.62 | 87.64 | 419.96 | -0.02 | -0.08 | -0.03 | 0.94 | 1.81 |
| **DSDV** | | | | | | | | | |
| **20** | 49.88 | 166.09 | 94.98 | 47.69 | -0.03 | 0.05 | 0.05 | -0.51 | -0.44 |
| **40** | 49.61 | 255.25 | 94.95 | 58.71 | 0.00 | 0.07 | 0.15 | -0.88 | -0.66 |
| **60** | 49.8 | 244.7 | 95.56 | 78.27 | -0.01 | 0.05 | 0.05 | -1.07 | -0.97 |
| **80** | 49.92 | 305.14 | 92.55 | 104.54 | -0.01 | 0.13 | 0.09 | -1.65 | -1.44 |
| **100** | 49.98 | 284.71 | 96.42 | 142.84 | -0.02 | 0.10 | 0.18 | -1.94 | -1.68 |

**Table 5.3 AODV, AOMDV, and DSDV Comparison**

The NET metric demonstrates that multipath protocols, such as AOMDV, outperform both AODV and DSDV when the number of nodes is equal to twenty. AOMDV's NET value is

0.37, compared to -0.36 and 0.44 for AODV and DSDV, respectively.

Additionally, increasing the number of nodes has no effect on the performance of AOMDV. For 100 nodes, the AOMDV records a value of 1.81, compared to 1.01 and -1.68 for the AODV and DSDV, respectively.

Another fact that can be proved by the use of the NET metric is that, unlike the other two protocols, the performance of AOMDV does not degrade as the number of nodes increases.

While AOMDV consumes somewhat more energy than the other two protocols, the throughput given compensates for the energy loss, i.e. the Throughput factor of 1.94 is excessive in relation to the minor energy loss produced by the Energy factor of -0.02. The downward trend in the Energy factor of multipath routing protocols, i.e. AOMDV, with increasing node count demonstrates the breadth of work that may be done to reduce energy usage.

Table 5.3 demonstrates the efficacy of employing a multipath routing protocol such as AOMDV. Apart from demonstrating the necessity of multipath routing, this paper studied and demonstrated the extent of work that can be done to optimize the performance of routing protocols in ad hoc networks by utilizing the energy factor.

## 5.5 SUMMARY:

Traditional performance indicators are critical inputs to the measurement process in ad hoc networks. There are numerous opportunities for development in ad hoc networking protocols. The simulation offered in the chapter demonstrated correctly that no single protocol can be superior in every metric of routing protocol performance measurement. Additionally, this does not indicate that in order to optimize a certain statistic, the other metric can be completely neglected. A cumulative metric is required to achieve the optimal combination of all the components. This chapter proposes a cumulative metric, NET, for evaluating protocols on the basis of their energy, PDR, throughput, and delay characteristics. However, the NET metric's variables may vary based on the comparative scenario. The NET metric enables effective examination of a protocol's overall performance, resulting in a full analysis of any protocol. Additionally, this statistic aids in identifying areas where a given technique falls short.

# CHAPTER 6

# CRITERIA FOR NEXT NODE SELECTION IN MANETS BASED ON FUZZY LOGIC

This chapter discusses how to design node selection criteria for data forwarding in MANETs. MANETs are self-organizing networks. MANET topology is highly unclear. Additionally, MANETs have a finite amount of energy accessible at each node. Each node's limited energy supply may become depleted. This further complicates the process of selecting the next node for data transmission. The suggested node selection criteria take into account the uncertainty inherent in MANETs while making the next node selection.

Two assumptions underpin the suggested design. To begin, each node is aware of the number of hops required to reach a specific destination via a particular neighbor node, and secondly, each node is aware of the neighbor nodes' energy levels. The technique uses a fuzzy controller to determine the likelihood of selecting the next node from a list of probable nodes. By minimizing uncertainties, the fuzzy controller's output determines. It returns a Fuzzy value that can be used to determine the next node. Additionally, this value may be used to establish a proportional load distribution across many lines.

Overutilization of nodes may also result in a drop in their energy level. This situation can deteriorate further if node usages continue in the same manner, as this can effectively kill nodes in MANETs. Fuzzy logic is capable of coping with these kinds of uncertainties. This is easily accomplished by portraying this condition as Fuzzy inputs and utilizing the output from the Fuzzy controller to prevent overutilization of a single node.

The proposed technique is an attempt to identify the optimal paths through the use of fuzzy logic to rate distinct paths.

## 6.1 FORMULATION OF THE PROBLEM:

Multipath routing enables a node to distribute data across various paths in order to maximize throughput. However, it is possible that a single path is being used frequently among all potential paths. This can result in a reduction in the energy levels of the nodes along that path. Thus, the initial challenge is to distribute the data across multiple pathways while avoiding excessive energy use. The second issue is to transmit data with the fewest possible nodes. However, there is a direct conflict between two issues. If we continue to use roads with short journey lengths, energy along those paths will deplete. Thus, an optimal combination of the two may suffice. This can be easily accomplished by the use of fuzzy logic to this situation. Both variables can be used as Fuzzy input variables for the Fuzzy controller.

The following procedures have been taken to process the inputs using fuzzy logic controllers: The input variables and their probable boundary values have been discovered.

- Output variables are listed alongside the predicted outcome and their associated boundary values.
- Establishment of a rule base, that is, a collection of rules that define and control the system.
- Define Fuzzy membership functions for both the input and output Fuzzy sets.
- Choosing how to carry out each rule's action.
- Aggregation of rules and defuzzification of Fuzzy output to produce crisp values

## 6.2 CRITERIA FOR SELECTION OF THE NEXT NODE:

Numerous loop-free pathways are a critical characteristic of multipath routing technologies. When comparing multiple pathways, some may have a higher utilization rate than others. It is preferable to take the shortest path to the destination in MANETs. However, this may result in an excessive use of energy resources along that trip. As a result, there is a direct contradiction between two variables. i.e. the number of hops and the amount of energy consumed.

Additionally, Chiang Kang Tan and Lionel Sacks demonstrated the importance of a fuzzy mixed metric method over a single metric approach. They optimized routing decisions by combining latency and connection use. Similarly, a mixed metric can be determined by combining two variables, namely hop count and energy use. This section discusses the various components of criteria and their implementation using fuzzy logic.

### 6.2.1 Criteria's Components:

Energy consumption is a critical aspect to consider when selecting a node to operate as a forwarding node in MANETs. If the energy associated with an intermediate node falls below a particular permitted level, the node may fail. This can result in the failure of the link, and hence the route. The primary objective of this section is to develop criteria for selecting the next node in order to lay a stronger foundation for an energy-efficient protocol. Each intermediate node is designed to avoid this type of route failure. This is simply accomplished by transmitting the node's energy state to its neighbors.

The selection of the next node in classic multipath routing protocols is entirely reliant on the number of hops required to reach a destination. For instance, suppose some node A is capable of forwarding packets to node D via three distinct routes. The three intermediary nodes along those pathways are denoted by X, Y, and Z. Assume that the routes through nodes X, Y, and Z have a hop count of 4, 5, and 6, respectively. Then node X has a greater chance of being selected because the route through it is the shortest.

Traditional methods do not take into account elements such as leftover energy. Thus, selecting routes with a residual energy factor in mind is a critical necessity for building an energy efficient procedure. Thus, the selection criteria must consider both elements, namely the number of hops and the energy. Equation 6.1 gives a selection criterion for the next node based on these parameters.

$$NNS(j) = NNP(j) * \ PEC(j) \tag{6.1}$$

NNS(j) in equation 6.1 denotes the probability of node j being selected as the next node, i.e. Next Node Selection. NNP(j) is the Next Node Probability for node j and is inversely proportional to the route length through j. PEC(j) denotes the Proportional Energy Change, which is equal to the ratio of node j's current energy level to its previous energy level.

In this case, employing the above function, fuzzy logic can prove to be an efficient tool for determining which node should be selected as the next node.

### 6.2.2 Implementation of Selection Criteria Using Fuzzy Logic:

Multiple paths between a source and destination can be easily identified using a multipath routing technique. Numerous paths developed may be identical in length (i.e. hop count). In this case, the optimal path can be determined using equation 6.1. To successfully apply and analyses this criterion, fuzzy logic can be implemented by employing NNP(j) and PEC(j) as Fuzzy inputs to the Fuzzy controller.

The Fuzzy logic output for a node's Next Node Selection is calculated by applying Fuzzy rules to two input parameters, namely the Next Node Probability (NNP) and the Proportional Energy Change (PEC). It is depicted in Figure 6.1.

A fuzzy logic controller operates according to a set of rules. The regulations are established based on a certain rationale. For instance, a node with a high Next Node Probability (NNP) and a large Proportional Energy Change (PEC) will have a very high Next Node Selection value (NNS).

The entire procedure of using fuzzy logic is as follows:

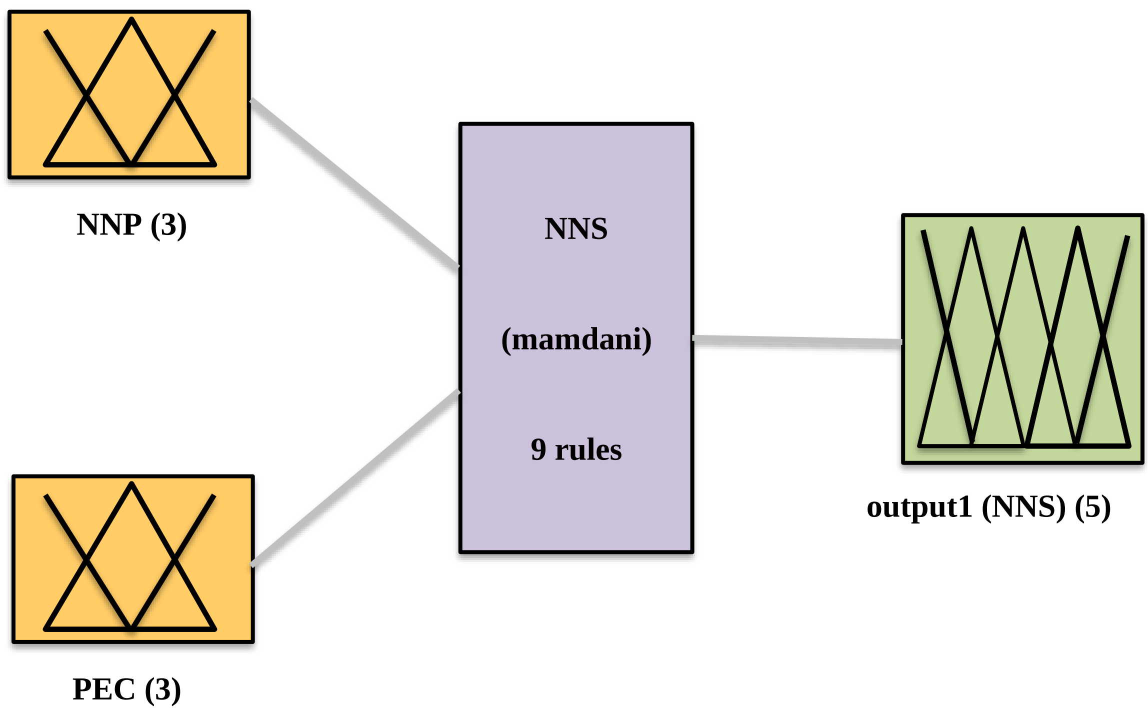


**Figure 6.1 Controller based on fuzzy logic**

**(a) Making Fuzzy Inputs and Outputs Decisions:**

The following are the fuzzy inputs for the fuzzy logic controller:

- Next Node Probability (NNP)
- Proportional Energy Change (PEC)

In a fuzzy inference system, the fuzzy logic system is composed of certain fuzzy input parameters. To obtain the desired result, the Fuzzy logic rules are applied to these inputs. The Input membership function, the output membership function, the Fuzzy rule matrix, and the Fuzzy rule base are all shown in Table 6.1-6.4, respectively. Thus, the following table summarizes the numerous inputs and outputs of the fuzzy logic controller:

**(b) Fuzzification:**

The Fuzzy controller is fed crisp values matching to NNP and PEC for possible next nodes. The input data is subsequently fuzzified using membership functions, as illustrated in Figure 6.2 and 6.3.

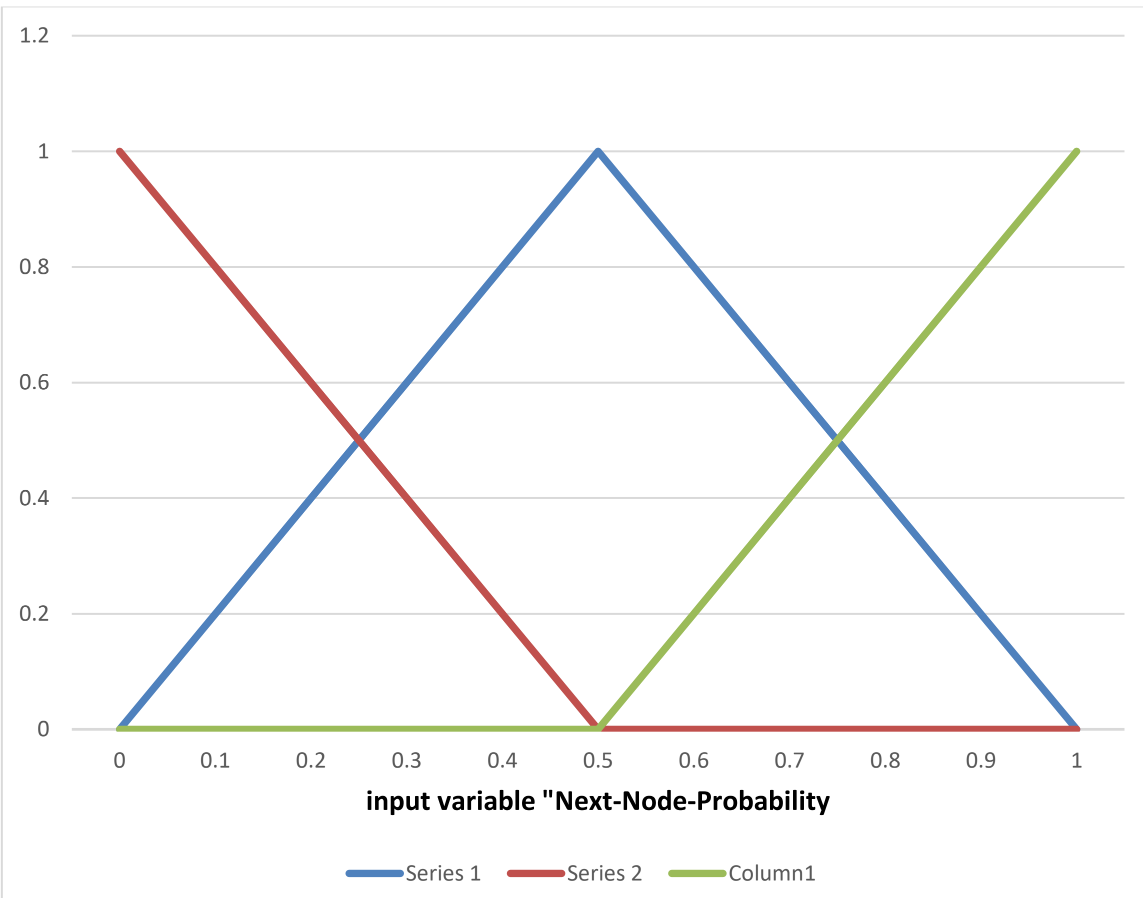


**Figure 6.2 Membership Function of the Probability of the Next Node**

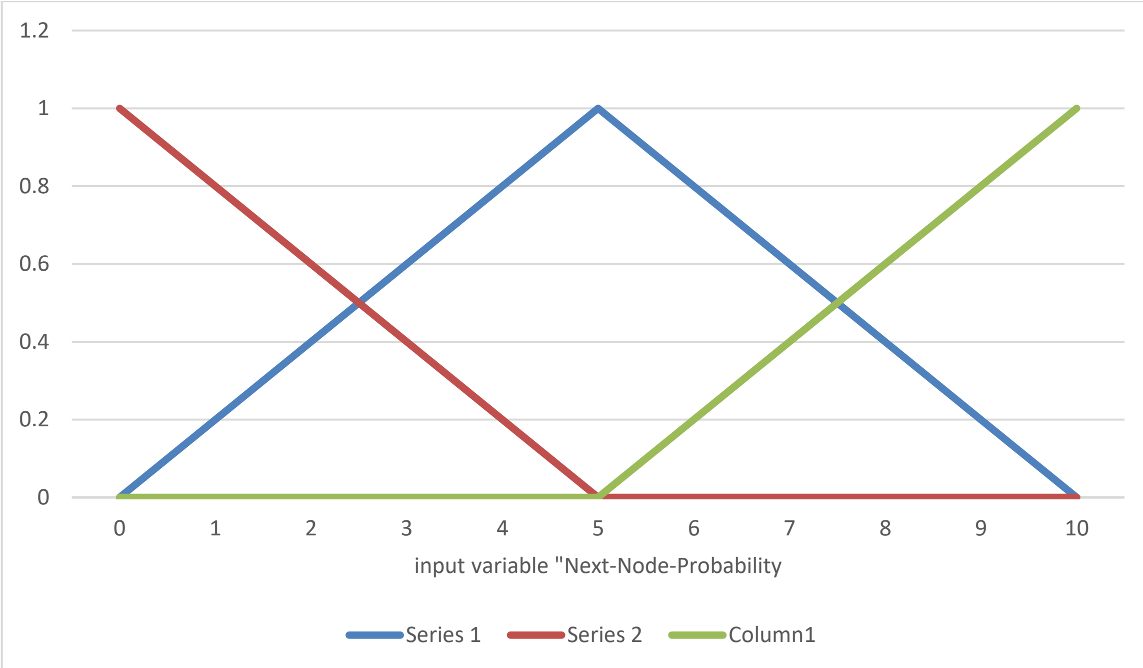


**Figure 6.3 Membership Function for Changes in Proportional Energy**

The membership function corresponding to the output function is depicted in Figure 6.4.

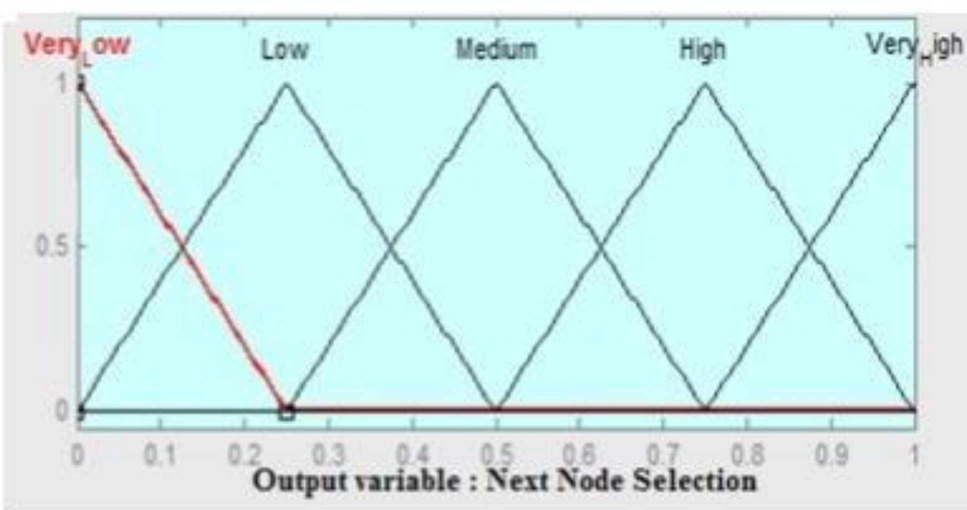


**Figure 6.4 Next Node Selection's Membership Function**

The following are the input and output Fuzzy sets with three and five parameters, respectively:

$$\mu_{NNP} = \mu_{low}, \mu_{med}, \mu_{high} \tag{6.4}$$

$$\mu_{PEC} = \mu_{low}, \mu_{med}, \mu_{high} \qquad (6.4)$$

$$\mu_{NNS} = \mu_{Vlow}, \mu_{low}, \mu_{medium}, \mu_{High}, \mu_{Vlow} \qquad (6.4)$$

Vlow and Vhigh denote extremely low and extremely high values, respectively.
The membership of the input and output functions is shown in Tables 6.1 and 6.2.

| **Input** | **Membership** | | |
|---|---|---|---|
| **Next Node Probability (NNP)** | Low | Medium | High |
| **Proportional Energy Change (PEC)** | Low | Medium | High |

**Table 6.1 Input Functions**

| **Output** | **Membership** |
|---|---|
| Next Node Selection | Vlow, Low, Medium, High, Vhigh |

**Table 6.2 Output Function**

**(c) Rule Base:**

As illustrated in Table 6.3 with the two inputs, a 3x3 matrix can be utilized to represent the rule basis. This rule base will consist of nine rules. The rule makes use of the Mamdani inference engine to determine the optimality of routes generated by the simulator's repeated iterations.

| | **Next Node Probability (NNP)** | | | |
|---|---|---|---|---|
| **Proportional Energy Change (PEC)** | | Low | Medium | High |
| | Low | Very Low | Low | Medium |
| | Medium | Low | Medium | High |
| | High | Medium | High | Very High |

**Table 6.3 Fuzzy Rule Matrix**

| | |
|---|---|
| Rule I | If NNP=High &PEC=low then<br>Node Selection Probability=Medium. |
| Rule2 | If NNP=High &PEC=Medium then<br>Node Selection Probability=High. |
| Rule3 | If NNP=High &PEC=High<br>then<br>Node Selection Probability=very High. |
| Rule4 | If NNP=Medium &PEC=low then Node Selection Probability=low. |
| Rule5 | If NNP=Medium &PEC=Medium then<br>Node Selection Probability=Medium. |
| Rule6 | If NNP=Medium &PEC=High then Node Selection Probability=High. |
| Rule7 | If NNP=low &PEC=low then<br>Node Selection Probability=very low. |
| Rule8 | If NNP=low &PEC=Medium then Node Selection Probability=low |
| Rule9 | If NNP=low &PEC=High then<br>Node Selection Probability=Medium. |

**Table 6.4 Fuzzy Rule Base**

## 6.3 RESULTS ANALYSIS WITH AN EXAMPLE:

The implementation was carried out with the help of the MATLAB Fuzzy logic tool**.**

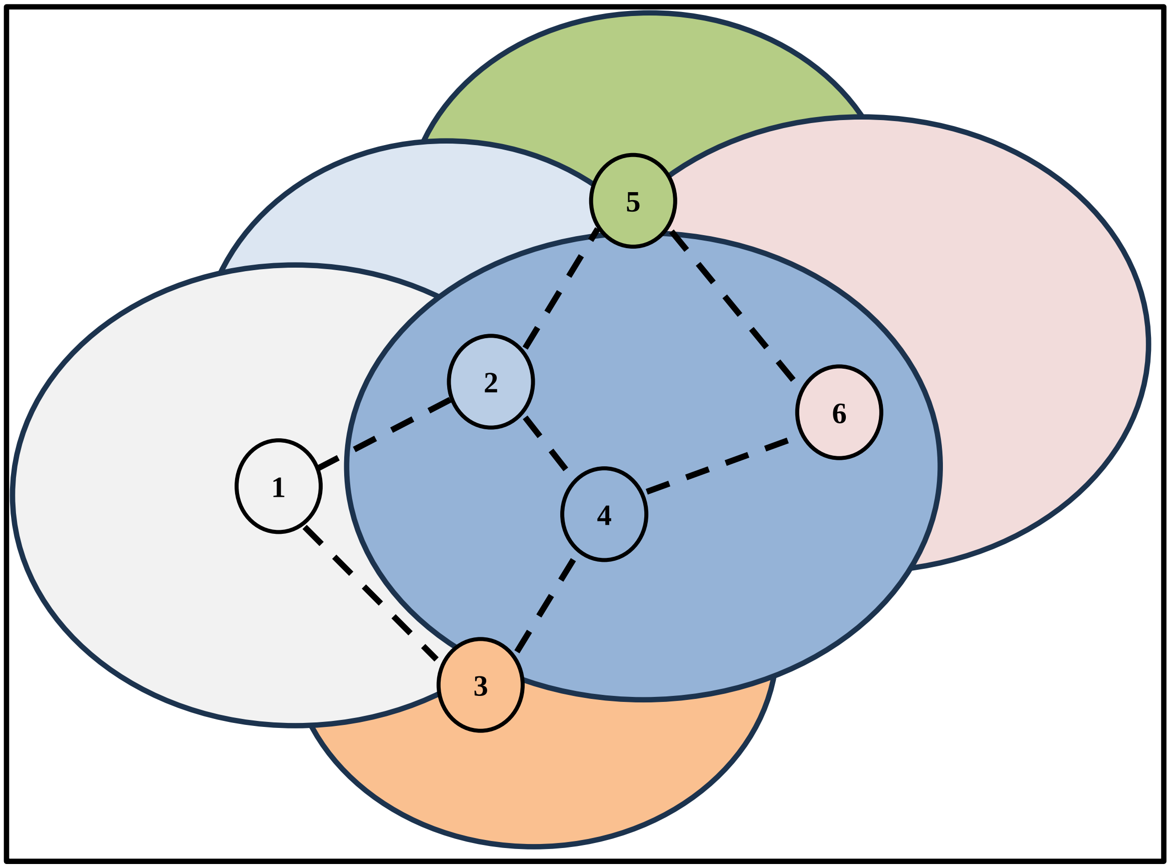


**Figure 6.5 Networks of 6 Nodes**

A MANET with six nodes was considered (Figure 6.5). Dashed lines represent probable connections based on the number of mobile nodes in the network. Node 1 is necessary to find a path to Node 6's destination. The following are the possible paths for transmitting data from Node 1 to Node 6:

1- - - -2- - - -5- - - -6

1- - - -2- - - - -4------6

1- - - - -3-------4-------6

Because all three paths have the same number of hops, determining the optimum path is a critical issue to resolve. Fuzzy logic has been applied to the two inputs, NNP and PEC, to solve this problem. The fuzzy rules assist in determining the optimal node to send the data to. The results of the Fuzzy Inference system are summarized in Table 6.5.

| **Current Node** | **Next Node** | **NNP** | **PEC** | **Next Node Selection** | **Selected Node** |
|---|---|---|---|---|---|
| **1** | **2** | **0.50** | **3** | **0.395** | **Node 2** |
| | **3** | **0.50** | **1** | **0.310** | |

**Tale 6.5 Node 1's next node is selected**

- Here is the link to the source. Node 1 is the starting point for two alternative nodes: Node 2 and Node 3.

- Node 2 will be chosen as the next node based on Next Node Selection (NNS) computed using Fuzzy logic controller on NNP and PEC.

| **Current Node** | **Next Node** | **NNP** | **PEC** | **Next Node Selection** | **Selected Node** |
|---|---|---|---|---|---|
| **2** | **5** | **0.50** | **4** | **0.440** | **Node 5** |
| | **4** | **0.50** | **2** | **0.355** | |

**Table 6.6 At Node 2, choose the next node**

Node 2 is now the following node. The same logic can be used to select the next node for different nodes. As stated in Table 6.6, Node 2 will choose Node 5 as the next node. Every node in the network can utilize the same approach. However, as stated in Table 6.7, there is only one potential node to forward the packet with Node 5, so Node 6 will be chosen automatically. Furthermore, because Node 6 is also a destination node, the operation is not required at this time. Finally, the method yields the optimum path from Node 1 to Node 6, which is 1-2-5-6.

| Current Node | Next Node | Destination Node |
|---|---|---|
| 5 | 6 | 6 |

**Table 6.7 Next Node Selection at Node 5**

## 6.4 SUMMARY:

Next Node Selection criteria have been provided in this chapter for constructing a multipath routing system. Fuzzy logic was used to implement the designed criterion. For determining the optimum node for selection, the technique employs a Fuzzy controller. Fuzzy inference rules are applied to the two inputs, Next Node Probability and Proportional Energy Change, to assign the nodes priority. For an example network, a manual representation for working with = criteria have been shown. The criterion is expected to offer a hopeful approach to developing an energy-efficient technique.

# CHAPTER 7

## ANT COLONY BASED ENERGY EFFICIENT MULTIPATH ROUTING (ACBEEMR)

Routing is the process of establishing and maintaining connections between two nodes. In the realm of Mobile Ad hoc Networks, energy is a critical resource (MANETs). In MANETs, the low energy available at a given node may result in the failure of a route. Each time a node participates in the transmission and forwarding of packets, energy is consumed. Thus, limiting the number of packets transmitted through a single node, i.e. utilizing a node as an intermediary node, may enhance the network's overall energy efficiency.

Ant Colony Based Energy Efficient Multipath Routing (ACBEEMR) is based on this principle and attempts to limit the number of packets routed through a specific node by setting an upper limitation on the node's minimal residual energy, also known as the energy factor. ACBEEMR combines the benefits of Ant Colony Optimization with the benefits of a multipath approach to evolve a strategy that is capable of adapting to the current topology and network conditions.

ACBEEMR improves the route construction and maintenance mechanism based on the remaining energy of nodes. The primary drawback of conventional routing protocols is the repetitive use of the same route. The majority of protocols are based on a single characteristic, such as length or traffic load. However, a robust solution can be obtained through an optimal combination of numerous parameters. Ant Colony Optimization characteristics such as pheromone updating, pheromone laying, and evaporation can assist in better adapting a routing protocol to network conditions. ACBEEMR priorities the following critical issues in order to give the best solution possible:

- Choice of a Proactive strategy, Reactive strategy or both i.e. Hybrid.
- Mechanism to prevent repeated use of same route.
- Minimizing and controlling the routing overhead.
- Realization of an adaptive behavior in the protocol.

ACBEEMR has been built to take advantage of multipath routing while also conserving energy. It aids in the control of the network's energy consumption and optimizes the routing process based on the remaining energy of nodes along the routes. Additionally, it makes use of the advantages of Ant Colony Optimization. Section 7.4 contains the functional definition for the proposed method, as well as a description of the data structures in Section 7.3. In Section 7.5, the algorithm's operation was demonstrated using an example network to demonstrate its correctness.

## 7.1 FORMULATION OF THE PROBLEM:

The problem formulation is based on the inferences made in chapters 2 and 3. The following are significant guidelines that inspired problem formulation:

- Developing a multipath routing strategy capable of transmitting data through various paths: While accomplishing this purpose, it should be sufficiently efficient to handle the uncertainties inherent in a Mobile Ad hoc Network
- Loop-free multiple pathways do not have to be discontinuous at nodes or links.
- Efforts to design a topology-aware intelligent strategy: The strategy should be capable of predicting the likelihood of a node failing.
- Developing an energy-efficient strategy: Excessive energy consumption should be avoided.
- Allows for hop-by-hop change of routing information for more efficient resource use and adaptability.
- Create a technique that will allow you to locate the most efficient routes feasible.
- Dynamic load balancing should be used to manage congestion.
- The plan must avoid excessive reliance on a single route.
- The routing decision cannot be made just on the basis of one parameter, e.g. the shortest route: It should operate efficiently on a variety of criteria in order to enable a thorough choice to be made regarding various aspects of routing.
- The strategy must employ a technique inspired by nature to increase its adaptability to

dynamic Ad hoc networks.

## 7.2 ENERGY ANTS:

The ACBEEMR project aims to build an efficient strategy that is capable of adapting to the network's prevailing energy conditions, or energy state. Additionally, the strategy is focused at regulating the network's total energy condition in order to extend the network's overall lifetime. This is accomplished by avoiding the failure of nodes that are prone to exhaustion as a result of their repeated usage. To avoid nodes becoming exhausted, other nodes in the region who wish to connect with the vulnerable nodes must be aware of their energy condition. This may assist other nodes in avoiding contact with vulnerable nodes. The concept of Energy ants has been suggested to facilitate such communication. These ants are in charge of relaying information about the energy output of the source node to neighboring nodes.

### 7.2.1 Structure of Energy Ants:

Energy Ants are packets transferred between network nodes with the aim of communicating information about the amount of energy available to the ants' originator. Apart from the initial element indicating the type of ant, the structure of the Energy Ant (EA) contains two additional information fields. These are the source node's id and the transmitting node's remaining energy. Energy Ants received at any of the neighbors' locations are responsible for updating the pheromone table entries relating to the Energy Ants' source based on energy information. The receiving nodes, i.e. neighbors of the transmitting node, will not forward the EA further. Thus, these Energy Ants are utilized to regulate the network's energy state. Energy Ants are depicted in Table 7.1

| |
|---|
| Type (EA) |
| Source Node identifier (i) |
| Residual Energy of Source node (RE) |

**Table 7.1 Structure of Energy Ant**

### 7.2.2 Conserving Energy at the Nodes:

The process of updating the pheromone probability table is governed by a threshold energy limit that can be specified for each node in the form of an Energy factor (). This threshold value specifies the maximum energy level at which a node may participate in the MANET. The Energy component denoted by may be assigned a minimum energy level below which the node must abstain from network participation. It is dynamically calculated in accordance with equation 7.1.

$$\emptyset \rightarrow \frac{I.E - R.E}{U_c} \qquad (7.1)$$

**Where:**

I.E: Initial Energy level of the transmitting node.

R.E: Current Energy level (Residual Energy).

$U_c$ : Usage Count of transmitting node.

### 7.2.3 Control of Route Selection Decisions:

Figure 7.1 illustrates a network scenario in which, if we consider only the residual energy of the neighbor node of nodes when modifying the pheromone probability table, the path through node B has a higher likelihood of being picked than the way through node A. However, the energies associated with both of B's neighbor nodes, namely G and C, are insufficient for either path to be used for data transmission. As a result, there must be a system that notifies all nodes about their neighbor nodes' energy statuses. This information can be used to determine whether S should choose Node B or Node A. Energy Ants have been developed to demonstrate this method. In Figure 7.1, vulnerable linkages are denoted by dashed lines.

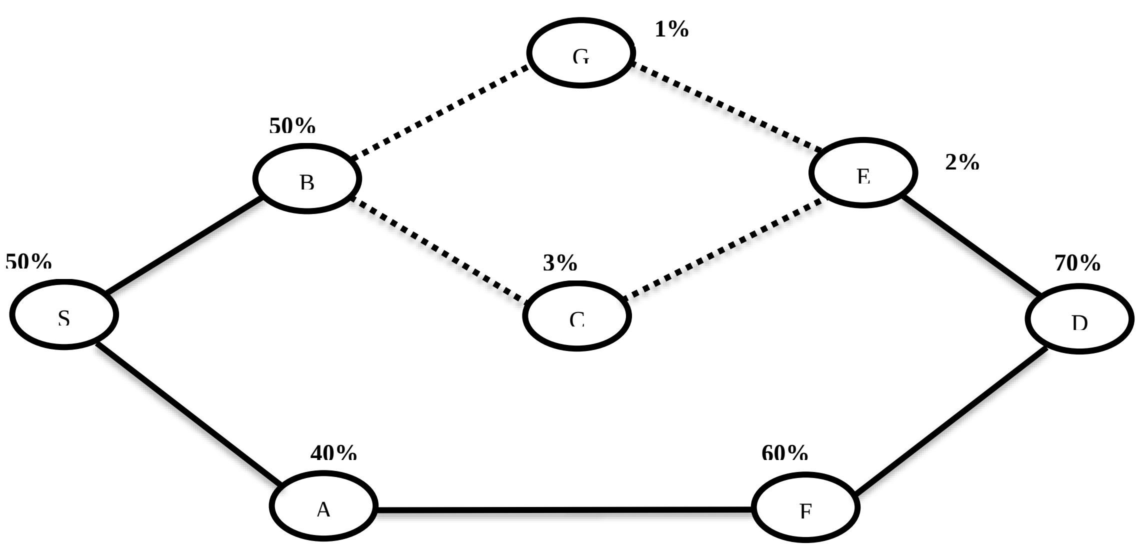


**Figure 7.1 Residual Energy Network**

### 7.2.4 Energy Ant's Application:

The solution to the preceding challenge was built in such a way that node B could not be utilized to transmit data packets intended for other nodes. However, it can be utilized for packets that are specifically addressed to it. This is possible if the residual energy value in the Energy Ants created by nodes G and C communicates to node B their unavailability.

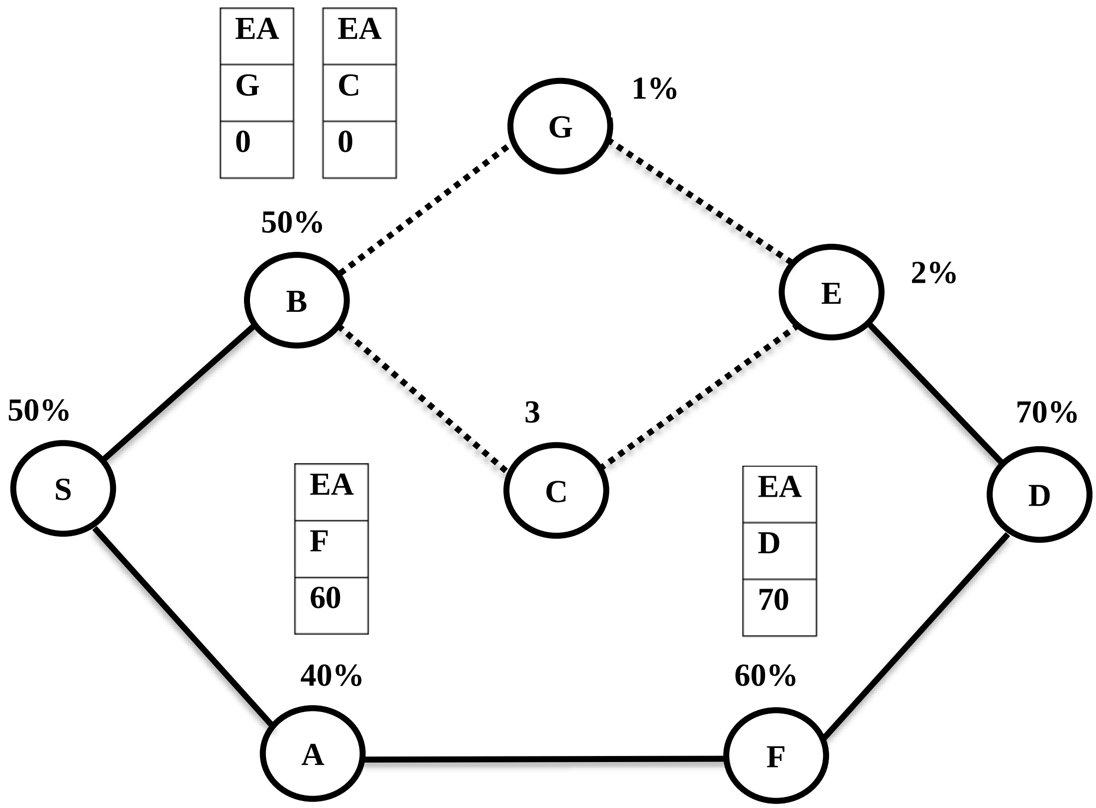


**Figure 7.2 Transmission of Energy Ants**

The scenario depicted in Figure 7.2 is one in which nodes G and C send EAs to node B, node F sends an EA to node A, and node D sends an EA to node F. This eliminates the need for node B to act as an intermediate node for transmissions directed at node D. The status of EA received by node A from F and EA received by node F from D, on the other hand, indicates that the path S- A-F-D between S and D was chosen. The energy packets are broadcast at predetermined intervals. The remaining energy is calculated using the Energy factor (). The scenario represented in Figure 7.2 was simulated using a 10% energy factor. The process for controlling the network's energy condition is as follows:

$IF\ (C.E\ >\ \emptyset)$
Then
{
$R.E\ =\ C.E;$

Broadcast Energy Ants;

}

Else
{
$R.E = 0;$

Broadcast Energy Ant;

}

**7.3 ACBEEMR'S DESIGN:**

ACBEEMR is an Ant Colony-based routing system that makes use of a variety of ACO-related properties in conjunction with a process to generate different paths. This is accomplished by utilizing a variety of structures.

The Algorithm is constructed using the following structures:

**(a) Forward Ant:**

The Forward Ants are spawned from the source node with the mission of determining multiple pathways from a source to a destination. Any Forward Ant on its way to the destination is programmed to keep track of all the nodes it visits. The Forward ant's structure is depicted in Table 7.2

| |
|---|
| Type (FA) |
| Packet Identifier |
| Destination Node Identifier |
| Source Node Identifier<br>VN [1] |
| VN [2] |
| VN [3] |
| Hop Limit |

**Table 7.2 Forward Ant Packet**

The following information is carried by forward ant packets:

**(1) Type:**

This parameter indicates the ant's type, such as Forward, Backward, or Energy Ant.

**(2) Packet Identifier:**

A packet's unique sequence number.

**(3) Identifier for the destination node:**

The identification of the target node is stored in this field.

**(4) Identifier of the source node:**

The identification of the person who created Forward Ant. It is also the most visited node, and as such, it is represented by the VN [1] node.

**(5) VN [2...n]:**

This variable records the identifiers of the nodes that the Forward Ant has visited.

**(6) Hop Limit:**

The maximum number of nodes that a Forward Ant can traverse in order to find a destination is defined by the Hop Limit parameter. It is assumed to be equal to the network's size in terms of the number of nodes. Every node visited causes the hop limit to be decremented by one. If the visited node reached is the destination node, or if the Hop limit is reached, the Forward Ant will be prevented from sending any additional information.

**(b) Backward Ant:**

After reaching their targeted destination node, the Forward Ants are eliminated and their positions are taken up by the Backward Ants. In addition, the array of visited nodes is transferred into the matching Backward Ants in the reverse order in which they were visited. Table 7.3 depicts the overall structure of the Backward Ant program.

| |
|---|
| Type (BA) |
| Packet Identifier |
| Destination Node Identifier |
| Source Node Identifier<br>N [1] |
| N [2] |
| N [3] |
| Hop Limit |

**Table 7.3 Ant Packet in Reverse**

The following information is carried by backward ant packets:

**(1) Type:** indicates the ant's species.

**(2) Packet Identifier:** A one-of-a-kind sequence number that uniquely identifies the Backward Ant.

**(3) Destination Node Identifier:** This field contains the Backward Ant's destination node and has the same value as the Forward Ant packet's source node identifier field.

**(4) Source Node Identifier:** holds the source node of the Backward Ant and has the same value as the Forward Ant packet's destination node identifier field. N[1] denotes it.

**(5) N [2...n]:** stores the identifiers of Forward Ant's visited nodes. This sequence is identical to the one followed by the Forward Ants.

**(6) Hop limit:**A packet will contain a value equal to the Forward Ant packet's hop count.

**(c) Node-maintained data structures:**

The Forward and Backward Ants are required for routing information to be transmitted across the network. Additionally, each node in the network is required to store the information. This objective can be accomplished through the use of various data structures on network nodes. Each node is responsible for the following data structures:

**1. Route Length Table (RLT):** At node k, the route length table is used to store the route length

R from source node k to destination j in terms of the number of hops via node i. Table 7.4 illustrates the structure of RLT kij. H represents the number of hops between nodes k and j via node I and is initialized with.

| i \ j | 1 | 2 | 3 | …. | n |
|---|---|---|---|---|---|
| 1 | $H_{k11}$ | $H_{k12}$ | $H_{k13}$ | …. | $H_{k1n}$ |
| 2 | $H_{k21}$ | $H_{k22}$ | $H_{k23}$ | …. | $H_{k2n}$ |
| 3 | $H_{k31}$ | $H_{k32}$ | $H_{k33}$ | …. | $H_{k3n}$ |
| …. | …. | …. | …. | …. | …. |
| n | $H_{kn1}$ | $H_{kn2}$ | $H_{kn3}$ | …. | $H_{knn}$ |

**Table 7.4: Structure of Route Length Table at node k**

**2. Pheromone Probability Table:** This table records the likelihood that a pheromone from a current node k relating to a neighbor node I will reach a destination node j. P denotes this. The chance of detecting a pheromone is a function of the route length and the energy of the neighboring nodes. Using equation 7.2, we can determine the cumulative value of P kij.

$$P_{kij} \leftarrow \frac{\frac{1}{R_{kij}}}{\sum_{i=1}^{n}\left(\frac{1}{R_{kjj}}\right)} * \left(\frac{RE_i}{E_i}\right) \tag{7.2}$$

**Where:**

$RE_i$: Represents the current residual energy level of node i as per the current Energy ant received from node i.

$E_{i:}$ Represents the residual energy level of node as per the last Energy ant received from node i.

$R_{kij}$: R, kij at node k represents the length of route through neighbor I to destination j in terms of number of hops.

n: represents the number of neighbor nodes for current node k .

$R_{kij}$: $R_{kij}$ at node k represents the length of route through neighbor t to destination j.

where value of t ranges from 1 to n.

Table 7.5 illustrates the structure of the Pheromone probability table.

| i \ j | 1 | 2 | 3 | ….. | n |
|---|---|---|---|---|---|
| 1 | $P_{111}$ | $P_{112}$ | $P_{113}$ | ….. | $P_{11n}$ |
| 2 | $P_{121}$ | $P_{122}$ | $P_{123}$ | ….. | $P_{12n}$ |
| 3 | $P_{131}$ | P132 | $P_{133}$ | ….. | $P_{13n}$ |
| …. | …. | …. | …. | …. | …. |
| n | $P_{1n1}$ | $P_{1n2}$ | $P_{1n3}$ | …. | $P_{1nn}$ |

**Table 7.5 Pheromone Probability Table Structure**

**3. Routing Table ($RT_k$):**

The next node I to which the packet must be forwarded for destination j is determined by $RT_k$ at a node k. Table 7.6 shows the structure of $RT_k$.

| j | 1 | 2 | 3 | …. | n |
|---|---|---|---|---|---|
| i | $T_{ki1}$ | $T_{ik2}$ | $T_{ik3}$ | …. | $T_{kin}$ |

**Table 7.6: Structure of Routing Table for node k**

**Where:**

k: is the current node.

n: is the total number of nodes in the network

j: destination node to be reached from node k.

i: next hop node to which node k will forward a packet for reaching destination j. It is represented as $T_{kij}$ in the routing table.

**4. Frequency of Uses:**

The number of packets processed by a node is saved here. As a result, it denotes the number of times a specific node has been used. Variable $U_c$ is used to represent it.

**5. Node's current energy:**

This field, which is represented by the variable $E_k$, maintains the thermal efficiency of a node k at a specific moment.

**6. Neighboring node energies ($E_{ki}$):**

According to the most recent Energy Ant obtained from the node I E ki saves the residual energy related to a neighbor node I received at a node k. Table 7.7 shows the structure of table E.

| i | 1 | 2 | 3 | …. | n |
|---|---|---|---|---|---|
| k | $E_{k1}$ | $E_{k2}$ | $E_{k3}$ | …. | $E_{kn}$ |

**Table 7.7: Energy table at node k**

## 7.4 ACBEEMR: CHARACTERISTICS FOR FUNCTIONING:

The steps below provide an ACBEEMR detailed definition with S as the intermediate host and D as the destination node.

**Step 1: Advancing Ants creation and transmitting:**

The Forward Ants are generated by "S" and transmitted to all of the nodes in the vicinity. Each Forward Ant keeps track of the following information:

- Type of Ant (FA)
- Packet Identifier
- Destination Identifier
- Source Identifier (first visited node)
- Array of Intermediate Nodes (array of visited nodes)
- Hop Limit.

**Step 2: Transferring Ants:**

After receiving the Forward Ant, any node other than the destination node, i.e. the intermediate node, is obligated can forward that ant to all of its neighbors.

**Step 3: Forward Ants' Updating:**

Forward Ants keep track of all the nodes they visit in their individual visited nodes array.

**Step 4: Backward Ants' Generation:**

If the current node is a destination node, each received Forward Ant is translated into a Backward Ant. To build a reverse path, the visited nodes from the Forward Ants are copied in reverse order to the matching Backward Ants. After that, the Forward Ants are eliminated. Through the reverse pathways, the Backward Ants are then sent back to the originating node. The following entries are stored by each Backward Ant:

- Type of Ant (BA)
- Packet Identifier
- Destination Identifier (Source node in corresponding FA)
- Source Identifier (Destination node in corresponding FA)
- Array of Visited Nodes
- Hop Limit

**Step 5: Updated Route Length and Pheromone Probability Calculation:**

On each node, the Backward Ants are utilized to update the Route Length Table data. The Route Length Table also aids in determining the Pheromone Probability Table entries, as shown in equation 7.3. The pheromone associated with a certain destination's neighbor node is inversely proportional to the size of the route to that destination via that neighbor.

$$P_{kjj} \leftarrow \frac{\frac{1}{R_{kjj}}}{\sum_{i=1}^{n} \frac{1}{R_{kji}}} \qquad (7.3)$$

**Where:**

$P_{kij}$: Represents pheromone probability at node k corresponding to neighbor I for destination j.

$R,_{kij}$: The $R,_{kij}$ at node k represents the length of route through neighbor for destination j.

n: represents the number of neighbor nodes for current node k.

$R_{kij}$: The $R,_{kij}$ at node k represents the length of route through neighbor t to destination j, where value of t ranges from 1 to n.

**Step 6: Pheromone Probability Table Update:**

Before the node begins receiving Energy Ants from its neighbors, the Pheromone Probability entries are started with a value of zero and changed on the basis of step 5.

**Step 7: Routing Table Updating:**

The Source node, upon receiving Backward Ants via various pathways, may initiate data packet transfer using the Routing Table at the $k^{th}$ node ($RT_k$). The following are the entries in the Pheromone Probability Table that determine RT:

$$i = 1$$

n = maximum number of nodes

$$While\ (i < n)$$

$$\{$$

$$T_{kij} = \{i: P_{kij} = (Max\ (P_{kij})\forall i)$$

$$\}$$

**Step 8: Energy Ants' Broadcasting:**

Each node also broadcasts Energy packets at regular intervals in order to keep the Pheromone Probability Table up to current. These ants also aid in the introduction of adaptive behavior in the network, as they are in charge of updating the Pheromone Probability table based on current energy levels and energy consumption at neighboring nodes. On the basis of the Energy factor (), the Energy Ants are propagated from the source node as follows:

$$If\ (C.E > \emptyset)$$

Then

$$\{$$

R.E = C.E;

Broadcast Energy Ants;

}

Else

{

R.E = 0;

Broadcast Energy Ant;

}

**Where:**

C.E: Current Energy Level at the source node.

R.E: Residual or the Remaining Energy entry in the Energy Ants

The entries for Pheromone Probability Table P are updated as follows using equation 7.2 after receiving the Energy Ants at node k for a total of n neighbors corresponding to neighbor node I and destination j.

$$P_{kij} \leftarrow \frac{\frac{1}{R_{kij}}}{\sum_{i=1}^{n}\left(\frac{1}{R_{kij}}\right)} * \left(\frac{RE_i}{E_i}\right) \qquad (7.2)$$

**Step 9: After receiving energy ants, the pheromone probability table was updated:**

After receiving energy ants from neighbor nodes, the values of $P_{ij}$ are changed according to equation 7.2 for each node. Equation 7.4 is used to calculate the updated probability corresponding to n neighbors for destination j at a node k.

$$P_{kij} \leftarrow \frac{P_{kij}}{\sum_{t=1}^{n} P_{ktj}} \qquad (7.4)$$

**Step 10: Routing Table Updating:**

The Routing table $RT_k$ is also updated at every node k corresponding to the neighbor node iwith maximum value of Pheromone Probability Table $P_{kij}$ for a destination j. The Data will be transmitted by using the updated $RT_k$.

Throughout the session, the pheromone Probability table and the routing table are being updated.

### 7.5 ILLUSTRATION:

An example network is shown in Figure 7.3. The ACBEEMR diagram shows node 1 as the source node and node 6 as the destination node.

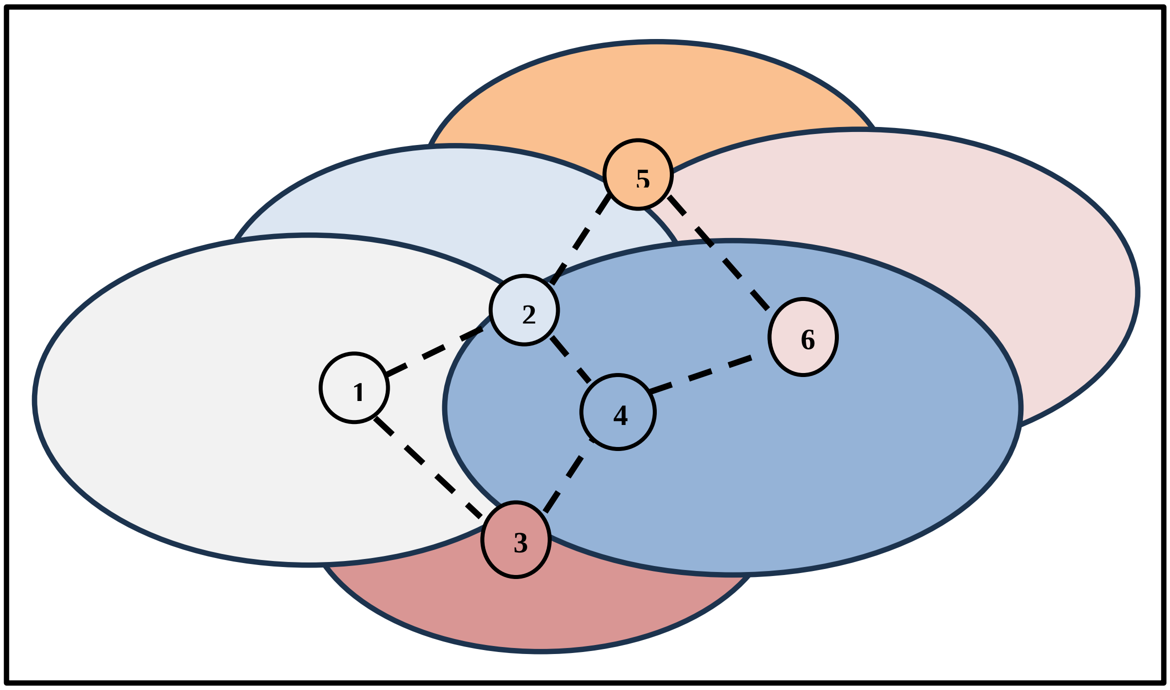


**Figure 7.3 Network as an example**

The following is a list of ACBEEMR's many steps:

**1. Forward Ants creation and broadcasting:**

Forward Ants are formed by "1" and disseminated to all of the nodes in the vicinity (2&3). Each Forward Ant keeps track of the following information:

- Type of Ant: FA
- Packet Identifier: 101
- Destination Identifier: 6
- Source Identifier (First visited node): 1
- Array of Visited Nodes: Nil
- Hop Limit: 6

A Forward Ant packet originated at source node 1 is shown in Figure 7.4.

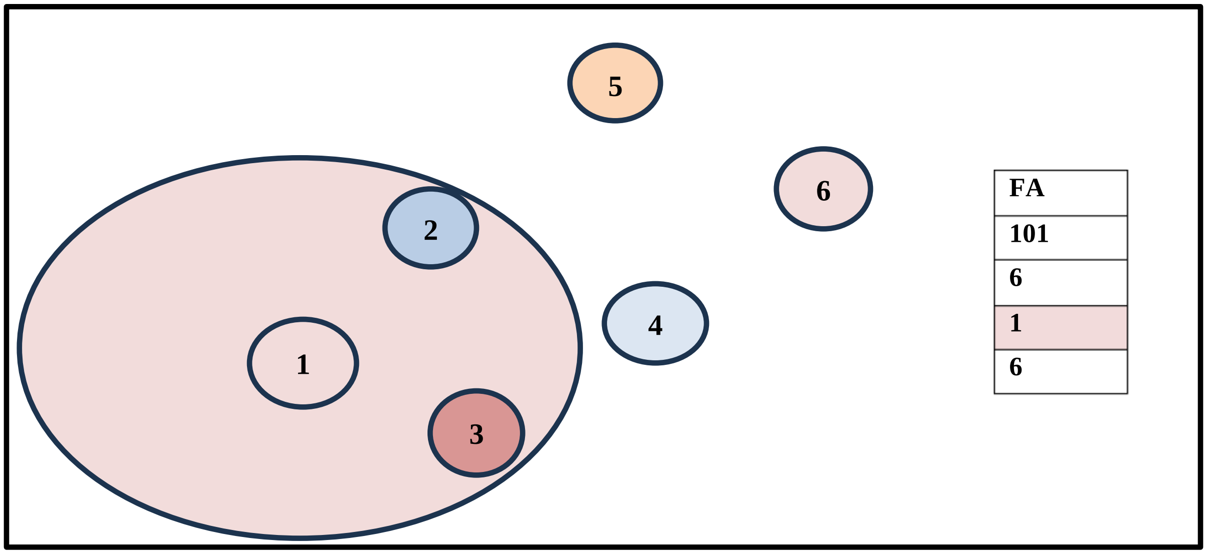


**Figure 7.4: Forward Ant at node 1**

**2. Forwarding of Ants:**

Node 1's forward ants are received by its neighboring nodes, node 2 and node 3.

**3. Forward Ants' Updating:**

Nodes 2 and 3 are visited and their visits are logged in their respective received Forward Ants (Figure 7.5) as shown in Figure 7.6, the aforementioned steps (steps 2 and 3) are repeated for neighbors of node 2(node 4, node 5) and node 3(node 4) and for neighbors of node 4(node 6) and node 5(node 6) as shown in Figure 7.7.

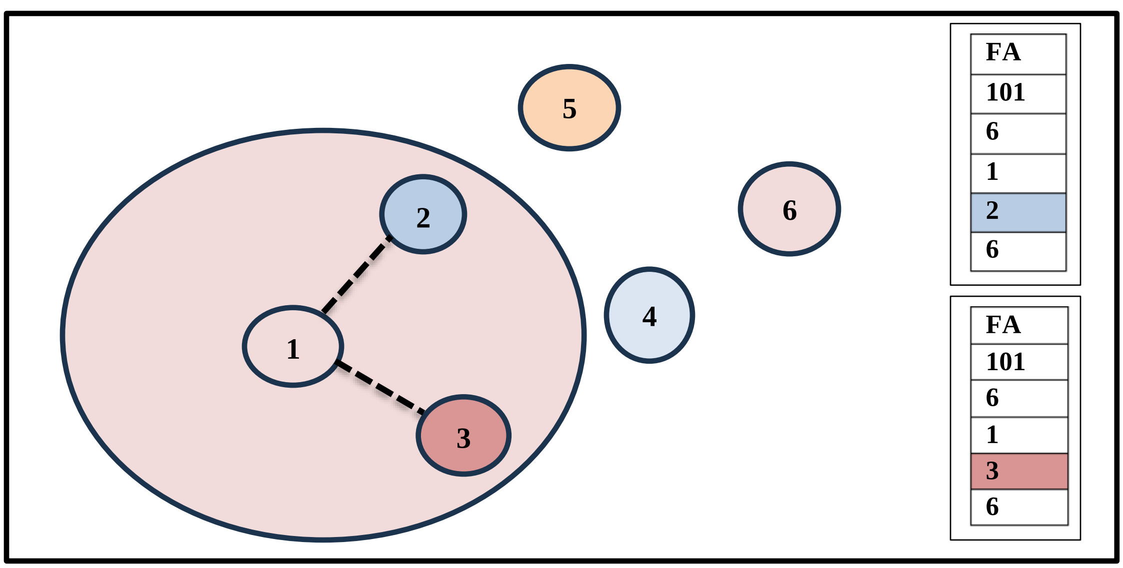


**Figure 7.6: Forward Ants at Node 2 and Node 3**

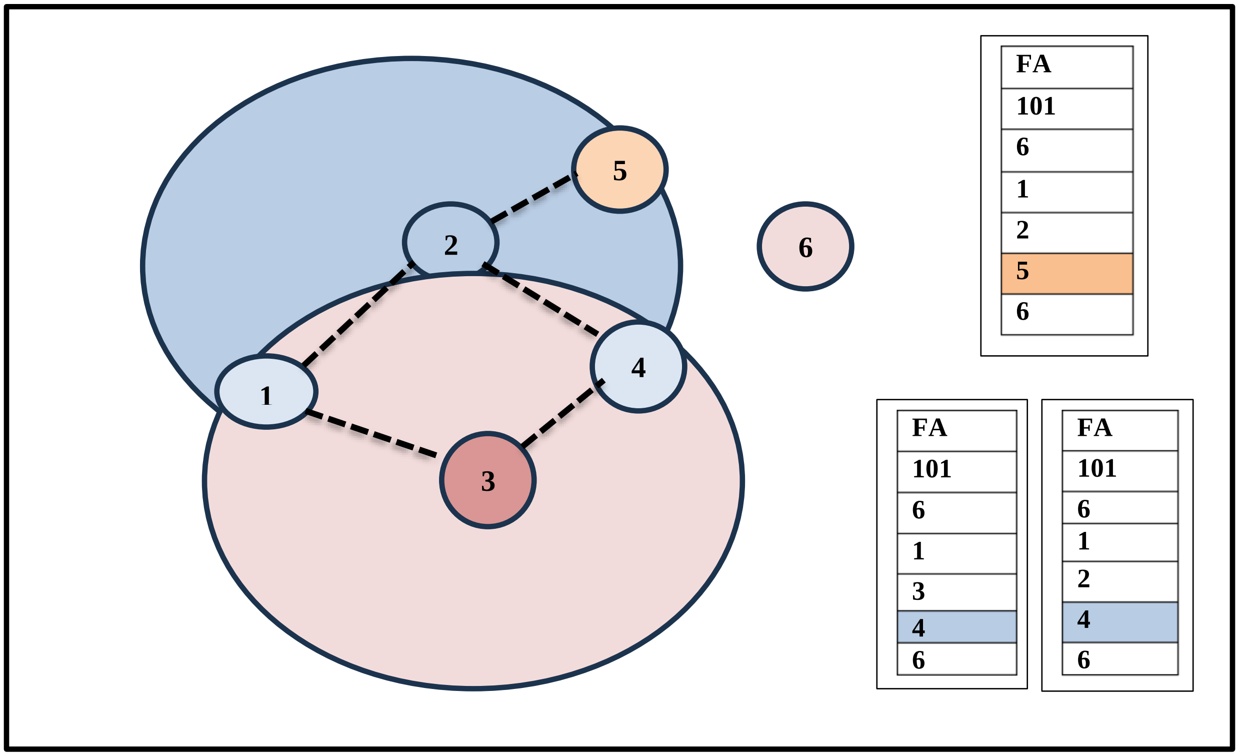


**Figure 7.6: Forward Ants at Node 4 and Node 5**

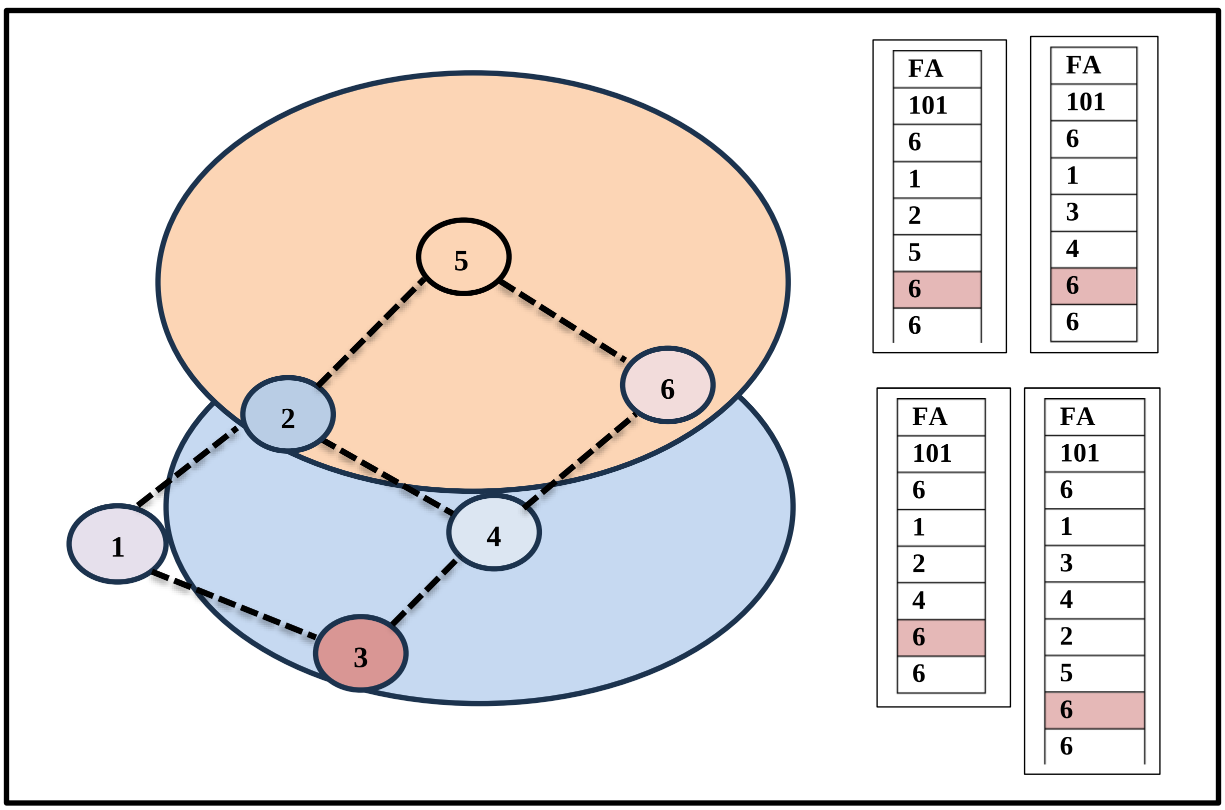


**Figure 7.7: Forward Ants Received at Node 6**

## 4. Backward Ant Generation:

When the Forward Ant reaches target node 6, it is discarded and a comparable Backward Ant is formed. The array that the Forward Ant was maintaining is replicated to the appropriate Backward Ant. The Forward Ants that may reach destination node 6 are listed in Table 7.8-7.11, along with their accompanying Backward Ants.

**(a) For path 1-2-5-6:**

| **FA** | **BA** |
|---|---|
| **101** | **102** |
| **6** | **1** |
| **VN [1] =1** | **N [1] =6** |
| **VN [2] =2** | **N [2] =5** |
| **VN [3] =5** | **N [3] =2** |
| **VN [4] =6** | **N [4] =1** |
| **Hop Limit=6** | **Hop Limit =4** |

**Table 7.8 Ants moving forward and backward in accordance with the 1-2-5-6 path**

**(b) For Path 1-3-4-6:**

| FA | BA |
|---|---|
| 101 | 103 |
| 6 | 1 |
| VN [1] = 1 | N [1] = 6 |
| VN [2] = 3 | N [2] = 4 |
| VN [3] = 4 | N [3] = 3 |
| VN [4] = 6 | N [4] = 1 |
| Hop Limit = 6 | Hop Limit = 4 |

**Table 7.9 Ants moving forward and backward in accordance with Paths 1-3-4-6**

**(c) For Path 1-2-4-6:**

| FA | BA |
|---|---|
| 101 | 104 |
| 6 | 1 |
| VN [1] =1 | N [1] = 6 |
| VN [2] =2 | N [2] =4 |
| VN [3] =4 | N [3] = 2 |
| VN [4] = 6 | N [4] = 1 |
| Hop Limit = 6 | Hop Limit = 4 |

**Table 7.10 Ants moving forward and backward in accordance with the 1-2-4-6 path**

**(d) For Path 1-3-4-2-5-6:**

| FA | BA |
|---|---|
| 101 | 105 |
| 6 | 1 |
| VN [1] = 1 | N [1] = 6 |
| VN [2] = 3 | N [2] =5 |
| VN [3] = 4 | N [3] =2 |
| VN [4] = 2 | N [4] =4 |
| VN [5] = 5 | N [5] =3 |
| VN [6] = 6 | N [6] = 1 |
| Hop Limit = 6 | Hop LIMIT =6 |

**Table 7.11 Ants moving forward and backward in accordance with Paths 1-3-4-2-5-6**

**5. Route Length Update and Pheromone Probability Calculation:**

The route length table for the Backward Ant received at node 5 is as follows: When a Backward Ant with Packet Id 102 reaches Node 5 (Table 7.12), the number of hops required to reach the destination is determined using the size of the traversed array of intermediate nodes.

| BA |
|---|
| Packet Id=102 |
| Destination Node ID=1 |
| Source Node ID=6 |
| AII the nodes recorded starting with source<br>N [1] =6 |
| N [2] =5--Current node |
| N [3] = 2 |
| N [4] =1 |
| Hop limit =4 |

**Table 7.12 Ant in reverse at Node 5**

It is |2 – 1| in the above example, indicating that just one hop is necessary to reach destination node 6 from node 5. However, the RLT entry, i.e. R kept at node k and traversed through nodes I to j, is updated only when the stored value exceeds the computed value of $Rk_{ij}$.

Similarly, Table 7.13 shows the Routing Length Table at node 1 for various Backward Ants received at node 1.

| $R_{ii}$ | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | ∞ | ∞ | ∞ | ∞ | ∞ | ∞ |
| 2 | ∞ | **1** | ∞ | **2** | **2** | **3** |
| 3 | ∞ | **3** | **1** | **2** | **4** | **3** |
| 4 | ∞ | ∞ | ∞ | ∞ | ∞ | ∞ |
| 5 | ∞ | ∞ | ∞ | ∞ | ∞ | ∞ |
| 6 | ∞ | ∞ | ∞ | ∞ | ∞ | ∞ |

**Table 7.13 Table of updated route lengths**

**6. Pheromone Probability Table Update:**

$P_{kij}$, for k=1 at node 1, can be updated using equation 7.3. The resulting Pheromone Probability Table is provided in Table 7.14.

$$P_{kij} = \frac{\frac{1}{R_{kij}}}{\sum_{t=1}^{n} \frac{1}{M_{kij}}} \tag{7.3}$$

| $P_{ii}$ | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| I | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0.75 | 0 | 0.5 | 0.66 | 0.5 |
| 3 | 0 | 0.25 | 1.0 | 0.5 | 0.34 | 0.5 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 7.14 Probability Table for Pheromones at Node 1**

**7. Routing Table Update:**

$RT_k$ stores Tkij that contains the next node to which the packet should be forward in order to reach the destination j from node k, where kis the current node.

The$T_{1ij}$ fornode1 is updated on the basis of pheromone probability Table7.14. The resulting $RT_k$ has been shown inTable7.15.

| $RT_1$ | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 1 | 2 | 3 | 2 | 2 | 2 |

**Table7.15: Routing table at node**

**8. Energy Ants' Broadcasting:**

The $RT_k$ indicated in Table 7.15 is utilized by node 1 to route data packets to various nodes. However, upon receipt of the Energy Ants, the value of RT k may alter in accordance with the new value of P. The Energy Ant (EA) received at node 1 from node 2 is shown in Table 7.16.

| EA |
|---|
| Source id=2 |
| Energy stored in the node ($RE_2$) =0.8 |

**Table7.16: Energy Ants**

**9. Updated Probability of Pheromones Following the Energy Ants' reception:**

The $P_{kij}$at node 1 is updated further using equation 7.4, as shown in Table 7.18.

| $P_{ii}$ | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0.7 | 0 | 0.44 | 0.60 | 0.44 |
| 3 | 0 | 0.3 | 1.0 | 0.56 | 0.4 | 0.56 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 7.18: Updated Pheromone Probability Table at node 1**

**10. Routing Table Update:**

Thus, Table 7.19 shows updated values for the Routing table ($RT_k$) corresponding to a single entry of the next node for each destination.

| | | | | | | |
|---|---|---|---|---|---|---|
| RT, | I | 2 | 3 | 4 | 5 | 6 |
| I | I | 2 | 3 | 3 | 2 | 3 |

**Table7.19: Updated Routing Table**

However, because the Energy Ants are responsible for maintaining the values of the pheromone probability tables kept at nodes, the next nodes for transmitting data packets to various destinations in $RT_k$ are always changing. These improvements also introduce an intrinsic load distribution mechanism into the network.

**7.6 SUMMARY:**

This chapter proposes a multipath method with ACO characteristics. The chapter begins with a concise overview and definition of the proposed ACBEEMR protocol's difficulty. The entire technique, as well as the data structures, are defined. It incorporates evaporation characteristics by lowering the amount of pheromone according to the energy change. The ACBEEMR considers both low- and high-load conditions in Mobile Ad hoc Networks. Additionally, routing tables are adjusted only during periods of high load and in response to energy changes in the MANETs topology. This feature enhances ACBEEMR's optimization by removing unneeded overhead. Additionally, ACBEEMR has the advantage of being a multipath routing system. ACBEEMR performs multipath routing based on the route length and energy level of the node, which modifies the probabilities based on the network's current condition. The objective of ACBEEMR has been to establish an energy-smart network. The example demonstrates the utility of strategy. Chapter 8 details the implementation and comparison to a modified version as well as to other related protocols.

# CHAPTER 8

## ACBEEMR AND ITS VARIANTS PERFORMANCE EVALUATION

Nodes in MANETs use energy during packet transmission, reception, and processing. As a result, energy is a critical factor in MANETs. Multipath routing is another feature that can contribute to the provision of Quality of Service in MANETs. Multiple pathways may improve energy efficiency by optimally utilizing the numerous possible paths for data transmission between the source and destination. These pathways may be utilized alternately or concurrently to transmit the data packets. The architecture of ACBEEMR takes into account both energy and multipath routing. The design of ACBEEMR as proposed in Chapter 7 has been updated to increase its performance in some areas. This chapter discusses the designs of such variants.

The ACBEEMR and its two derivatives' designs have been simulated to demonstrate their efficacy in exploring many pathways in an energy-efficient manner. NS2 is used for simulation. The remainder of the chapter is devoted to two ACBEEMR variations, their simulation and comparative analysis.

### 8.1 ACBEEMR VARIANTS:

ACBEEMR optimizes the routing mechanism in MANETs by utilizing fundamental Ant Colony Optimization characteristics. ACBEEMR makes use of a variety of critical processes, such as pheromone deposition and ACO evaporation, to manage data traffic and avoid congestion along a route. Additionally, these are the steps that result in the development of adaptive behavior in the ACBEEMR mechanism. This has been accomplished in the case of ACBEEMR by mapping the biological pheromone to the conceptual pheromone. The amount of this pheromone is determined by a variety of parameters connected with MANETs. For instance, the pace of pheromone deposition and the amount of pheromone deposited along a route are inversely related to the route's length to the destination node. Additionally, energy sensitivity was created by directly mapping the amount of pheromone deposition to the amount of remaining energy.

The concept of Energy Ants is another significant aspect of ACBEEMR. These ants are generated by each node in the MANET and are responsible for transporting the node's energy state information. This information is used by the network's surrounding nodes to create an energy-conscious topology. Additionally, because these ants are broadcast at regular periods of time, they are valuable for managing routing decisions based on established energy states. Additionally, broadcasting at regular intervals aids in tailoring routing decisions to the network's present energy situation. The old ACO-based approaches assume that evaporation occurs at a constant rate. The rate of evaporation, on the other hand, cannot be constant. Thus, in the instance of ACBEEMR, it has been linked to energy savings. However, ACBEEMR has a few factors that can be modified to further increase performance and eliminate some redundancy associated with data upkeep. The following significant areas have been worked out in order to propose a modified variant of ACBEEMR:

- The issue of redundancy in the data retained at each node is critical and must be addressed. Two distinct tables are kept for routing computations and the pheromone quantity. Due to the fact that the calculations relating to the amount of pheromone content are used to determine the next node, there is no need to keep two distinct tables, namely the pheromone table and the routing table.

- The Energy Ants make the most significant contribution to sustaining a stable energy condition. One critical element of the Energy Ant is that once a threshold for residual energy on a node is reached, the Energy Ants carry a value of zero matching to the originator node's energy level. This appears to result in a situation where, upon hitting certain threshold values, each node begins broadcasting a zero value via the energy ants. Thus, the nodes' participation in the network is disabled. As a result, the network appears to be in a condition of death. In light of the foregoing, a slight tweak has been made to the function used to calculate the pheromone content, extending the network's longevity.

### 8.1.1 ACBEEMR with modifications:

The modified ACBEEMR (MACBEEMR) was introduced to improve the performance of the existing ACBEEMR by modifying the pheromone distribution function to limit the rate of energy depreciation in the network. This assists in avoiding the network appearing to be in a state of inactivity. To save redundancy, the MACBEEMR routes data packets using the data from the pheromone probability table rather than a separate routing database. This eliminates the overhead associated with maintaining a separate routing table on the node.

The issue addressed in MACBEEMR is limiting the rate of residual energy decay. The establishment of a threshold constraint on the degree of leftover energy was discovered to be responsible for the network approaching an apparent dead state. The energy state appears to be dead in the sense that, while energy is accessible to each node and thus the nodes are not yet dead, they are not participating in the network since the relevant threshold values have been reached. Thus, even after each node in the network has sufficient energy, the nodes broadcast Energy Ants with a leftover energy value equal to zero. Thus, an upgrade to MACBEEMR has been made to more effectively employ the threshold limit to manage the rate of degradation of node energies. The fundamental mechanism of path discovery employing Forward and Backward Ants is identical for MACBEEMR and ACBEEMR.

The quantity of pheromone determined by ACBEEMR is dependent on two factors: the journey length to the destination and the proportional change in residual energy. The ACBEEMR selects the pheromone based on the amount of remaining energy. It does not, however, take into account the rate of depreciation in a given node. The rate at which energy is consumed is also critical. Thus, by determining the rate of change in energy and combining it with the threshold limit to compute the energy usage component, it is possible to effectively control the energy status of the network.

$$P_{kj} = \left[\frac{1}{H_{kij}}\right] * \left[\frac{R_{ki}}{E_{ki}} - \frac{\phi}{100}\left(\frac{l \cdot E_{ki} - R_{ki}}{l \cdot E_{ki}}\right)\right] \tag{8.1}$$

**Where:**

$P_{kij}$: pheromone stored at node k for a path along neighbor to destination j.

$H_{kij}$: Length of route from node k along neighbor i to destination j

$R_{ki}$: Residual energy of node i as received in the current energy ant at node k.

$E_{ki}$: Energy level of neighbor node i at node k as received in last energy ant i.e. $E_{ki}$

$I.E_{ki}$: Initial energy of neighbor node I as received at node k.

P: Threshold limit to the Energy factor decided for a network.

In the instance of MACBEEMR, the updated function can be represented as indicated in equation (8.1). The following summaries the technique for Modified ACBEEMR (MACBEEMR):

**MACBEEMR Scheme:**

**//Generation of Forward Ants**

**//Begin**

Forward Ants are broadcasted towards the destination.

Intermediate Nodes are recorded on the stack by the Forward Ants

**//Generation of Backward Ant//**

After reaching the Destination, Forward Ants are discarded and Backward Ants are produced in the reverse direction.

**Begin While (Node ≠Source Node)**

Pheromone table at a node is updated by the Backward Ants based on the number of Hops to destination through that node

$$P_{kij} = \left[\frac{1}{H_{kij}}\right] * \left[\frac{R_{ki}}{B_{ki}} - \frac{\phi}{100}\left(\frac{I\cdot E_{ki} - R_k}{I\cdot E_{ki}}\right)\right] \qquad (8.1)$$

**End While**

**//Updating Pheromone Table Using Energy Ants//**

The Pheromone table is updated at regular intervals of time using the **Energy Ants** From neighbor.

**End**

**Scheme for Energy Ants:**

**Begin While (Energy of node < Maximum Limit)**

**Energy factor (Ø) (Energy Consumption)/ Usage Count**

**If (Ø> Current energy level)**

**then**

Broadcast the Energy ants with energy of transmitting Node equal to 0;

**Else**

Broadcast the Energy ants with energy of transmitting Node equal to its current energy.

**End While**

The next section compares MACBEEMR to various multipath routing protocols using the NS2 simulator.

## 8.2 COMPARISON OF ACBEEMR AND MACBEEMR BASED ON SIMULATION:

NS2 is a powerful simulation tool for designing and analyzing mobile ad hoc network scenarios. NS2 was used to implement the ACBEEMR and MACBEEMR. The various simulation parameters have been provided, as well as a comparison of these two protocols to a few additional protocols such as AOMDV, FF-AOMDV, and AOMR-LM. This comparative study focuses on the energy efficiency and effectiveness of employing ant behavior in MANETs.

### 8.2.1 Parameters for Simulation:

The simulation parameters evaluated are listed in Table 8.1.

| | |
|---|---|
| Routing Protocol | ACBEEMR, MACBEEMR, AOMDV, FF-AOMDV, AOMR-LM |
| Network topology | 1500*1500 |
| MAC Type | 801.11 |
| Max. Packet in IFQ | 50 |
| Radiopropagation model | Two ray ground |
| Number of Nodes | 50 |
| Packet size | 64,128,256,512,1024bytes |
| Max. Simulation time | 50s |
| Initial Energy | 100 joules |
| Transmission Power | 0.02 joule |
| Receiving Power | 0.01joule |
| Traffic Type | CBR |
| Transmission Range | 250m |

**Table 8.1 Parameters for Simulation**

The redesigned ACBEEMR operates in such a way as to avoid network virtual failure. MACBEEMR has enhanced the network's longevity by modifying the function that updates the pheromone value. MACBEEMR demonstrates its effectiveness mathematically by decreasing the rate of energy consumption in overutilized nodes. The node that approaches the threshold value more quickly is less utilized than the node that approaches it more slowly. To validate the computational performance of MACBEEMR, the simulation of the protocol and the results obtained using the above simulation parameters were compared to the results obtained using the ACBEEMR, AOMDV, FFAOMDV, and AOMR-LM protocols.

### 8.2.2 Comparative Analysis:

#### (a) Packet Delivery Ratio:

The Packet Delivery Ratio quantifies the proportion of data packets delivered at the destination to those originating at the source. The results are presented as a percentage. The Packet Delivery Percentages obtained for various protocols demonstrate MACBEEMR's superiority over other protocols.

Table 8.2 and Figure 8.1 show the results for Packet Delivery Percentage.

The results also indicate that as packet size increases, the packet delivery fraction tends to decrease. However, the pace of decline is slower with MACBEEMR than with other regimens.

| Packet Size / Protocols | 64 | 128 | 256 | 512 | 1024 |
|---|---|---|---|---|---|
| **AOMDV** | 89.56 | 83.00 | 81.00 | 78.00 | 70.67 |
| **ACBEEMR** | 90.00 | 86.00 | 85.00 | 84.00 | 81.00 |
| **MACBEEMR** | 93.91 | 95.54 | 86.75 | 86.00 | 85.00 |
| **FF-AOMDV** | 95.45 | 93.00 | 90.00 | 89.00 | 81.06 |
| **AOMR-LM** | 93.12 | 91.00 | 88.00 | 87.00 | 79.90 |

**Table 8.2: Packet Delivery Percentage vs Packet size**

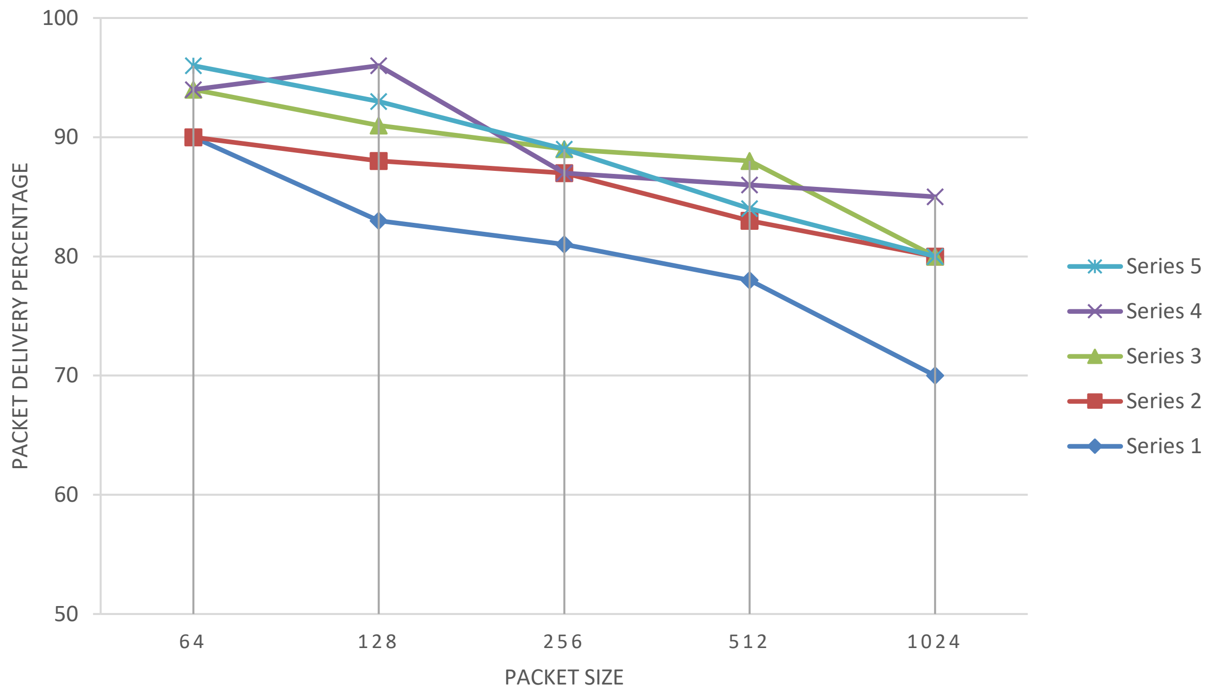


**Figure 8.1 Packet Delivery Packet Size**

**(b) Energy Consumption:**

The achievement of MACBEEMR's purpose, namely extending the life of a network, can be seen in the results produced for Energy Consumption (joules) for varied packet sizes, as shown in Table 8.3 and Figure 8.2. The findings of the Energy Consumption during the routing process demonstrate MACBEEMR's dominance over the other protocols.

- The results for ACBEEMR and MACBEEMR demonstrate the utility of ACO-based routing algorithms.

- FF-AOMDV and AOMR-LM consume less energy than AOMDV. Both MACBEEMR and ACBEEMR are significantly superior than other protocols in terms of energy consumption. In the case of MACBEEMR, the outcomes are considerably more favorable.

The low energy consumption in the cases of MACBEEMR and ACBEEMR can be linked to the usage of Energy Ants, which contribute to the maintenance of an energy conscious state, hence minimizing energy wastage. The results for Energy Consumption are depicted in Figure 8.2.

| Packet Size / Protocols | 64 | 128 | 256 | 512 | 1024 |
|---|---|---|---|---|---|
| **AOMDV** | 81.00 | 84.00 | 90.00 | 93.00 | 120.00 |
| **ACBEEMR** | 15.04 | 15.96 | 17.72 | 21.52 | 23.52 |
| **MACBEEMR** | 10.00 | 11.00 | 12.00 | 14.00 | 17.00 |
| **FF-AOMDV** | 69.00 | 71.00 | 77.00 | 84.00 | 93.00 |
| **AOMR-LM** | 63.00 | 65.00 | 73.00 | 79.00 | 87.00 |

**Table 8.3: Energy Consumption vs Packet Size**

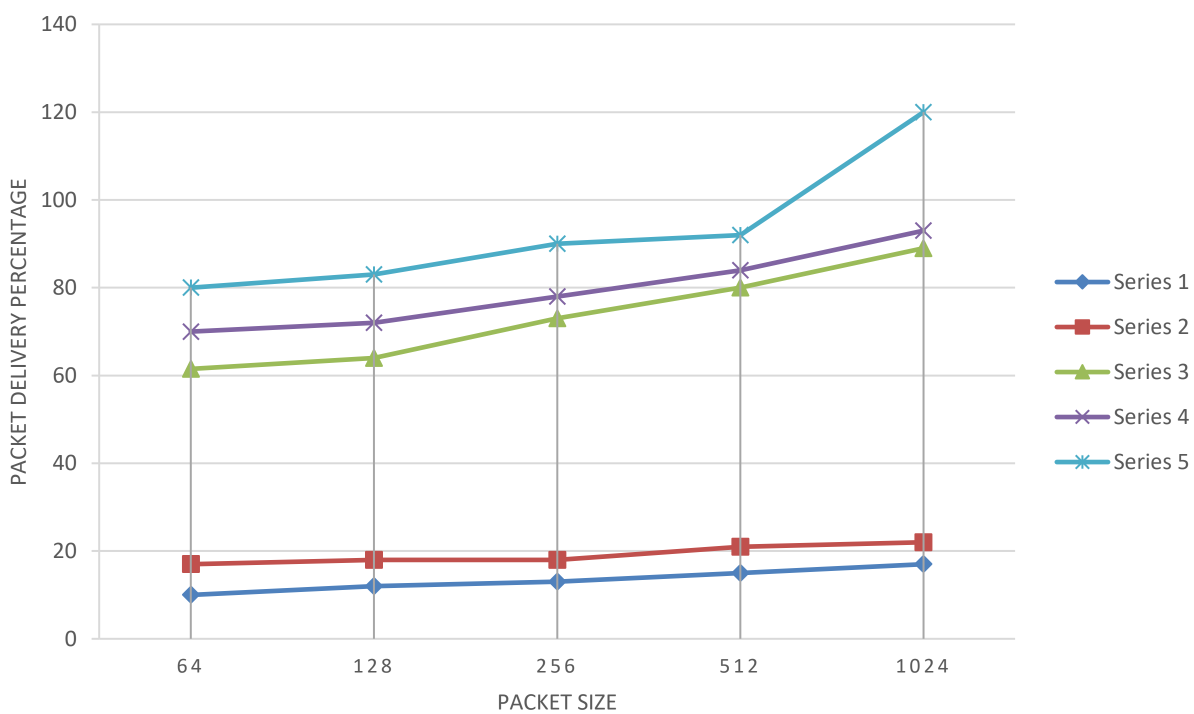


**Figure 8.2: Energy Consumption vs Packet Size**

**(c) End-to-End delay:**

The term "end-to-end delays" refers to the time required to successfully transport data packets from the source to the destination node.

The results for End-to-End latency are presented in Table 8.4 and Figure 8.3. (ms). The following are critical observations:

- For data packets of small and average size. ACBEEMR and MACBEEMR both perform better than other protocols.

- End-to-end delays significantly rise in response to extremely big data packets. This also has a major effect on ACBEEMR and MACBEEMR performance, resulting in increased delays.

| Packet Size / Protocols | 64 | 128 | 256 | 512 | 1024 |
|---|---|---|---|---|---|
| **AOMDV** | 21.63 | 26.50 | 29.70 | 32.50 | 43.06 |
| **ACBEEMR** | 9.47 | 20.27 | 21.76 | 28.21 | 48.54 |
| **MACBEEMR** | 9.69 | 18.52 | 24.67 | 24.77 | 42.03 |
| **FF-AOMDV** | 17.53 | 24.00 | 25.50 | 26.00 | 32.32 |
| **AOMR-LM** | 18.64 | 25.00 | 26.80 | 27.00 | 37.12 |

**Table 8.4: End-to-End Delay vs Packet Size**

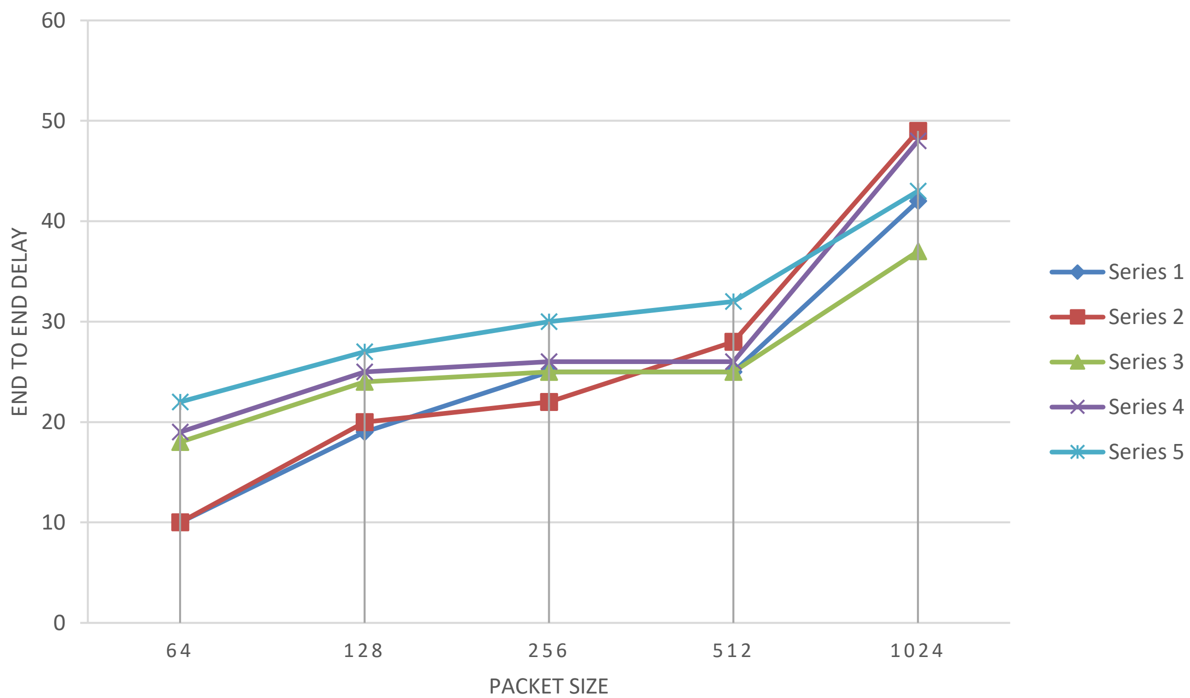


**Figure 8.3: End-to-End Delay vs Packet Sizes**

### (d) Impact on the Node's Exhaustiveness:

Another critical energy issue is preventing network nodes from becoming exhausted, allowing them to continue receiving incoming messages designated for them and acting as sender in the appropriate instances. Figure 8.4 and Table 8.5 demonstrate the effectiveness of both ACBEEMR and MACBEEMR in keeping the network's nodes from exhausting. The concept of imposing a threshold limit on the amount of energy required to use a particular node as an intermediary node aid in preventing the node from completely failing. The data demonstrate this, as all other protocols have a greater number of tired nodes than these two.

- In comparison to other protocols, AOMDV has a high number of fatigued nodes.

| Packet Size / Protocols | 64 | 128 | 256 | 512 | 1027 |
|---|---|---|---|---|---|
| **AOMDV** | 4 | 4 | 5 | 6 | 6 |
| **ACBEEMR** | 0 | 0 | 0 | 0 | 0 |
| **MACBEEMR** | 0 | 0 | 0 | 0 | 0 |
| **FF-AOMDV** | 2 | 2 | 2 | 3 | 4 |
| **AOMR-LM** | 0 | 1 | 1 | 1 | 2 |

**Table 8.5: Number of Exhausted Nodes vs Packet Size**

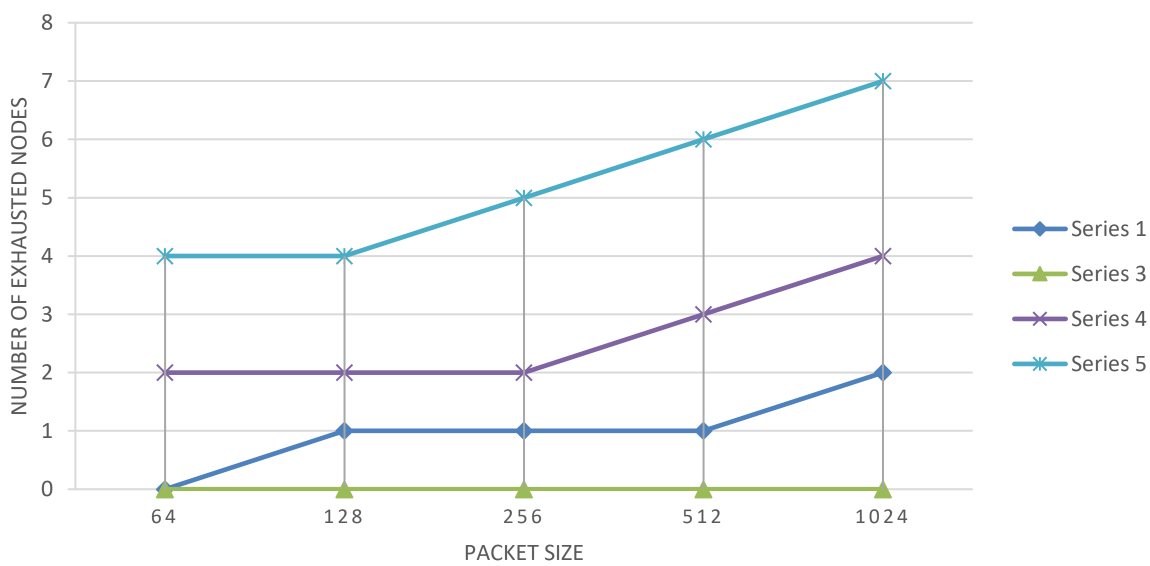


**Figure 8.4: Number of Exhausted Nodes vs Packet Size**

The packet delivery %, energy consumption, number of fatigued nodes, and end-to-end latency all demonstrate the superiority of Ant-based techniques, specifically ACBEEMR and MACBEEMR, over alternative protocols.

### 8.2.3 Cumulative Metric Analysis:

The findings acquired in Section 8.2.2 are utilized to examine the performance of all protocols by employing the NET measure presented in Chapter 5.

The following are the many NET metrics elements that were utilized to examine the performance of the various protocols discussed in Section 8.2.1:

- Packet Delivery Percentage factor (Pd)
- Energy Consumed factor (Ec)
- End-to-End Delay (Ed)
- Number of Exhausted Nodes (Ne)

| | Packet Delivery Ratio (Pd) | Energy Consumed (E.c) | End to End Delay (Ed) | No. of Exhausted Nodes (Ne) | MAX Pd | MIN Pd | MAX Ec | MIN Ec | MAX Ed | MIN Ed | MAX Ne | MIN Ne | Pd FACTOR | Ec FACTOR | Ed FACTOR | Ne FACTOR | NET |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***AOMDV*** | | | | | | | | | | | | | | | | | |
| *64* | 89.56 | 81.00 | 21.63 | 4.00 | 95.45 | 89.56 | 81.00 | 10.00 | 21.63 | 9.47 | 4.00 | 0.00 | -0.07 | -7.10 | -1.28 | -4.00 | -12.45 |
| *128* | 83.00 | 84.00 | 26.50 | 4.00 | 95.54 | 83.00 | 84.00 | 11.00 | 26.50 | 18.52 | 4.00 | 0.00 | -0.15 | -6.64 | -0.43 | -4.00 | -11.22 |
| *256* | 81.00 | 90.00 | 29.70 | 5.00 | 90.00 | 81.00 | 90.00 | 12.00 | 29.70 | 21.76 | 5.00 | 0.00 | -0.11 | -6.36 | -0.36 | -5.00 | -11.98 |
| *512* | 78.00 | 93.00 | 32.50 | 6.00 | 89.00 | 78.00 | 93.00 | 14.00 | 32.50 | 24.77 | 6.00 | 0.00 | -0.14 | -5.64 | -0.31 | -6.00 | -12.10 |
| *1024* | 70.67 | 120.00 | 43.06 | 6.00 | 85.00 | 70.67 | 85.00 | 17.00 | 48.54 | 32.32 | 6.00 | 0.00 | -20 | -6.06 | -16 | -6.00 | -12.42 |
| ***ACBEEMR*** | | | | | | | | | | | | | | | | | |
| *64* | 90.00 | 15.04 | 9.47 | 0.00 | 95.45 | 89.56 | 81.00 | 10.00 | 21.63 | 9.47 | 4.00 | 0.00 | -0.06 | 6.09 | 1.28 | 4.00 | 11.32 |
| *128* | 89.00 | 15.96 | 20.27 | 0.00 | 95.54 | 83.00 | 84.00 | 11.00 | 26.50 | 18.52 | 4.00 | 0.00 | -0.08 | 5.73 | 0.24 | 4.00 | 9.90 |
| *256* | 85.00 | 17.72 | 21.76 | 0.00 | 90.00 | 81.00 | 90.00 | 12.00 | 29.70 | 21.76 | 5.00 | 0.00 | -00.0 | 5.55 | 0.36 | 5.00 | 10.90 |
| *512* | 84.00 | 21.52 | 28.21 | 0.00 | 89.00 | 78.00 | 93.00 | 14.00 | 32.50 | 24.77 | 6.00 | 0.00 | 0.01 | 4.57 | 0.03 | 6.00 | 10.62 |
| *1024* | 81.00 | 23.52 | 48.54 | 0.00 | 85.00 | 70.67 | 85.00 | 17.00 | 48.54 | 32.32 | 6.00 | 0.00 | 0.09 | 5.29 | -0.50 | 6.00 | 10.88 |
| ***MACREEMR*** | | | | | | | | | | | | | | | | | |
| *64* | 93.91 | 10.00 | 9.69 | 0.00 | 95.45 | 89.56 | 81.00 | 10.00 | 21.63 | 9.47 | 4.00 | 0.00 | 0.03 | 7.10 | 1.24 | 4.00 | 12.37 |
| *128* | 95.54 | 11.00 | 18.52 | 0.00 | 95.54 | 83.00 | 84.00 | 11.00 | 26.50 | 18.52 | 4.00 | 0.00 | 0.15 | 6.64 | 0.43 | 4.00 | 11.22 |
| *256* | 86.75 | 12.00 | 24.67 | 0.00 | 90.00 | 81.00 | 90.00 | 12.00 | 29.70 | 21.76 | 5.00 | 0.00 | 0.03 | 6.50 | 0.10 | 5.00 | 11.63 |
| *512* | 86.00 | 14.00 | 24.77 | 0.00 | 89.00 | 78.00 | 93.00 | 14.00 | 32.50 | 24.77 | 6.00 | 0.00 | 0.06 | 5.64 | 0.31 | 6.00 | 12.02 |
| *1024* | 85.00 | 17.00 | 42.03 | 0.00 | 85.00 | 70.67 | 85.00 | 17.00 | 48.54 | 32.32 | 6.00 | 0.00 | 0.20 | 6.06 | -0.10 | 6.00 | 12.16 |
| ***FF-AOMDV*** | | | | | | | | | | | | | | | | | |
| *64* | 95.43 | 69.00 | 17.33 | 2.00 | 95.45 | 89.56 | 81.00 | 10.00 | 21.63 | 9.47 | 4.00 | 0.00 | 0.07 | -4.70 | -0.42 | 0.00 | -5.05 |
| *128* | 93.00 | 71.00 | 24.00 | 2.00 | 95.54 | 83.00 | 84.00 | 11.00 | 26.50 | 18.52 | 4.00 | 0.00 | 0.09 | -4.27 | -0.16 | 0.00 | -4.34 |
| *256* | 90.00 | 77.00 | 25.50 | 2.00 | 90.00 | 81.00 | 90.00 | 12.00 | 29.70 | 21.76 | 5.00 | 0.00 | 0.11 | -4.33 | 0.02 | 1.00 | -3.20 |
| *512* | 89.00 | 84.00 | 26.00 | 3.00 | 89.00 | 78.00 | 93.00 | 14.00 | 32.50 | 24.77 | 6.00 | 0.00 | 0.14 | -4.36 | 0.21 | 0.00 | -4.00 |
| *1024* | 81.00 | 93.00 | 32.32 | 4.00 | 85.00 | 70.67 | 85.00 | 17.00 | 48.54 | 32.32 | 6.00 | 0.00 | 0.09 | -2.88 | 0.50 | -2.00 | -4.29 |
| ***AOMR-LM*** | | | | | | | | | | | | | | | | | |
| *64* | 93.12 | 63.00 | 18.64 | 0.00 | 95.45 | 89.56 | 81.00 | 10.00 | 21.63 | 9.47 | 4.00 | 0.00 | 0.01 | -3.50 | -0.65 | 4.00 | -0.14 |
| *128* | 91.00 | 65.00 | 25.00 | 1.00 | 95.54 | 83.00 | 84.00 | 11.00 | 26.50 | 18.52 | 4.00 | 0.00 | 0.04 | -3.18 | -0.27 | 2.00 | -1.41 |
| *256* | 88.00 | 73.00 | 26.80 | 1.00 | 90.00 | 81.00 | 90.00 | 12.00 | 29.70 | 21.76 | 5.00 | 0.00 | 0.06 | -3.67 | -0.10 | 3.00 | -0.70 |

**Table 8.6: Analysis using cumulative metric**

Table 8.6 summaries the NET metric results for all protocols. The following are critical observations:

- The large negative values associated with AOMDV demonstrate AOMDV's ineffectiveness across all parameters.

- The high positive values associated with MACBEEMR and ACBEEMR demonstrate the two treatments' overall effectiveness. However, the higher values of MACBEEMR in comparison to ACBEEMR demonstrate MACBEEMR's effectiveness.

- FF-AOMDV and AOMR-LM are inefficient in terms of energy consumption (Ec), as indicated by the negative values for Ec.

## 8.3 APPLICATION OF LOAD BALANCING TO ACBEEMR:

To maximize the benefits of multipath routing in a multipath scheme such as ACBEEMR, load balancing is critical. Additionally, ACBEEMR incorporates an intrinsic system for load balancing in response to proportional energy changes. To validate the effectiveness of the intrinsic load balancing mechanism in ACBEEMR, a variant of ACBEEMR with roulette wheel- based load balancing, dubbed ACBEEMR-LB, was built. The findings of both tests, ACBEEMR and ACBEEMR-LB, were compared in order to determine the influence of load balancing on ACBEEMR.

Roulette wheel selection is one of the most often used classical procedures in Genetic Algorithms for population selection. When using a roulette wheel selection strategy, populations with a higher fitness value have a greater probability of being selected than populations with a lower fitness value. Section 8.3.1 summarizes the fundamentals of the roulette wheel selection approach.

### 8.3.1 Selection of roulette wheel:

In the Roulette wheel selection strategy, each population type is given an equal probability of selection based on its fitness value. For instance, suppose there are four distinct populations available, namely Types A, B, C, and D. Type A, B, C, and D have fitness values of 0.60, 0.25, 0.10, and 0.05, respectively. Then, as illustrated in Figure 8.5, these can be represented by a roulette wheel.

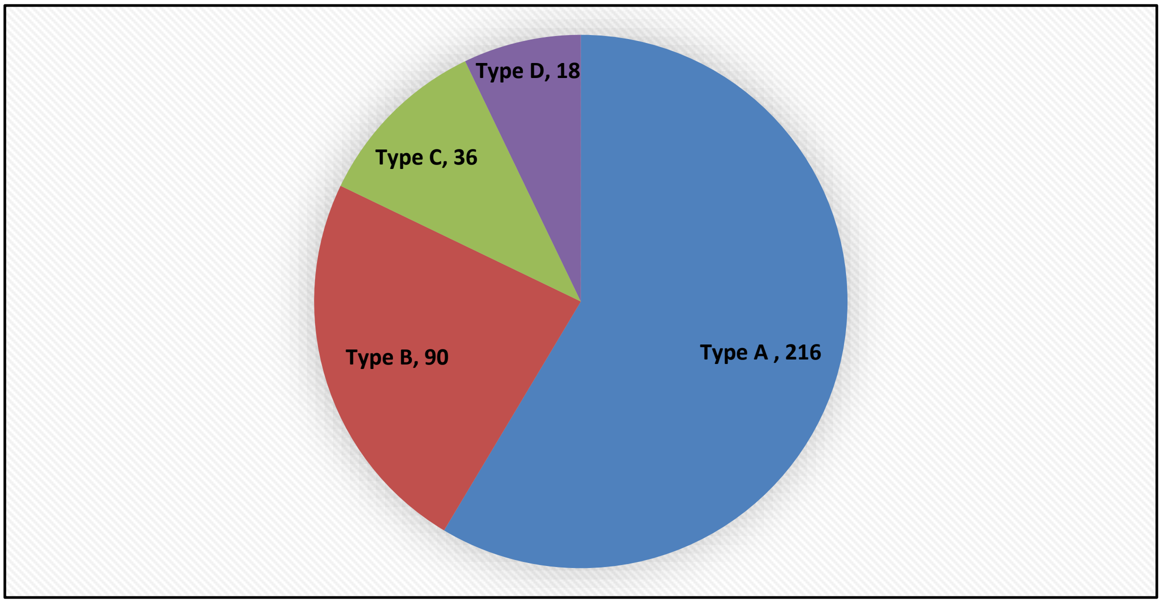


**Figure 8.5: Roulette wheel Selection**

**Equation 8.2 represents the portion of Type A on the Roulette Wheel:**

$$Portion\ of\ A = \frac{Finess\ of\ A}{Fitness\ of\ A + \ Fitness\ of\ B\ + \ Fitness\ of\ D} \tag{8.2}$$

$$Area\ for\ Type\ A\ on\ Roulette\ Wheel\ = \left(\frac{0.060}{I}\right) *\ 360 = 216$$

Similar procedure can be followed for Type B, C and D.

$$Area\ for\ Type\ B\ on\ Roulette\ Wheel\ = \left(\frac{0.25}{I}\right) *\ 360 = 90$$

$$Area\ for\ Type\ C\ on\ Roulette\ Wheel\ = \left(\frac{0.1}{I}\right) *\ 360 = 36$$

$$Area\ for\ Type\ D\ on\ Roulette\ Wheel\ = \left(\frac{0.05}{I}\right) *\ 360 = 18$$

Thus, when the wheel is rotated for population selection, Type A will have a greater probability of selection than Type B, which will have a greater chance than Type C, and Type C will have a greater chance than Type D.

### 8.3.2 Application of Roulette wheel selection for Load distribution:

ACBEEMR is modelled after the behavior of biological ants during Ant Colony optimization. ACBEEMR's fundamental procedure can be stated as follows:

The ACBEEMR is primarily concerned with two factors: hop count and the proportionate energy shift in the neighbor node's residual energy. At each point in time, adjacent nodes' remaining energy is supplied by Energy Ants from those nodes.

The ACBEEMR generates pheromone values that correspond to the numerous paths that can be taken from the present node to various neighbor nodes. These pheromone values can be used to distribute loads and can also be mapped into a roulette wheel. The following summaries the technique for dispersing load among many paths:

Load Distribution Scheme (ACBEEMR-LR)

**//Generation of Forward Ants**//

Begin

Find different pheromone values corresponding to different routes through various neighbor nodes.

//**Generation of Backward Ant**//

Generate the fitness value corresponding to different routes by dividing the pheromone value for a particular route with the sum of pheromone values of all the routes.

Here Fki represents the pheromone fitness corresponding to the routes through node i to destination j

$$F_{kij} \leftrightarrow \frac{\mathrm{P}K_{ij}}{\sum_{t=1}^{n} \mathrm{P}K_{ij}} \tag{8.3}$$

Map these values on scale of 100 by multiplying the value of Fkijcorresponding to each route by

100.
/* As an example, if value on scale of 100 for three possible routes i.e. route A is 33, B is 60 and C is 7 then assign the slot 0 to 33 to route A. followed by a slot of 34 to 93 to Route B and Slot of 94 to 100 to Route C*/

//**Generation of random number**//

For each newly arrived packet, generate a random number from 0 to 100.
And find the slot in which it lies.
Transmit the packet over the route selected through the random number generation.
End

This technique favours the path with a higher pheromone value by increasing its likelihood of selection. Simultaneously, it provides an opportunity for paths with low pheromone levels to compete for selection.
The following section compares the load balancing strategy to the old approach using simulations.

## 8.4 SIMULATION BASED COMPARISON OF ACBEEMR ANDACBEEMR-LB:

### 8.4.1 Comparative Analysis Using Simulations:

The roulette wheel is an effective selecting tool. ACBEEMR-LB selects a path for packets using a Roulette wheel from a collection of identified potential paths. This section simulates the proposed approach with the NS2 simulator. Table 8.7 illustrates many simulation parameters. A packet size of 512 bytes was used for this experiment, which lasted 200 seconds. On the basis of the number of connections, the proposed technique was compared to the original protocol, ACBEEMR, and two other protocols, AOMDV and TALB-AOMDV. The connection count specifies the maximum number of connections that can be established between mobile nodes.

| **Routing Protocol** | **ACBEEMR, AOMDV, ACBEEMR-LB, TALB-AOMDV** |
|---|---|
| Network topology | 1000* 1000 |
| MAC Type | 802.11 |

| | |
|---|---|
| Max. Packet in IFQ | 50 |
| Radio propagation model | Two ray ground |
| Number of Nodes | 50 |
| Packet size | 512bytes |
| Max. Simulation time | 200s |
| Initial Energy | 100 joule |
| Transmission Power | 0.02joule |
| Receiving Power | 0.01joule |
| Traffic Type | CBR |
| Transmission Range | 250m |
| Number of Connections | 5,10,15,20,25,30 and 35 |

**Table 8.7: Various Simulation Parameters**

**(a) Packet Delivery Ratio:**

The Packet Delivery Ratio (PDR) is a useful indicator for evaluating the protocol's routing mechanism's efficacy. It calculates the ratio of data packets delivered at a destination to those transmitted from the source. The findings for the Packet Delivery Ratio are shown in Figure 8.6 and Table 8.8. The following observations are noteworthy:

- The results indicate that load balancing does indeed increase a protocol's performance. The findings obtained with ACBEEMR-LB are superior than those obtained using the ACBEEMR methodology.

- Additionally, the results of both ACBEEMR and ACBEEMR-LB are consistently superior than those of the other two protocols by a large margin.

| **No. of Connections** / **Protocols** | **5** | **10** | **15** | **20** | **25** | **30** | **35** |
|---|---|---|---|---|---|---|---|
| AOMDV | 0.70 | 0.51 | 0.425 | 0.35 | 0.30 | 0.22 | 0.20 |
| TALB-AOMDV | 0.66 | 0.505 | 0.41 | 0.35 | 0.30 | 0.28 | 0.24 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ACBEEMR | 0.90 | 0.64 | 0.56 | 0.53 | 0.51 | 0.46 | 0.44 |
| ACBEEMR-LB | 0.90 | 0.70 | 0.59 | 0.56 | 0.54 | 0.46 | 0.46 |

**Table 8.8: PDR vs Number of Connection**

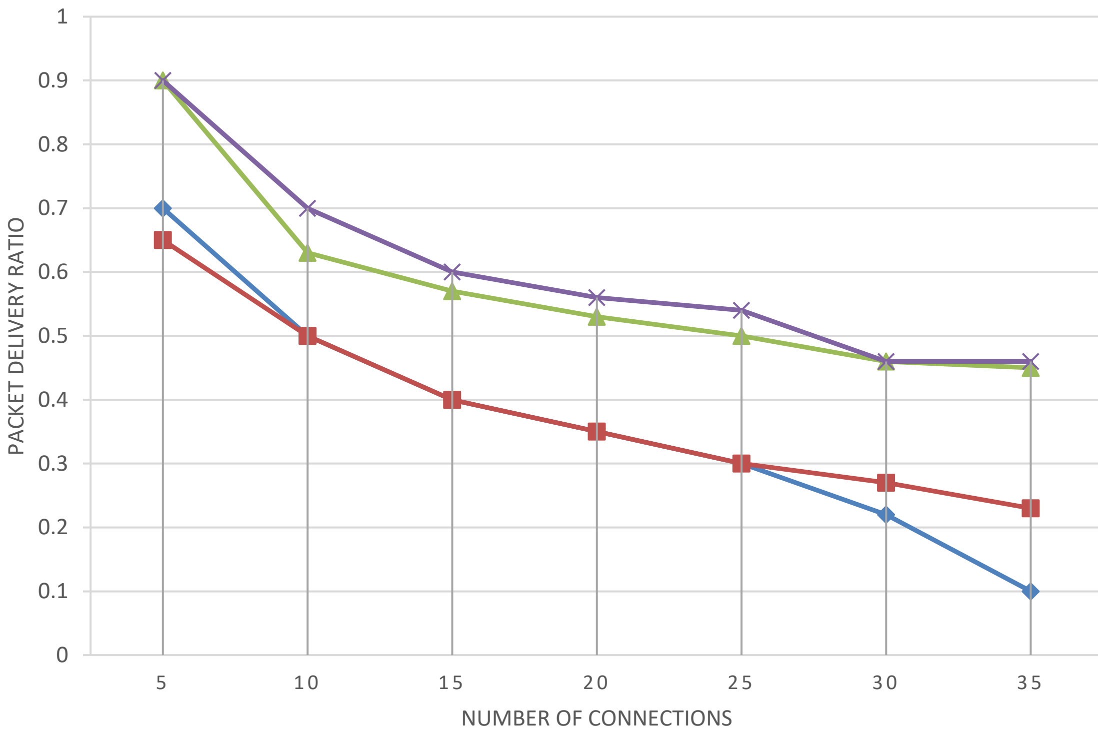


**Figure 8.6: PDR vs Number of connections**

**(b) Throughput:**

Throughput is a unit of measurement that indicates the rate at which data is delivered to a destination. It is expressed in kbps.

- The results (Figure 8.7) indicating throughput further demonstrate ACBEEMR- dominance LB's over alternative protocols. However, when connecting a large number of devices, the performance of ACBEEMR and ACBEEMR-LB is practically same.
- Additionally, it can be noted that ACBEEMR-LB and ACBEEMR perform better than the other two protocols, except when the number of connections is quite low.

| No. of Connection / Protocols | 5 | 10 | 15 | 20 | 25 | 30 | 35 |
|---|---|---|---|---|---|---|---|
| **AOMDV** | 105.00 | 160.00 | 180.00 | 180.00 | 200.00 | 175.00 | 172.00 |
| **TALB-AOMDV** | 100.00 | 160.00 | 177.00 | 180.00 | 200.00 | 205.00 | 202.00 |
| **ACBEEMR** | 56.57 | 206.64 | 232.83 | 319.66 | 247.3 | 268.61 | 231.79 |
| **ACBEEMR-LB** | 50.32 | 219.33 | 257.28 | 328.4 | 277.76 | 283.29 | 224.77 |

**Table 8.9: Throughput vs Number of Connections**

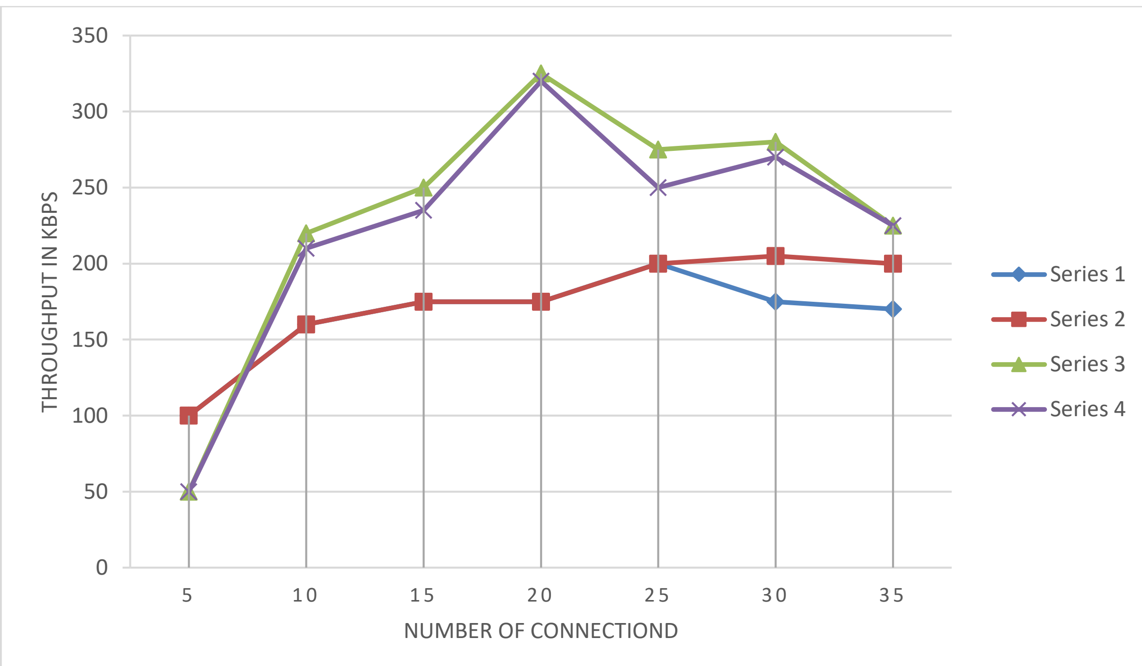


**Figure 8.7: Throughput vs Number of connections**

**(c) End-to-End Delay:**

The results for the Average End-to-End latency are shown in Figure 8.8. The findings demonstrate the superiority of ACBEEMR-LB over alternative regimens.

- Table 8.10 and Figure 8.8 demonstrate that ACBEEMR-LB has a shorter End-to-End delay than other protocols.

### 8.4.2 Analysis using Cumulative Metric:

The data from section 8.4.1 are utilized to analyses the performance of all protocols using the NET metric.

| No.of Connections / Protocols | 5 | 10 | 15 | 20 | 25 | 30 | 35 |
|---|---|---|---|---|---|---|---|
| **AOMDV** | 75.00 | 850.00 | 1510.00 | 1850.00 | 2000.00 | 2350.00 | 2150.00 |
| **TALB-AOMDV** | 90.00 | 1025.00 | 1075.00 | 1650.00 | 1920.00 | 1900.00 | 2050.00 |
| **ACBEEMR** | 20.64 | 685.284 | 699.42 | 690.35 | 568.661 | 677.294 | 551.731 |
| **ACBEEMR-LB** | 21.13 | 495.303 | 407.394 | 624.235 | 551.645 | 500.965 | 461.598 |

**Table 8.10: Avg. End-to-End Delay vs Number of Connection**

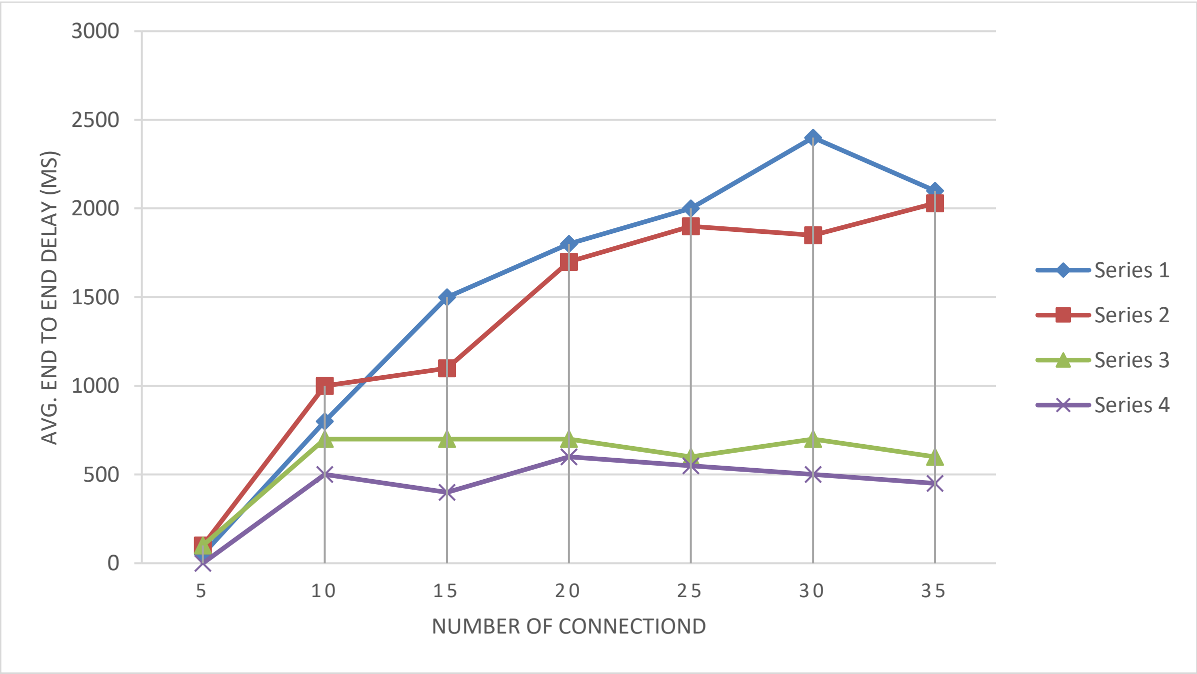


**Figure 8.8: Avg. End-to-End delay vs Number of connection**

| | Packet Delivery Ratio(Pd) | Throughput (d1) | End to End Delay (Ed) | MAX Pd | MIN Pd | MAX Tp | MIN Tp | MAX Ed | MIN Ed | Pd FACTOR | Tp FACTOR | Ed FACTOR | NET |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AOMDV | | | | | | | | | | | | | |
| **5** | 0.70 | 105.00 | 75.00 | 0.90 | 0.66 | 105.00 | 50.32 | 90.00 | 20.64 | -0.24 | 1.09 | -1.91 | -1.06 |
| **10** | 0.51 | 160.00 | 850.00 | 0.70 | 0.51 | 219.33 | 160.00 | 1025.00 | 495.30 | -0.37 | -0.37 | -0.36 | -1.10 |
| **15** | 0.43 | 180.00 | 1510.00 | 0.59 | 0.41 | 257.28 | 177.00 | 1510.00 | 407.39 | -0.37 | -0.42 | -2.71 | -3.49 |
| **20** | 0.35 | 180.00 | 1850.00 | 0.56 | 0.35 | 328.40 | 180.00 | 1850.00 | 624.24 | -0.60 | -0.82 | -1.96 | -3.39 |
| **25** | 0.30 | 200.00 | 2000.00 | 0.54 | 0.30 | 277.76 | 175.00 | 2000.00 | 551.65 | -0.80 | -0.30 | -2.63 | -3.73 |
| **30** | 0.22 | 175.00 | 2350.00 | 0.46 | 0.22 | 283.29 | 172.00 | 2350.00 | 500.97 | -1.09 | -0.61 | -3.69 | -5.39 |
| **35** | 0.20 | 172.00 | 2150.00 | 0.46 | 0.20 | 231.79 | 202.00 | 2150.00 | 461.60 | -1.30 | -0.44 | -3.66 | -5.40 |
| TALB-AOMDV | | | | | | | | | | | | | |
| **5** | 0.66 | 100.00 | 90.00 | 0.90 | 0.66 | 105.00 | 50.32 | 90.00 | 20.64 | -0.36 | 0.89 | -3.36 | -2.84 |
| **10** | 0.51 | 160.00 | 1025.00 | 0.70 | 0.51 | 219.33 | 160.00 | 1025.00 | 495.30 | -0.39 | -0.37 | -1.07 | -1.83 |
| **15** | 0.41 | 177.00 | 1075.00 | 0.59 | 0.41 | 257.28 | 177.00 | 1500.00 | 407.39 | -0.44 | -0.45 | -0.57 | -1.46 |
| **20** | 0.35 | 180.00 | 1650.00 | 0.56 | 0.35 | 328.40 | 180.00 | 5850.00 | 624.24 | -0.60 | -0.82 | -1.32 | -2.75 |
| **25** | 0.30 | 200.00 | 1920.00 | 0.54 | 0.30 | 277.76 | 175.00 | 2000.00 | 551.65 | -0.80 | -0.30 | -2.34 | -3.44 |
| **30** | 0.28 | 205.00 | 1900.00 | 0.46 | 0.22 | 283.29 | 172.00 | 2350.00 | 500.97 | -0.50 | -0.26 | -1.89 | -2.70 |
| **35** | 0.24 | 202.00 | 2050.00 | 0.46 | 0.20 | 231.79 | 202.00 | 2150.00 | 461.60 | -0.90 | -0.15 | -3.22 | -4.27 |
| ACBEEMR | | | | | | | | | | | | | |
| **5** | 0.90 | 56.57 | 20.64 | 0.90 | 0.66 | 105.00 | 50.32 | 90.00 | 20.64 | 0.36 | -0.84 | 3.36 | 2.89 |
| **10** | 0.64 | 206.64 | 685.28 | 0.70 | 0.51 | 219.33 | 160.00 | 1025.00 | 495.30 | 0.15 | 0.21 | 0.30 | 0.66 |
| **15** | 0.56 | 232.83 | 699.42 | 0.59 | 0.41 | 257.28 | 177.00 | 1500.00 | 407.39 | 0.29 | 0.18 | 1.27 | 1.74 |
| **20** | 0.53 | 319.66 | 690.35 | 0.56 | 0.35 | 328.40 | 180.00 | 5850.00 | 624.24 | 0.43 | 0.73 | 1.75 | 2.91 |
| **25** | 0.51 | 247.30 | 568.66 | 0.54 | 0.30 | 277.76 | 175.00 | 2000.00 | 551.65 | 0.60 | 0.24 | 2.56 | 3.40 |
| **30** | 0.46 | 268.61 | 677.29 | 0.46 | 0.22 | 283.29 | 172.00 | 2350.00 | 500.97 | 1.09 | 0.48 | 2.99 | 4.55 |
| **35** | 0.44 | 231.79 | 551.73 | 0.46 | 0.20 | 231.79 | 202.00 | 2150.00 | 461.60 | 1.10 | 0.15 | 3.27 | 4.51 |
| ACBEEMR-LB | | | | | | | | | | | | | |
| **5** | 0.90 | 50.32 | 21.13 | 0.90 | 0.66 | 105.00 | 50.32 | 90.00 | 20.64 | 0.36 | -1.09 | 3.31 | 2.59 |
| **10** | 0.70 | 219.33 | 495.30 | 0.70 | 0.51 | 219.33 | 160.00 | 1025.00 | 495.30 | 0.39 | 0.37 | 1.07 | 1.83 |
| **15** | 0.59 | 257.28 | 407.39 | 0.59 | 0.41 | 257.28 | 177.00 | 1500.00 | 407.39 | 0.44 | 0.45 | 2.71 | 3.60 |
| **20** | 0.56 | 328.40 | 624.24 | 0.56 | 0.35 | 328.40 | 180.00 | 5850.00 | 624.24 | 0.60 | 0.82 | 1.96 | 3.39 |
| **25** | 0.54 | 277.76 | 551.65 | 0.54 | 0.30 | 277.76 | 175.00 | 2000.00 | 551.65 | 0.80 | 0.59 | 2.63 | 4.01 |
| **30** | 0.46 | 283.29 | 500.97 | 0.46 | 0.22 | 283.29 | 172.00 | 2350.00 | 500.97 | 1.09 | 0.65 | 3.69 | 5.43 |
| **35** | 0.46 | 224.77 | 461.60 | 0.46 | 0.20 | 231.79 | 202.00 | 2150.00 | 461.60 | 1.30 | 0.08 | 366 | 5.04 |

**Table 8.11 Analysis using Cumulative Metric**

The following are the many NET metrics elements that were utilized to examine the performance of the various protocols discussed in Section 8.4.1:

- Packet Delivery Ratio factor (Pd)
- Throughput factor (Tp)
- End-to-End delay (Ed)

Table 8.11 summarizes the NET metric findings for all protocols. The following are critical observations:

- The negative scores for AOMDV and TALB-AOMDV demonstrate their ineffectiveness un terms of the three criteria.
- The positive values for ACBEEMR-LB and ACBEEMR demonstrate the two procedures' overall effectiveness. However, higher ACBEEMR-LB values indicate superior performance when the number of connections is increased.

ACBEEMR-LB demonstrates its efficacy in terms of packet delivery, throughput, and end-to- end delay. However, it must be evaluated for energy efficiency. The primary goal of developing the ACBEEMR technique was to address the energy restriction. Thus, while applying load balancing to ACBEEMR, i.e. ACBEEMR-LB, it should not jeopardize the network's energy consumption.

To demonstrate this, the performance of ACBEEMR-LB was compared to that of ACBEEMR and AOMDV over a range of packet sizes. To do this, simulations were run using the simulation settings indicated in Table 8.1. The following are critical observations:

- ACBEEMR-LB consumes less energy than the other protocols throughout a range of packet sizes.
- ACBEEMR's energy consumption has not decreased much as a result of the load balancing strategy implemented S.

| Packet Size / Protocols | 64 | 128 | 256 | 512 | 1024 |
|---|---|---|---|---|---|
| **AOMDV** | 81.00 | 84.00 | 90.00 | 93.00 | 120.00 |
| **ACBEEMR** | 15.04 | 15.96 | 17.72 | 21.52 | 23.52 |
| **ACBEEMR-LB** | 6.01 | 7.68 | 8.59 | 12.88 | 13.03 |

**Table 8.12 Energy Consumption vs Packet Size**

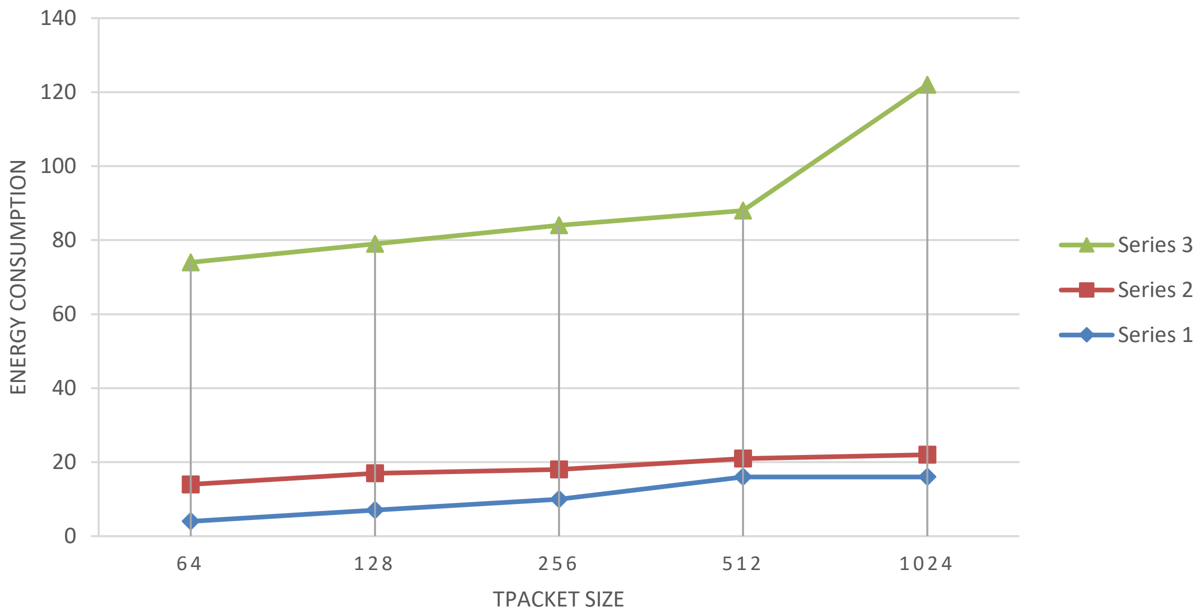


**Figure 8.9: Energy Consumption vs Packet Size**

## 8.5 Summary:

The chapter discussed two ACBEEMR variations, MACBEEMR and ACBEEMR-LB. NS2 was used to mimic the ACBEEMR and its derivatives. Additionally, their performance has been quantified using a variety of parameters, including energy consumption, packet delivery ratio, throughput, and end-to-end delay. The simulated comparison demonstrates the advantages of ACBEEMR and its derivatives. Additionally, Modified ACBEEMR presented a method for extending the network's lifetime. Additionally, the use of Energy Ants demonstrates its usefulness in terms of a large reduction in energy consumption. Additionally, the incorporation of load balancing in ACBEEMR, owing to its inherent procedural computing, facilitates the conception of recommended methods.

# CHAPTER 9

# CONCLUSION

The goal of this thesis was to develop a nature-inspired multipath routing protocol capable of optimizing the routing process in ad hoc networks. The design was oriented around mimicking the foraging behavior of real ants, specifically ACO. The study was founded on cognition and inferences taken from a survey of pertinent literature on multipath routing, Ant Colony optimization, and their application in MANETs. Numerous intriguing factors for problem formulations were given. These factors were taken into account when designing the proposed protocol, Ant Colony Based Energy Efficient Multipath Routing (ACBEEMR), which aims to optimize the routing mechanism in ad hoc networks. The following summary summarises the objectives and their accomplishments:

**Objective 1:** Create a cumulative metric for analyzing MANET protocols.

Measuring is critical for evaluating the quality-of-service support in MANETs. Numerous areas can be investigated to optimize the routing process. A single protocol cannot be superior in all performance metrics. A cumulative metric is required to achieve the optimal combination of all the components. NET is a cumulative statistic proposed in Chapter 5 for analyzing protocols based on their energy, PDR, throughput, and delay characteristics. NET's framework is adaptable and easily accommodates new factors. The NET metric enables effective examination of a protocol's overall performance, resulting in a full analysis of any protocol. Additionally, this statistic aids in identifying the reasons why a certain protocol is not doing as well as it does with other influencing parameters.

**Objective 2: Create criteria for node selection and implement them using fuzzy logic:**

Chapter 6 proposes a criterion for selecting the next node. This criterion can be used by any protocol to determine the next possible node for data forwarding in MANETs. Fuzzy logic was used to implement the designed criterion. The method makes use of a fuzzy controller to determine which node is the best candidate for selection. Two factors were employed as inputs to the fuzzy controller, namely the chance of the next node forming and the proportional energy change. A manual illustration of how criteria work has been demonstrated using an example network. This criterion was also used to choose the next node in ACBEEMR.

**Objective 3: To implement an energy-efficient technique that would avoid the same node from being used repeatedly as an intermediary node. This can help to avoid node failure due to insufficient energy.**

Two operations are carried out by the Energy Ants: pheromone depositing and evaporation. At each node, the Energy Ants adjust the pheromone content based on the network's energy condition. At regular intervals, a node broadcasts the Energy Ants to its neighbor. Additionally, the Energy Ants block the use of a node whose energy is less than a threshold value. Thus, ACBEEMR updates multiple routes to the destination based on the network's energy level, thereby increasing the network's life. The Energy Ants concept contributes to the development of an energy-aware smart network. These networks are intelligent in the sense that once a node learns of the likelihood of failure owing to a shortage of energy, it withdraws from the network as an intermediary node. However, as a source node, it can still commence transmission and discovery for other nodes. Chapter 7 discusses the concept of Energy Ants and their significance in the operation of ACBEEMR.

**Objective 4: Utilize Ant Colony Optimization to develop an effective routing method for investigating multiple paths between nodes in a Mobile Ad hoc Network**

Artificial Ants have been employed to replicate the ACO approach's nature. There are two types of synthetic ants used: Forward Ants and Backward Ants. These ants were used to discover paths and update them in the routing tables. Each Forward Ant that reaches the target identifies all viable routes from the source to the destination. The source node generates Forward Ants, whereas the destination node generates Backward Ants. This is a reversible technique. The Backward Ants are in charge of maintaining the pheromone by retracing the Forward Ants' passage back to the source. The amount of pheromone deposited at any node is inversely proportional to the number of hops necessary from that node to reach the destination. Energy Ants are naturally proactive. These proactive ants are responsible for maintaining numerous channels for transmission by advising neighbour nodes of the availability of alternate nodes. Chapter 7 details the whole capability of ACBEEMR and includes an example to demonstrate its accuracy. Additionally, ACBEEMR incorporates a load distribution system. This is demonstrated in Chapter 8 through a simulation-based comparison of ACBEEMR and its load balanced variation ACBEEMR-LB. Without a specific load distribution technique, ACBEEMR delivers results comparable to ACBEEMR-LB.

The aims outlined above were accomplished through the use of algorithms and procedures implemented in NS2. Additionally, the cumulative metric proposed in Chapter 5 was used to conduct the review procedure in Chapter 8. The ACBEEMR protocol was simulated using NS2 and its performance was compared to that of other multipath protocols under various parameter conditions. Additionally, the selection criterion for the next node selection was built using MATLAB's Fuzzy tool. The simulation-based comparison with AOMDV and other protocols such as TALBAOMDV, AOMR-LM, and FF-AOMDV demonstrates ACBEEMR's superior performance in terms of throughput and energy efficiency.

Recognized the following:

- The objectives, articulation of the problem, and review of pertinent literature, as well as the conclusions reached from it.
- Developing a cumulative metric for measuring routing protocol performance
- Formulation and implementation of node selection criteria using MATLAB's fuzzy logic tool
- A routing strategy for MANETs is designed and shown using an example network.
- The suggested method and its variants are implemented in a network simulator, and the proposed strategies' performance is compared to that of existing protocols.

**Future Directions:**

The proposed strategy's operation has been simulated utilizing various network sizes. The protocol demonstrated an increase in network energy efficiency. The work can be extended to create an intelligent network by incorporating learning capabilities into the nodes and enabling them to forecast the network's energy state based on the current behavior of mobile nodes, thereby controlling packet forwarding in advance rather than waiting for a threshold hold limit to be reached. Nonetheless, the effort undertaken may always be open to directions other than those first apparent.

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Soft Computing, Artificial Intelligence, Computer Network, Software Engineering, Computer Vision, Cyber Security, Discrete Structure and theory of logic, Computer Architecture, Computer application in pharmacy.

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## DECLARATION:

I hereby declare that the information furnished above is true to the best of my knowledge.

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# A Hypothesis for Ad-Hoc Routing Algorithm Improvement

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**ABSTRACT:**

In this article, a new approach to reducing the complexity of routing algorithms is discussed to improve routing in ad hoc networks. To avoid duplicating the routing process for each data transfer, nodes create binary matrices for each base station and update them when the routing is complete. Routing may be made much simpler using the method given here.
Keywords: Routing Train, Protocol, Algorithm Protocol, Algorithm and Routing Train in Ad-hoc Networks.

## 1. INTRODUCTION:

AD-HOC networks are growing in popularity because they are simple to set up, don't rely on infrastructure, and are the only practical way to connect several nodes.

### (a) Terminology:

Anywhere and at any time, with just a few plug-in wireless nodes, an Ad-hoc network can be set up without any prior network architecture [1, 2, 3, 4, 5]. Ad hoc networks include dynamic topologies, bandwidth constraints, energy consumption restrictions, and physical security restrictions [6, 7].

### (b) The most commonly used protocols:

The following are a few of the most common routing protocols:

Each node uses the Bellman-Ford Algorithm [10] to select the most efficient path based on the information stored in their tables in this table-driven/proactive protocol. [1].

An election is used to pick the cluster-heads in Clusterhead-Gateway Switch Routing (CGSR). DSDV Protocol [1] often uses cluster-heads to locate the shortest path.

To route traffic, each OLSR node uses the Dijkstra Algorithm [10] based on its tables [11, 12]. This methodology is table-driven and proactive.

The WRP table-driven/proactive protocol continues as each node sends a hello message to its neighbors and views them as successors [13].

ZRP is a hybrid protocol in which each node specifies a route request from its neighbors. ZRP is a hybrid protocol. A route reply is a node that contains the destination node in its zone.

Routing is based on packet movement in the Dynamic Source Routing Protocol (DSR) [1, 2, 4, 12, 14, 15, 16, 17, 18]. Packet broadcasting may be found in greater detail in [18].

Ad-hoc A protocol called On-demand Distance Vector Routing (AODV) works only when necessary. It's just like DSR. Unlike DSR, AODV responds more quickly to hello messages when there is no means to reach the target [4, 12, 14, 16, 17, 18]. [4, 12, 14, 16, 17, 18]

For those times when you need it, there's the Temporally-Ordered Routing Algorithm (TORA). A query packet, an update packet, and a clear packet are all sent. As a result, after the questions are answered, the entire graph is updated for each node.

LAMAR is a cluster-based or hierarchical routing protocol. Nodes are used as landmarks and are followed to the target. Core-Extraction [20] CEDAR is a protocol that uses a cluster-based or hierarchical structure. When a node needs aid from a leader, it reaches out to that leader. After that, they send instructions to each node regarding the best course of action.

### (c) The Issue:

Table-driven and proactive routing algorithms are the most common, while hybrid, on-demand, and reactive protocols are standard in ad hoc networks [8]. Several routing strategies are available to each group, each with advantages and disadvantages. One or more of the most often used approaches have been evaluated and improved, resulting in new ways. Because these algorithms were built for a single protocol, most cannot be utilized on other protocols.

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**(d) Strategy:**

Network training can improve routing protocols, as we show in this paper. Eventually, the complexity of the routing protocol will fall into the most efficient range after using this method. Running the routing protocols n times is not a good idea. We try to find the quickest way to accomplish our goals in every procedure. If we repeat the optimization process n times, it becomes a burden. A new technique has been developed to reduce the number of times routing protocols are repeated. Even though the proposed method is still simply a theory and has yet to be implemented, we feel it will be incredibly advantageous.

**(e) The Petition:**

We believe that a middle ground has been reached. A binary matrix is created for each network node, and then the routing protocol is used to find a path to the destination. Finally, the matrices update the path to reflect the new route. See [9] for more details on protocol rerouting.

**(d) Purpose:**

A novel solution has been proposed to reduce the complexity of multipath routing. This idea allows us to get to the point where nodes don't need to request a route anymore and instead learn how to send their data. As a result, data is only accessed and sent through the nodes along the way.

**(e) Outline of the paper:**

There are four sections to this article. In Section 1, we introduced the problem, provided a solution, and claimed that the answer was the best one available. Some of the challenges in route design are addressed in Section 2. There are many advantages to the Training Algorithm, discussed in Section 3. For ad-hoc networks, a novel method is proposed in Section 4.

## II PRIOR WORK:

Even though some research and surveys have already been done, it's still possible to improve routing and security in ad-hoc networks. Several studies outlining efforts to optimize routes are explored and offered below as predecessors for our idea in this investigation.

A lifetime route optimization model for ad-hoc wireless networks was examined in [22]. The route lifetime value is an essential factor when constructing ad-hoc routing methods. This option determines the routing database's active path/route duration, ensuring reliable packet transmission. The purpose is to prevent the routing table from discovering a new route or deleting an active route already in existence. Updates to routing databases may be delayed, even though some paths are no longer operational since the route lifetime is too long [22].

A fuzzy logic system is proposed in the cited work to estimate the adaptive route's life span. Fuzzy logic was developed in response to the limitations of mathematical models and the inherent ambiguity in calculating node mobility. The new fuzzy ART approach should be characterized by membership functions and a set of rules, according to some experts (rule base). We employed the AODV routing protocol to test this new strategy and believed it might be applied to other ad hoc routing systems.

A self-repairing and optimized routing technique is demonstrated using fuzzy logic concepts [23]. Since there are a lack of global topology and mobility of nodes, standard dynamic source routing protocols yield paths that are far from ideal. Optimizing routing when the network is stressed can substantially affect performance. Greater distance increases bandwidth and power consumption and increases the likelihood of a system failure. When a shortcut is available, SHORT (Self Healing and Optimizing Routing Technique) will shorten the journey. We'll use GloMoSim [23] to examine and compare the proposed fuzzy logic method to the conventional one.

Securitization of routing protocols, which are still infants, is the primary emphasis of [24]. Ad-hoc routing protocols are more challenging to design because of the previously stated high dynamics and other limits. It usually requires a good trade-off between multiple criteria, including boosting routing optimally, decreasing traffic volume, and regulating power consumption. We believe that security considerations are rarely taken into account while developing new protocols.

Control channels are made available to each node in the network via [25] time slots, which allows any node to broadcast the control packet to any one-hop neighbor in just a single cycle. [25] The objective is to minimize the number of time slots available during the scheduling cycle. As a result, a predetermined channel access schedule is generated. The broadcasting on the defined timeslots will reach its neighbors correctly since each node is granted one or more chances to access the control channel (timeslot in TDMA systems) (s). The length of the scheduling cycle limits the maximum delay on the control channels. A single time slot can be reused if two nodes do not communicate. [25] The purpose of the challenge in access scheduling is to keep the scheduling cycle as short as feasible.

Three fundamental optimization solutions for the well-known AODV routing protocol are provided in [26] to utilize some of the proactive protocol characteristics. Routes

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can be built up in three ways: backward, forwards, or randomly. The key goals are shortest-path routing and traffic-independent control.

Using criteria such as path length, energy consumption along the way, and energy-conscious load balancing among nodes, the SHORT framework (Self-Healing and Optimising Routing Techniques) for mobile ad hoc networks [27] specifies routing optimality. Neighboring nodes watch and improve the route if a better local sub-path becomes available when using SHORT. The upshot is that SHORT lowers latency and bandwidth consumption without increasing overall costs. SHORT can be used to find routes with low energy usage or the best use of the battery's remaining power.

## III THE PROPOSED ALGORITHM:

### (a) Representation of the Algorithm:

Prioritizing route optimization over routing complexity reduction is the primary goal of all routing algorithms. Routing should be repeated whenever data needs to be transferred. In DSR, various optimizations are made, but the fundamental shortcoming of these optimization efforts is that they are protocol-dependent. In the DSR protocol optimization mechanism, the passed route is saved in a cache and repeated as many times as necessary.

The training time was also considered, but we also used a binary matrix, which reduces storage requirements while simultaneously speeding up the training process.

The network's presuppositions are specified before developing the algorithm:

1. Nodes and edges make up the network's structure.
2. Numbers are used to representing nodes.
3. The numbering of the edges that connect one node to its neighbors is done similarly. The ordering of edges is made simpler by assigning a number to each node. Is there any necessity for a sequential order in the number of nodes associated with one node?
4. Training and bandwidth management are both available on each node. For control, not training, the bandwidth array increases transfer quality. The method may be set up by saving data in a table.
5. The entire graph is based on a single adjacent matrix.
6. There are four different types of symbols used in this graph: a source, a destination, and a routing array, all represented by the letters "G," which stand for "w" or "weight."

The code of the algorithm is as follows:

```
Training_Algorithm (G,w,s,d)
If ! R[d]
 Ro = get_route_from_a_routing_algorithm(G,w,s,d)
send_update(G,Ro,0,d)
-----------------------------------
Send_data(data,s,d)
Training_ Algorithm (G,w,s,d)
Transfer_data(data,s,d)
-----------------------------------
Transfer_data(data,s,d)
If s <> d
J=index_vertex(s, lg R[d])
Transfer(data,j,d)
-----------------------------------
Send_update(G,Ro,start,d)
If Ro[start] <> d
K=index_Edge(Ro[start], Ro[start+1])
R[d]=2^k
Send_update(G,Ro,start+1,d)
-----------------------------------
Index_Edge(i,j) As integer
K=0
Flag = false
While (flag)
Do
If A[i][k]
Counter=counter+1
K=k+1
If (counter=j)
Flag=false
Return counter
-----------------------------------
Index_vertex(i,k) As integer
K=0
Flag = false
While (flag)
Do
If A[i][k]
Counter=counter+1
L=L+1
If (counter=k)
Flag=false
Return L
```

As demonstrated, the algorithm initially checks to see if the graph has been trained. It sends data only if it has been educated or if a routing protocol sends it as an array. Nodes are then trained by receiving updates via a defined route. Training is performed via updating.

Each node has a one-dimensional binary matrix. Numeric labels for each node are displayed in the rows or indexes of that matrix. The bits are arranged in rows to determine the edge through which a node can transmit data. Logarithm and the method make filling in a binary matrix so simple. To do training and routing more efficiently, the binary matrix requires less memory, and access takes only O(1) time.

### (b) The Advantages of This Technique:

Even though this strategy does not optimize the routing protocol, it teaches and leads the network to learn and utilize the protocol once and use the route given thousands of times. During the update, all the nodes on a path are updated. Several nodes must be updated when a destination is far away and travels through most nodes; this reduces routing protocol repetition.

Because it is protocol-free, this approach could theoretically be used in any mobile or wireless ad hoc network without restriction.

Traffic increases when packets or messages for requesting and responding are sent via the network. On the other hand, we never employ such packets or messages after the initial routing stage.

Time complexity is now an "L," indicating that the data has been transmitted correctly due to training. When a binary matrix is used for each node, the memory complexity for n nodes is n bytes. When it comes to fast and efficiently transporting significant amounts of data, this method is excellent.

## IV CONCLUSION:

Routing protocols must be repeated for each node, which takes time. As explained in Section 2, the temporal complexity of currently relevant algorithms makes them unsuitable for this application. The number of times routing protocols are repeated can be reduced by training the network, according to a new technique described in Section 3. After a few routing attempts, the nodes themselves figure out where to send data.

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# Techniques for Diversified Optimization of Routing Algorithms in Mobile Ad-Hoc Wireless Connections

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**Abstract:**

MANETs, for example, are a type of network that lacks a well-established infrastructure. Creating ad-hoc networks is difficult because of a lack of infrastructure. Choosing a routing protocol in an ad-hoc network may be difficult due to the network's volatility. To obtain the optimum performance, Zone Routing Protocol (ZRP) is a hybrid routing protocol that combines the best aspects of proactive (Optimized Link State Routing) and reactive (Ad hoc On-Demand Distance Vector) routing approaches. MANET performance can be improved using a Genetic Algorithm and Ant Colony Optimization.

**Keywords:-**Distance vector ad-hoc (AODV), zone routing protocol (ZRP), ant colony optimization technique, proactive routing, reactive routing, hybrid (ACO) route.

## 1. Introduction:

A router is used to connect two separate wireless networks. The demand for a local network was driven by connecting two or more computers to share files. Routers were created so that two or more networks may communicate without sharing all of their data.

### 1.1 MANET:

In mobile ad hoc networks, nodes can be moved at any time. Multihop wireless links can connect a large number of nodes in a network. There are no routers between nodes. The primary goal of routing is to move data from one location to another. With mobile nodes and inefficient routes, this is a challenge for MANETs. A few of MANET's attributes include its adaptability, portability, and wireless connectivity [2]. Since their introduction, ad hoc networks have become increasingly popular because of their diverse applications. A lack of transmission power may have caused the topology to alter. The high operating frequencies in an urban area interfere with and fade out the linkages, making them inoperable. Ad-hoc networks are becoming increasingly popular because of this. Using high-frequency lines in a city puts them at risk of interference and signal degradation due to the high frequencies utilized. Networks of mobile nodes with dynamic topologies, such as MANETs, do not have a stable infrastructure. Ad-hoc networks' dynamic topology and lack of infrastructure necessitate flexible routing algebraic techniques.

### 1.2 Genetic Algorithm:

Darwin's natural selection (GAs) idea is a genetic algorithm's base. This is an excellent solution if you're concerned about enormous computation costs. Natural selection has been replaced by a computer fitness function in the modern world, where bits have taken the role of genetic material.

Genetic algorithms can solve problems where the intended function is nondifferentiable, stochastic, or excessively nonlinear. The evolutionary approach can address mixed integer programming problems in which some components can only have integer values.

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### 1.3 Ant Colony Algorithm:

As part of the umbrella term "swarm intelligence," the Ant Colony Optimization (ACO) subfield examines the collective problem-solving abilities of ants in a group. The fascinating thing about this is that the ants communicate indirectly rather than directly to solve problems. Different optimization issues have been solved using methods based on ant colony problems.

According to this study, ad hoc routing protocols can be improved using evolutionary algorithms and ant colonies. The proactive routing protocol OLSR, the reactive routing protocol AODV, and the hybrid routing protocol ZRP all use this optimization technique. The packet delivery rate and the throughput and end-to-end delay are measured (PDR).

## 2. Mobile Ad-Hoc Routing Networks (MARNs):

Ad-hoc wireless network routing techniques can be divided into three types based on the method used to update routing information. Thus, they can be either proactive or reactive or a combination of the two (both proactive and reactive). Figure 1 shows a breakdown of MANET routing protocols.

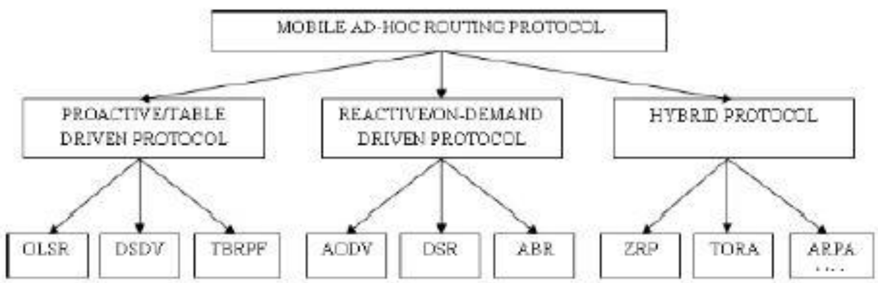


**Figure-1.** MANET routing protocols.

### 2.1 proactive Router protocol:

Routing in Advance Maintaining nodes where no packets are exchanged is a task that requires protocols. These strategies are put into operation if the topological changes have no impact on traffic. "Table-driven techniques" is another name for these methods. Hosts can quickly get route information and establish a session by utilizing this class of protocols. Even if no data is being exchanged, the network continues to function normally by sending out control messages. An evaluation of proactive routing is carried out using the OLSR protocol.

### 2.2 Routing protocol that responds in real-time:

When the data transfer is required, Reactive Routing Protocols are used. As long as they are explicitly needed, routes are created. "On-demand" methods may be referred to as "reactive" strategies. When there is little traffic, and the topology is stable, there is no need to discover and maintain routes with no traffic; routing overhead is decreased dramatically. Establish the routes for forwarding data, it will take longer, and the control messages will be overloaded, resulting in network congestion during the process. The data in this inquiry is examined using AODV, an Ad-hoc On-Demand Distance Vector from a reactive methodology.

### 2.3 Hybrid routing protocol:

Proactive and reactive routing strategies are combined in hybrid routing protocols. It uses less bandwidth and is faster than reactive routing systems while using less bandwidth and slower than proactive routing technologies. An analysis of Zone Routing Protocol (ZRP) is conducted in this study.

## 3. RELATED WORK:

Ant Colony Optimization (ACO) and Cuckoo Search (CS) are discussed in [1] as an optimization strategy for higher overall performance.

With and without black hole assaults, numerous measures such as Packet Delivery Ratio (PDR), Average Jitter, and End-to-End Delay are compared in this study [2].

Ad hoc networks are better served by [3]. End-to-end delay and control overhead were decreased by as much as 80% due to these changes in the simulation environment.

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Crossover occurs when two chromosomes of different classes are combined to create a new chromosome. Node attributes are analyzed using a Genetic Algorithm, which subsequently provides information on assaults. The Genetic Algorithm incorporates the Request Forwarding Rate, Reply Rate, and Receive Rate of OLSR, AODV, and ZRP. To better understand how Genetic Algorithm optimization works, consider the flowchart shown in Figure 2.

### 4.5 Optimization of ant species:

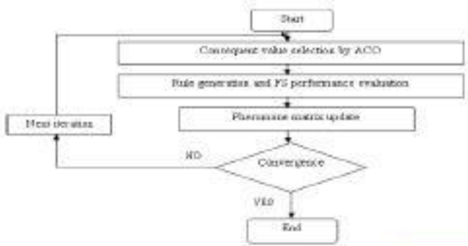


**Figure 3 Ant Colony Optimization Flowchart (ACO)**

Ant Colony Optimization revolves around finding the quickest route between the colony and a food supply. There doesn't appear to be a central or active coordination mechanism in an ancient colony to select the best method of obtaining nourishment. For the best possible travel, the Ant uses its high pheromone concentration. Simply put, a computer program is an artificial ant. Probabilistic path selection led to the creation of an artificial Ant. If a multi-path section is required, ACO-based metaheuristic techniques are the best option. The use of ACO-based algorithms eliminates the requirement for nearby networks to receive routing tables or other network information. The current node's pheromone value is used to make the selection. It gives you a wide range of options for your journey. Techniques for solving stochastic optimization problems, NP-hard industrial difficulties, and emotional problems in communication networks are among the many applications of meta-heuristic algorithmic techniques. Ant Colony Optimization's flowchart is shown in Figure-3.

## 5. SIMULATION:

The NS2 simulator is used to implement the proposed idea. A grid with a dimension of 1000 meters by 1000 meters is used to measure the performance of 100 nodes. The number of data packets sent and received and the total number delivered are metrics used to evaluate network performance. This method's success is evaluated using a variety of parameters, including packet delivery and throughput as well as latency, packet loss ratio, and power usage. Measure. Table-1 lists the parameters that were used in the experiment.

**Table-1.** Simulation parameters.

| Parameter | Value |
|---|---|
| Surface of the network | 1000m² |
| Number of nodes | 100 |
| Size of data packet | 500 Byte |
| $E_{el}$ | 50nJ/bit |
| RTS, CTS, ACK size | 30 Bytes |
| Traffic type | Constant Bit Rate (CBR) |
| Routing protocol | AODV, OLSR, ZRP |
| Antenna type | Omni-Antenna |
| Channel bandwidth | 20kpbs |
| Initial energy | 2J |
| Transmission range | 250m |

### 5.1 Metrics of performance:

#### 5.1.1 Ratio of Packet Delivery (PDR):

To determine the PDR, divide the total number of packets sent from one location to another. D/S = Delivery per second.

Notation is used to indicate how many packets the destination has received. Internet slang refers to D. S packets as "source-generated packets.

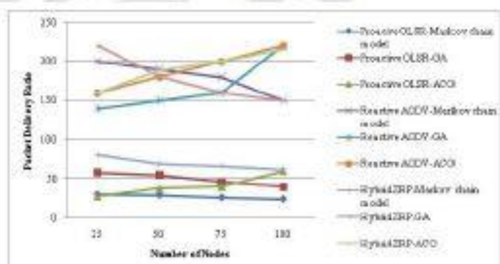


**Figure-4.** Packet delivery ratio vs. No. of nodes.

**Table-2.** Packet delivery ratio with 100 nodes.

| | Various protocols | Packet delivery ratio | | |
|---|---|---|---|---|
| | | Markov chain | Genetic Algorithm (GA) | Ant Colony Optimization (ACO) |
| Number of nodes is 100 | Proactive OLSR | 24 | 40 | 60 |
| | Reactive AODV | 150 | 220 | 220 |
| | Hybrid ZRP | 62 | 150 | 215 |

Figure-4 and Table-2 illustrate the packet delivery ratios for 100 nodes, as well as the number of nodes.

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The PDR for anti-proactive OLSR is the lowest, but the PDR for reactive AODV and hybrid ZRP is the greatest because of their ant colony optimization. A better packet delivery ratio is required to increase performance. It has been found that Ant colony-optimized reactive AODV and hybrid ZRP are best in delivering packets in this study.

### 5.1.2 Delay from start to finish on an average basis:

The amount of time it takes for a data packet to travel over the network is measured in milliseconds. To arrive at the final result, the time at which the source's first data packet arrived at the destination is subtracted from the time at which it was transmitted. For better performance, there needs to be a short end-to-end delay. Latency is a function of S/N.

When a packet reaches its final destination, the time it takes for the delivery process is known as "S."

Each destination node has received a certain amount of data, which we will call N.

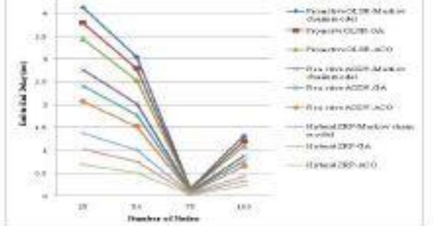

Figure-5. End-to-End delay vs. No. of nodes.

Table-3. End-to-End delay with 100 nodes

| No.of node 100 | Various Protocol | Average End-to-End delay (sec) | | |
|---|---|---|---|---|
| | | Markov chain | Genetic Algorithm (GA) | Ant Colony Optimization (ACO) |
| | Proactive OLSR | 1.32 | 1.21 | 1.1 |
| | Reactive AODV | 0.88 | 0.77 | 0.66 |
| | Hybrid ZRP | 0.44 | 0.33 | 0.22 |

Table-3 compares the End-to-End delay for 100 nodes for various protocols and displays the End-to-End latency as a function of node count in Figure-5 (see fig. 5).

Ant colony optimized hybrid ZRP has a smaller End-to-End delay than ant colony optimized proactive OLSR. Propagation, transmission, queue, and processing time are all causes of end-to-end delays. The time to market hybrid ZRP based on ant colony optimization is shorter.

### 5.1.3 Throughput:

It is calculated by taking the time to receive one shipment from the sender and dividing it by that number. Throughput is commonly measured in bits per second (bps) or bytes per second (bps). According to Little's Law, R/T is equal to R/T throughput.

The amount of data received by the receiver is denoted by R, while the delivery time is indicated by T.

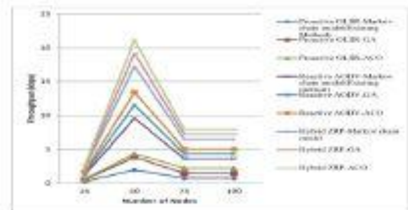

Figure-6. Throughput vs. No. of nodes.

Table-4. Throughput for 100 nodes.

| No.of node 100 | Various protocols | Throughput (kbps) | | |
|---|---|---|---|---|
| | | Markov chain | Genetic Algorithm (GA) | Ant Colony Optimization (ACO) |
| | Proactive OLSR | 7.2 | 14.4 | 22.2 |
| | Reactive AODV | 36 | 43.2 | 50.4 |
| | Hybrid ZRP | 64.8 | 72.0 | 79.2 |

As depicted in Figure-6 and Table-4, the Throughput Vs. Node Count is shown in the figures. Enhancing system throughput is critical for ad-hoc wireless networks. Hybrid ZRP has the highest throughput of our proposed ways, while ant colony optimized proactive OLSR has the lowest throughput of any of our approaches. Ant colony optimized hybrid ZRP routing protocol has the most significant possible data transfer rate out of the three.

### 5.1.4 Ratio of Dropped Packets (PLR):

If there is a high percentage of packets lost in transit, this is called a high packet loss ratio (HPLR).

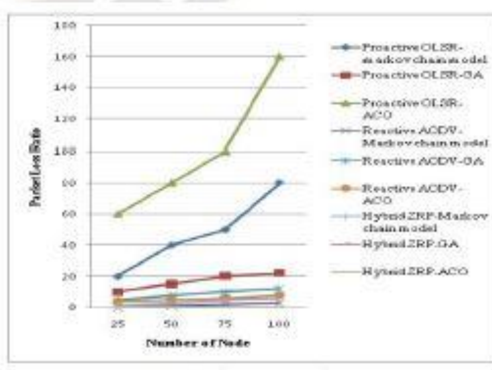


Figure-7. Packet loss ratio vs. No. of nodes.

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Table-5. Packet Loss Ratio with 100 nodes

| | Various Protocol | Packet loss ratio (Dropped packets) | | |
|---|---|---|---|---|
| | | Markov chain | Genetic Algorithm (GA) | Ant Colony Optimization (ACO) |
| No.of node 100 | Proactive OLSR | 80 | 22 | 160 |
| | Reactive AODV | 3 | 12 | 8 |
| | Hybrid ZRP | 6 | 5 | 4 |

A packet loss ratio for various protocols and the number of nodes is shown in Figure-7 and Table-5, respectively.

As a rule, the system's packet loss ratio should not exceed a certain threshold. Hybrid ZRP has a lower packet loss ratio than Ant colony-optimized proactive OLSR. Thus, the ant colony optimized hybrid ZRP packet loss ratio is superior to all three routing protocols evaluated.

### 5.1.5 Consumption of Electricity:

The International Energy Agency defines the total quantity of energy consumed by a process or system.

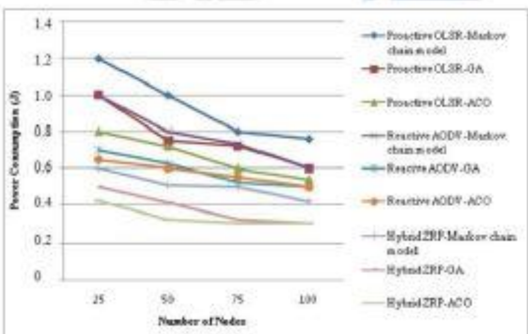


Figure-8. Power consumption vs. No. of nodes.

Table-6. Power consumption with 100 nodes.

| | Various Protocol | Power consumption | | |
|---|---|---|---|---|
| | | Markov chain | Genetic Algorithm (GA) | Ant Colony Optimization (ACO) |
| No.of node 100 | Proactive OLSR | 0.76 | 0.6 | 0.54 |
| | Reactive AODV | 0.60 | 0.5 | 0.5 |
| | Hybrid ZRP | 0.42 | 0.3 | 0.3 |

Node count can be seen in Figure-8, while Table-6 indicates how much power each protocol requires to run a 100-node network.

However, the Ant colony-optimized proactive ZRP consumes more power than hybrid ZRP. The hybrid ZRP protocol outperforms the other two protocols examined regarding energy consumption.

## 6. CONCLUSION:

This study used a combination of the Genetic Approach and the Ant Colony Optimization method to improve ad hoc networks. Proactive (OLSR), reactive (AODV), and hybrid strategies were all considered in this study. Comparisons with results from the Genetic Algorithm and the Markov chain model show the proposed Ant Colony Optimization approach to be effective. Throughput and end-to-end delay were among the performance metrics that might be predicted using the NS-2 simulator. This comprised the use of power, the delivery ratio, and the loss ratio of the packets sent and received. Ant colony-enhanced ZRP performs better in a simulated environment.

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