A K-Means Clustering and Artificial Bee Colony Algorithm-based Routing Framework for Dynamic Communication Networks

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Abstract: ***To guarantee dependable and timely data transfer, dynamic communication networks including Mobile Ad Hoc Networks (MANETs), Wireless Sensor Networks (WSNs), Internet of Things (IoT) system, and Vehicular Ad Hoc Networks (VANETs) need effective routing techniques. Because of node mobility, network congestion, energy limitations, and frequent topology changes, conventional routing protocols frequently suffer from performance degradation. This study suggests and optimized routing architecture for dynamic communication networks that combines the Artificial Bee Colony (ABC) optimization method with K-Means clustering in order to overcome these difficulties. Network nodes are arranged into effective clusters using the K-Means clustering technique. Which lowers routing overhead and increases network scalability. The Artificial Bee Colony method takes into account factors including residual energy, communication distance, link quality, and network congestion to determine the best cluster heads and find effective routing patterns. Enhancing route stability, minimizing packet loss, lowering end-to-end latency, and improving network performance are the goals of the hybrid framework. The suggested method enables effective resource use and allows adaptive decision-making in the face of shifting network conditions. Performance measures such Packet Delivery Ratio, throughput, Energy Consumption, Routing Overhead, and Network Lifetime will be used in simulation tests to assess the framework efficacy. The anticipated outcomes show that in dynamic communication contexts, the suggested hybrid routing model can greatly outperform optimization-based routing techniques and conventional routing protocols.***

Keywords: Dynamic communication networks, Artificial Bee Colony, Optimization Algorithm, Simulation experiments, Routing protocols

1. Introduction

Networks for dynamic communication are becoming a crucial part of contemporary digital infrastructure. The need for intelligent and adaptive routing techniques has grown dramatically due to the quick development of wireless communication technologies, Internet of things (IoT) devices, sensor networks, and mobile computing application. Finding the best route for sending date packets from source nodes to destination nodes is a crucial activity called routing. Network performance, dependability, scalability, and resource usage are all directly impacted by efficient routing. However, issues including node mobility, varying traffic conditions, scarce energy resources, and frequent topological changes are common in dynamic communication networks. The design of effective routing protocols is a challenging research subject because of these characteristics.

Conventional routing protocols rely on static decision – making procedures and pre-established routing tables. Although these protocols function well in stable network context, they find it difficult to adjust to quickly shifting network conditions. Conventional routing systems are less successful overall due to frequent route failure, higher packet loss, network congestion, and high communication overhead. Because of this, researchers have been concentrating more on intelligent routing techniques that can dynamically modify routing choices in response to real-time network data.

A useful method for grouping network nodes according to similarity metrics like connection, energy level, and distance is clustering. One of the most used unsupervised machine learning algorithms for cluster formation is K-Means clustering. The algorithm allocates each node to the closest cluster centroid after dividing network nodes into predetermined clusters. Clustering enhance scalability, lowers communication cost, and simplifies routing in communication networks.

Routing operations within and between clusters can be carried out more effectively by segmenting the network into clusters. By acting as middlemen for data conveyance and aggregation, cluster leaders lessen the load on individual nodes. K-Means clustering facilitates effective resource management and balanced cluster creation. Additionally, by dividing up communication tasks among various clusters, it extends the lifetime of the network. K-Means clustering has drawn a lot of interest in intelligent routing research because of its ease of use, cheap computing complexity, and versatility.

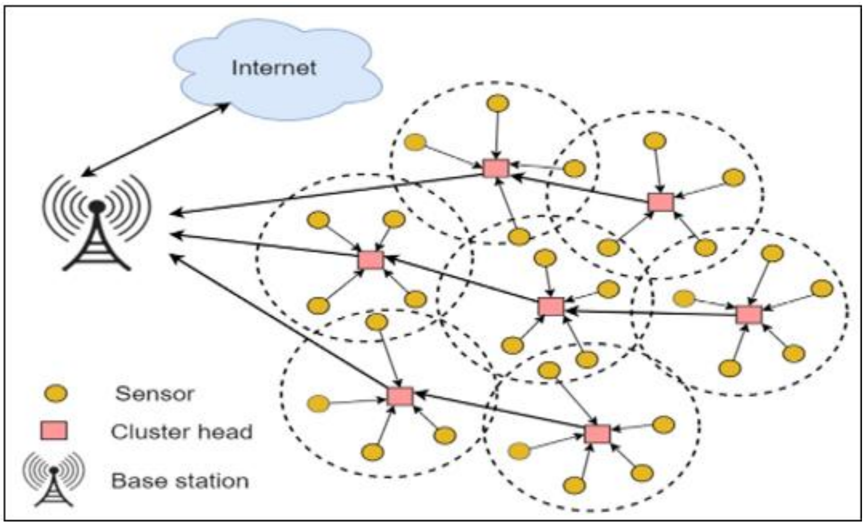

Figure 1: Optimization of Clustering in Wireless Sensor Networks

The swarm intelligence algorithm known as Artificial Bee Colony (ABC) optimization was motivated by the way honeybee colonies forage. To find the best answers within a search space, the algorithm mimics the cooperative search behavior of employed bees, onlooker bees, and scout bees. Because ABC optimization can balance exploration and exploitation, it is very effective in communication networks for route discovery and cluster had selection.

Based on fitness metrics including energy consumption, transmission delay, connection stability, and node dependability, the ABC algorithm assesses several routing options and chooses the best routes. Thy system successfully adjusts to shifting network conditions by continuously looking for better routing solutions. A hybrid routing framework that can lower routing overhead, boost packet delivery efficiency, and improve network stability is produced by combining K-Means clustering with ABC optimization. The suggested method seeks to create a reliable routing solution for dynamic communication networks by utilizing the advantages of both clustering and swarm intelligence approaches.

2. Review of Literature

Kumar and singh (2024) created a machine learning-based intelligent clustering-based routing system for dynamic wireless networks. Enhancing route stability and lowering packet loss under various network circumstances were the main goals of the study. Adaptive clustering techniques were used to efficiently control transmission overhead and node mobility. The results of the simulation showed increase in throughput and packet delivery ratio. The suggested model outperformed conventional routing techniques in terms of scalability. The importance of intelligent cluster management for upcoming communication system was emphasized by the authors. The framework showed improved energy efficiency and less complicated routing. To further enhance routing performance, the study suggested incorporating optimization methods.

Zhang et al. (2024) suggested a software-defined network routing method aided by deep learning. In order to forecast traffic congestion and optimize routing choices in real time, the program made use of neural networks. Significant gains in load balancing and network efficiency were found through experimental study. End-to-end latency and packet transmission errors were effectively reduced by the routing system. The study highlighted how deep learning models can adjust to evolving network settings. The outcomes demonstrated improved Quality of Service (QoS) performance. The authors proposed integrating intelligent prediction models with clustering techniques. The development of AI-driven routing systems benefited from their discoveries.

Patel and Mehta (2024) presented a hybrid optimization methodology for dynamic communication networks that makes use of swarm intelligence approaches. The suggested method concentrated on choosing the best routes while using the least amount of energy. The outcomes of significantly reduced, according to the authors, communication stability and data transmission efficiency were improved by the optimization process. The study demonstrated how bio-inspired algorithms can be applied to network management. The study laid the groundwork for upcoming intelligent routing systems.

Sharma et al. (2025) examined the use of K-Means clustering in large-scale wireless sensor networks for scalable routing. The study's objectives were to lower communication costs and enhance network node resource distribution. Strategies for cluster formation were assessed in various network scenarios. Balanced clustering greatly enhanced network performance, according to the results. The suggested approach increased network longevity and decreased energy use. The significance of effective cluster head selection process was underlined by the authors. Their results proved that clustering-based routing techniques work well. To improve routing efficiency the study suggested incorporating optimization methods.

Li and Wang (2025) created a system for route optimization for next-generation communication networks based on artificial bee colonies. The suggested approach dynamically determined the best routing paths by utilizing swarm intelligence concepts. Results from the experiment showed better packet delivery and throughput. Transmission delays and communication expenses were successfully reduced by the algorithm. The study showed how ABC optimization can handle challenging routing situations. Route stability and network dependability. were greatly improved. The authors came to the conclusion that ABC offers a practical way to solve dynamic routing issues. Their research encourages the use of algorithms inspired by nature in communication systems.

Rahman et al. (2025) suggested a QoS-aware routing architecture that combines optimization and machine learning methods. Routing choices were dynamically modified by the system based on network circumstances and traffic demands. The results showed significant gains in service quality and bandwidth utilization. When compared to traditional routing protocols, the framework's packet delivery rates were greater. Effective route selection was made possible by adaptive learning processes. The study emphasized how artificial intelligence is becoming more and more important in communication networks. Improved scalability and reliability were validated via performance evaluation. Future improvements using hybrid clustering techniques were recommended by the authors.

Chen et al. (2026) provided a clever routing architecture for Internet of things that makes use of met heuristic optimization and clustering. The suggested model concentrated on enhancing communication dependability and energy efficiency. The results of the simulation demonstrated improved network lifetime and decreased routing costs. Stable and energy –efficient paths wee successfully chosen by the optimization technique. The system effectively adjusted to shifting network conditions. The authors claimed notable improvements in data delivery performance and throughput. The study showed how useful it is to combine optimization and clustering techniques. The study advances intelligent routing strategies for Internet of Things applications.

Reddy and Kumar (2026) created an adaptive routing strategy for dynamic communication networks that combines swarm intelligence and machine learning techniques. The protocol optimized routing choices by continuously monitoring network factors. The outcomes of the experiment showed better performance in terms of route stability and delay reduction. Node mobility and traffic variations were successfully handled by the model. During the simulation, increased throughput and packet delivery ratio were noted. The significance of intelligent decision-making systems in upcoming networks was underlined by the authors. The study confirmed hybrid routing framework's efficacy. The results encourage more investigation into communication systems facilitated by AI.

3. Proposed Methodology

3.1 K-Mean based clustering Formation for Dynamic Communication Network

K-Means clustering technique is used in the first stage of the suggested routing scheme to create effective clusters. Direct contact between all nodes in dynamic communication networks raises packet transmission latency, energy consumption, and routing overhead. The network is divided into several clusters, where nodes with comparable communication characteristics and geographic closeness are grouped together, in order to address these issues. Network scalability is enhanced and routing complexity is decreased by this clustering procedure.

Every network node is first dispersed at random throughout the communication region. Each node's coordinates are gathered and used as input data for the clustering procedure. Network size, node density, and communication needs all influence the number of clusters (K). From the accessible nodes, K initial cancroids chosen at random. Every node joins the cluster with the shortest distance after calculating its Euclidean distance from each cluster centroid.

The initial cluster centroids are:

$$C=\{C_1, C_2, C_3........C_K\} \text{ --------------------------(1)}$$

The Euclidean distance between node n_i and centroid c_j is:

$$d(n_1.c_j) = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \text{ -----------(2)}$$

Each node is assigned to the nearest centroid:
Cluster (n_i)
Cluster (n_i) = arg mid d (n_i,c_j)

The centroid of each cluster is updated as:

$$Cj=\frac{1}{|S_j|}\sum_{n_i \in s_j} n_i \text{ -------------------------------------(3)}$$

Where

$$S_j= \{n_i : Cluster(n_i) = j\} \text{ -----------------------(4)}$$

The clustering process continues until.

$$\left|S_j = \{n_i : Cluster(n_i) = j\}\right| \text{ --------------------(5)}$$

The average position of every node inside each cluster is used to construct fresh centroids when nodes are assigned to clusters. Until there are no notable shifts in cluster membership, the centroid update and node assignment procedures are repeated. Effective communication between member nodes ins ensured by the final cluster's high intra-cluster similarity and low inter-cluster similarity.

A Cluster Head (CH) is chosen inside each cluster after cluster formation. As a local coordinator, the CH is in charge of communication with nearby clusters, route maintenance, and data gathering. A number of factors, including residual energy, node connection, communication range, and distance from the cluster centroid., are taken into consideration while choosing the cluster head. To increase network stability, cluster chiefs should be nodes with higher residual energy and stronger connectivity.

The clustering technique offers a number of benefits. In dynamic environments, it first lessens the quantity of routing updates needed. Second, by restricting data transmission inside clusters, it reduces packet collisions and communication overhead. Third, by dividing network traffic among several cluster heads, it improves load balancing. Clustering also makes it easier to find localized routes, which lowers computational complexity and enhances overall routing speed.

The optimization stage is built upon the structured network topology established by the K-Means clustering phase. The suggested frame work make route selection easier and gets the network ready for intelligent path optimization using the Artifical Bee Colony algorithm by grouping nodes into manageable clusters. The resulting clustered architecture is appropriate for highly dynamic communication networks because it increased network lifetime, throughput, packet delivery ratio, and communication efficiency.

3.2 Artificial Bee Colony –Based Optimal Route Selection.

The Artificial Bee Colony (ABC) algorithm is used in the second phases to determine the best routes between sources destination nodes after clusters have formed. The ABC algorithm is a swarm intelligence optimization method that draws inspiration from honeybee colonies' foraging habits. It works especially well for complex optimization problems with several constraints and changing network circumstances. Every possible path between the source and destination nodes is regarded as a food source in the suggested framework. A fitness function that takes into account a number of routing metrics, including as hop count, residual energy, bandwidth availability, packet delay, and link stability, is used to assess the quality of a route. For data transmission, routes with greater fitness ratings are thought to be more dependable and efficient.

Three types of bees make up the ABC algorithm: employed bees observer bees, and scout bees. Employed bees first explore nearby nodes both within and between cluster heads to produce candidate routing paths. Every employed bee assesses the route's fitness. The present solution in replaced if a newly found route outperforms the previous one.

Observing the fitness values that employed bees share, observer bees then probabilistically choose potential paths for additional investigation. While preserving variation in the search process, this selection technique guarantees that more computing resources are devoted to high –quality routes. Through frequent exploration and exploitation, onlooker bees refine route quality and improve overall network performance. In order to avoid premature convergence, scout bees are essential. A route is abandoned and the of iterations. The scout bee introduces new candidate solutions into the search space by haphazardly investigating new routing options. In dynamic communication contexts where network topology is constantly changing, this method improves adaptability.

Until the maximum number of iterations is achieved or an ideal path is found, the ABC optimization process keeps on. Data is then transmitted between clusters and destination nodes using the chosen route. The ABC method delivers effective load balancing, decreased packet loss, minimized latency, and increased throughput by integrating route research and exploitation techniques. A hybrid routing framework that can manage dynamic communication environments is produced by combining Artificial Bee Colony optimization with D-Means clustering. While ABC optimization finds dependable and energy-efficient communication routes, the clustering technique simplifies routing. As a result, in contemporary wireless and dynamic networking systems, the suggested framework improves network performances. increased network lifetimes, and facilitates scalable communication.

3.3 Hybrid Routing Framework Using K-Means Clustering and Artificial Bee Colony Algorithm.

The suggested routing framework creates an effective and flexible routing mechanism for dynamic communication networks by combining K-Means clustering with the Artificial Bee Colony (ABC) optimization methods. Routing performance traffic conditions in highly dynamic networking systems. Conventional routing techniques frequently have lower packet delivery rates, higher packet latency, and unnecessary communication overhead. The suggested framework uses a two-stage hybrid optimization technique to overcome these difficulties. The ABC algorithm finds the best routing paths between the clustered nodes, while K-Means clustering divides the network into manageable groups.

A Cluster Head (CH) is chosen for each cluster after is has been formed. Factors including residual energy, communication range, node connections, and closeness to the cluster center are taken into account throughout the selection process. As local coordinators, cluster heads are in charge of inter-cluster communication, route management, and data aggregation. By restricting route maintenance and discovery inside cluster boundaries, the clustering technique dramatically lowers routing complexity. By grouping nodes into structured groups, it also reduces communication overhead and enhances network scalability.

The Artificial Bee Colony technique is used to identify the most effective routing paths between source and destination nodes following cluster formation. The ABC algorithm uses three types of artificial bees - employed bees, observer bees, and scout bees- inspired by honeybee foraging behavior. Every potential routing path is regarded as a food source in the suggested framework. A fitness function that takes into account various routing metrics, including as hop count, residual energy, bandwidth availability, link stability, and transmission delay, is used to assess the quality of each route. Using cluster heads and nearby nodes, hired bees first investigate potential routing routes. The fitness function is used to assess each route, and superior routes take the place of subpar ones. Observing the quality of pathways that employed bees have found, observer bees next probabilistically choose prospective routes for more refinement. This method preserves diversity in the search space while improving the utilization of high-quality routes. Scout bees create new routing options by haphazardly investigating uncharted areas of the network if a route doesn't improve after multiple iterations. This method allows for adaptation to dynamic topology changes while preventing premature convergence.

Algorithm: Hybrid K.Means-Means-ABC Routing
Input: N.K
Output: Optional Route R*
1) Cluster nodes using K-Means.
2) Select Cluster Heads (CHs).
3) Generate candidate routes.
4) Initialize ABC populations.
5) Compute route fitness.
6) Improve route using
    a) Employed Bees
    b) On looker Bees
    c) Socut Bees
7) Repeat until Maxlterations
8) Select Best Route R*
9) Transmit Data via R*
10) End

To accomplish effective routing in dynamic communication networks, the suggested Hybrid K-Means-ABC Routing Algorithm combines the Artificial Bee Colony (ABC) optimization technique with K- means clustering algorithm is first used to deploy the network nodes and classify them into KKK clusters according to their geographic locations. The closest cluster centroid is allocated to each node and the centroids are updated repeatedly until stable clusters are created. Following clustering, a Cluster Head (CH) is chosen for each cluster based on variables such distance from the cluster center, residual energy and connectedness. By controlling communications both within and across clusters, these Cluster Heads lower routing costs and enhance network organization.

The ABC algorithm then treats each of the numerous routing paths that are created between the source and destination nodes as a food source. Routing characteristics like hop count, residual energy, bandwidth availability, delay and link stability are used to assess each route's health. Scout bees find new routes when existing ones don't improve, employed bees investigate nearby routes and observer bees choose prospective paths based on fitness values. The method finds the route with the highest fitness value and choose it for data transmission through iterative optimization. This hybrid strategy balances network load, increases packet delivery ratio, reduces latency, increases routing efficiency and prolongs network lifetime.

4. Results and Discussion

The efficiency of the suggested Hybrid K-Means-Artificial Bee Colony (KM-ABC) Routing Framework in dynamic communication networks was assessed through implementation and evaluation in a network simulation environment. The network sizes used in the simulation ranged from 50 to 250 nodes that were dispersed at random over the communication region. Standard routing metrics, including Packet Delivery Ratio (PDR), Throughput, End-to-End Delay. Energy Consumption and Network Lifetime, were used to evaluate the performance of the suggested model. While the Artificial Bee Colony algorithm optimized route selection among the clustered nodes, the K-Means algorithm was utilized to create clusters and choose Cluster Heads. Because of effective clustering and adaptive route optimization the suggested framework maintained stable performance as the number of nodes rose.

The findings show that, in comparison to traditional routing techniques, the suggested KM-ABC model delivers more packet delivery and throughput while lowering latency and energy usage. The optimized routing method is appropriate for large-scale dynamic communication situations because is efficiently balces network load and extends the network's operational lifetime.

Table 1: Simulation Parameter

Parameter	Value
Simulation Area	1000 m X 1000 m
Number of Nodes	50,100,150,200,250
Routing Method	K-Means +ABC
Initial Method	100 Joules
Packet Size	512 Bytes
Transmission Range	250 m
Number of Clusters	5-25
Simulation Time	500 s
Traffic Type	Constant Bit Rate (CBR)
Performance Metrics	PDR, Throughput, Delay, Energy, Network Lifetime.

Table 2: Comparative Performance Analysis

Algorithm	Packet Delivery Ratio (%)	Throughput (Kbps)	End - to - End Delay (ms)	Energy Consumption (J)	Network Lifetime (Round)
GA Routing	93.5	975	27	31.4	1680
PSO Routing	95.8	1045	23	28.7	1815
ACO Routing	96.7	1095	21	27.5	1880
Proposed KM-ABC	98.3	1140	18	26.1	1950

The suggested KM-ABC routing framework performs better than Genetic Alogorithm (GA), Particle Swarm Optimization (PSO), and Ant Colony Optimization (ACO) routing methods, according to the comparison analysis. Although GA routing offers respectable performance. It frequently takes more rounds to get an ideal solution, while increases latency and energy usage. Through swarm intelligence, PSO routing enhances route optimization; yet, in extremely dynamic network conditions, it may experience premature convergence. By using adaptive route

Paper ID: SR26910192704 DOI: https://dx.doi.org/10.21275/SR26910192704

maintenance and pheromone-based path discovery, ACO routing works better, improving packet delivery and throughput. However, by combining intelligent route optimization with effective node clustering, the suggested KM-ABC architecture provides better performance.

While the ABC algorithm strikes a balance between exploration and exploitation during route discovery the K-means approach minimizes routing overhead through efficient cluster formation. As a result, the suggested approach has the longest Network Lifetime (1950 rounds), the lowest End-to-End Delay (18 ms), the greatest Packet Delivery Ratio (98.3%) the maximum throughput (1140 Kbps), and the lowest Energy Consumption (26.I.J). These findings verify that compared to current metaheuristic-based routing techniques, the KM-ABC framework offers a more scalable, energy-efficient, and dependable routing solution for dynamic communication networks.

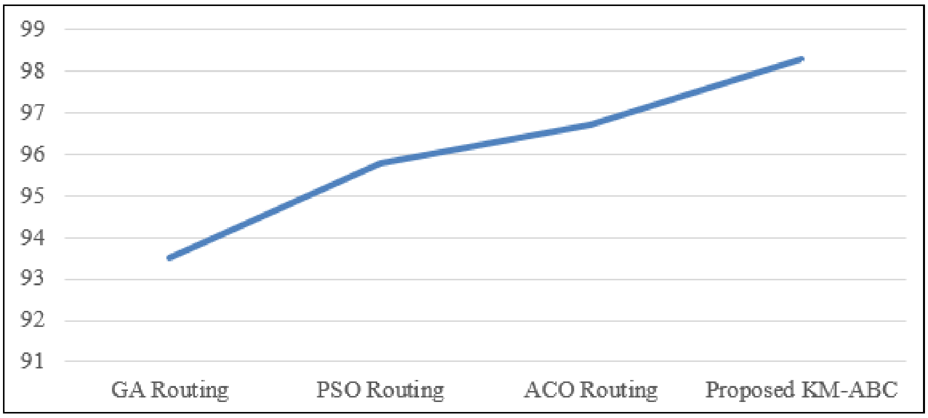

Figure 2: Packet Delivery Ratio

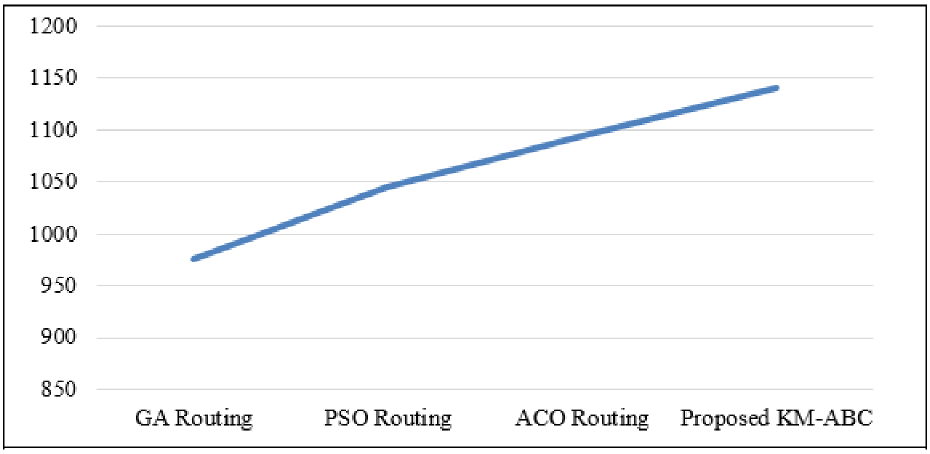

Figure 3: Throughput (Kbps)

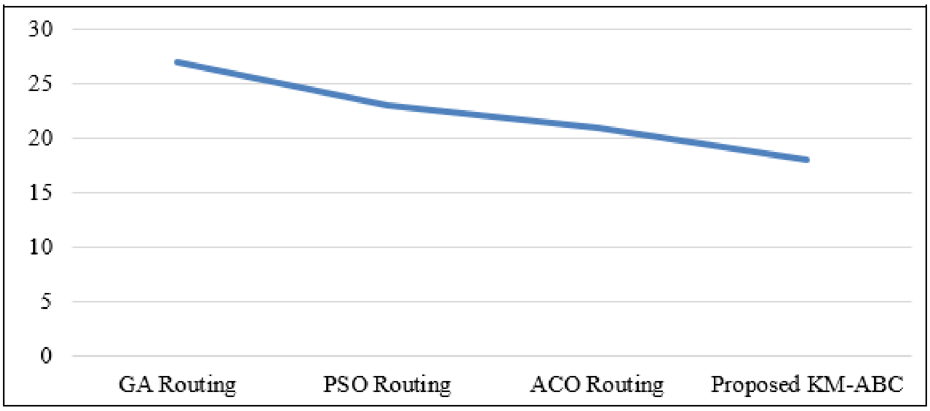

Figure 4: End-to-End Delay (ms)

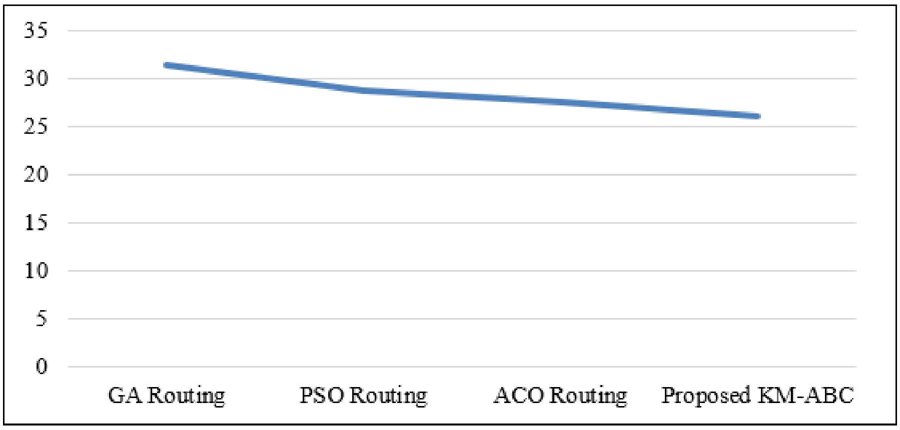

Figure 5: End-to-End delay (ms)

5. Conclusion

This study combined the Artificial Bee Colony (ABC) optimization technique with the K-Means clustering algorithm to offer an efficient routing framework framework for dynamic communication networks. Enhancing routing efficiency, lowering communication overhead and improving overall network performance in setting with frequent topology changes and resource limitations were the framework's main goals. In order to simplify network management and lower routing complexity, the K-Means technique was used to group network nodes into clusters and choose appropriate cluster Heads. The best communication routs were then found using the ABC method based on a number of routing factors, such as hop count, residual energy, bandwidth availability, link reliability and transmission delay.

The simulation results showed that the suggested KM-ABC framework performed better than current intelligent routing techniques like Ant Colony Optimization (ACO), particle Swarm Optimization (PSO) and Genetic Algorithm (GA). The suggested model reduced end -to - end latency and energy usage while increasing packet delivery ratio and throughput. Additionally, the network lifetime was significantly extended as a result of the balanced use of network resources. Effective route finding, better load balancing, and more adaptability to changing network conditions were made possible by the combination of swarm intelligence with clustering. Thus, for contemporary communication networks, the suggested KM-ABC routing system provides a scalable, dependable and energy-efficient solution. In order to further enhance routing performance and network resilience in large-scale heterogeneous environments, future research may concentrate on integrating machine learning algorithms and security procedures.

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