**CSF 407 – ARTIFICIAL INTELLIGENCE**

**Improved Network Routing via Hybrid Metaheuristics**

**USING**

**Genetic Algorithm, Ant Colony optimisation,** **Artificial Bee Colony Optimization Algorithm and Depth First Search Algorithms**

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# 1. INTRODUCTION

**NETWORK ROUTING**

The ability to efficiently manage and direct data traffic within a network is paramount in today's interconnected world. Network routing primarily deals with determining the optimal path for data packets to travel from a source to a destination within a computer network. Preprocessing, organization, and integration of data are also significant concerns in network routing. The entire process of using computer-based methodologies and algorithms to make decisions about how data should flow through a network is known as network routing.

There are several terms and concepts associated with network routing:

1. Routing Algorithm: This is the heart of network routing. It's a set of rules and calculations that determine the path a data packet will take from its source to its destination. Routing algorithms can be based on various factors like distance, cost, or quality of service.

2. Data Packet: In network routing, data is broken down into smaller packets for transmission. These packets are sent individually and may take different routes to reach the destination. Efficient routing ensures that these packets are delivered correctly and in a timely manner.

3. Routing Table: Network routers maintain routing tables that contain information about the network's topology and available paths. These tables are crucial for making routing decisions.

4. Hop Count: The number of intermediate devices (routers or switches) that a data packet passes through on its way to the destination is referred to as the hop count. Minimizing the hop count is often a goal in network routing.

5. Quality of Service (QoS): In some cases, network routing must consider QoS requirements, such as ensuring low latency or high bandwidth for certain types of traffic, like video streaming or voice calls.

Network routing involves a series of steps, which are :

1. Data Gathering: In the context of network routing, this corresponds to collecting data about the network's topology, traffic patterns, and available resources.

2. Data Preprocessing: Network data often needs to be cleaned and prepared for routing decisions. This can include tasks like removing duplicate routes or updating routing tables.

3. Data Integration: Network routing may involve integrating information from various routers and switches.

4. Routing Decision: This is the core of network routing, where algorithms determine the best path for data packets based on various criteria, such as shortest path or least congested route.

5. Data Evaluation: After routing decisions are made, the network's performance is continually evaluated to ensure that data is flowing smoothly and efficiently.

6. Routing Presentation: Network administrators and operators use visualizations and monitoring tools to understand and present the state of network routing.

The primary goals of network routing are :

1. Optimal Routing: Network routing aims to find the optimal path for data packets to reach their destination efficiently.

2. Network Monitoring and Description: Network routing also involves understanding and describing the network's behavior, such as identifying bottlenecks or congestion points.

The techniques and tasks in network routing can vary depending on the specific network architecture and requirements. Some common network routing tasks include:

1. Static Routing: Setting fixed paths for data packets, which are appropriate for simple network configurations.

2. Dynamic Routing: Using algorithms that adapt to changing network conditions, such as the OSPF (Open Shortest Path First) protocol.

3. Quality of Service (QoS) Routing: Ensuring that certain types of traffic receive priority in routing decisions to meet QoS requirements.

4. Load Balancing: Distributing network traffic evenly across multiple paths to prevent congestion.

5. Security Routing: Making routing decisions that enhance network security, such as avoiding malicious routes.

In conclusion, network routing is a critical aspect of managing modern computer networks. It involves the use of search algorithms and optimizing techniques to make informed decisions based on data for predicting network traffic patterns.

# 2. Literature Survey

This section provides a summary of current research projects that have utilised knowledge gained from professional data sources for a variety of objectives.

Zou et al. (2019)**[1]** focus on enhancing wireless sensor network routing through an improved ant colony algorithm to overcome traditional ant colony optimization limitations, including local optima and slow convergence. The methodology incorporates a transfer function for sensor nodes and dynamic pheromone update rules within the IACO algorithm to adaptively select data routes based on network conditions. Simulation-based evaluations compared the IACO algorithm to other routing methods, including ACO, dijkstra algorithm, and data equilibrium based algorithm , in a 100x100m area with 100 nodes and an initial energy of 0.4 J per node. Results indicated IACO's significant gains in energy use, transmission latency, and packet loss, highlighting its capacity to reduce energy use, increase transmission efficiency, and retain data integrity. Although the paper highlights IACO's advantages, it does not explicitly address any potential limitations. In conclusion, the study presents an effective solution for WSN routing, particularly in applications like intelligent manufacturing, significantly improving network quality of service.

S. Kumar et al.. (2017)**[2]** introduce an intelligent solution for wireless networks: an efficient fast re-routing algorithm using a modified Depth-First Search (DFS). Its purpose is to simplify packet routing, especially when network problems arise. The modified DFS quickly finds the shortest route within wireless networks and shines when network issues occur, ensuring packets keep moving even during glitches. As internet use grows, routing algorithms become crucial. However, network troubles can disrupt data delivery. That is where fast re-routing occurs, ensuring data packets and communication continue smoothly, even if links or nodes fail. The main aim is to gracefully handle node and link failures without causing problems like packet drops or loops. This algorithm uses the modified DFS method to determine the shortest route and manage communication in wireless networks. It also incorporates Equal Cost Weight Analysis and the ECMP Method to balance loads and detect multiple failures. Practically, the algorithm is implemented with specific hardware and software, using JAVA and SWING technologies for the front end. It effectively handles network setup, communication, packet management, pathfinding, and routing. In conclusion, this proposed fast re-routing algorithm simplifies packet routing powered by modified DFS. Its fast re-route capabilities reduce downtime during network problems, ensuring smooth communication. Its real-world implementation proves its efficiency as a reliable routing solution. The article demonstrates that the proposed "Fast Re-route using BFS" method outperforms BFS and DFS by reducing the average number of visited nodes after a failure by 33% and enhancing re-routing efficiency.

Sunitha Goni et al. (2017) **[3]** tackled the challenge of optimizing data transfer pathways in wireless sensor networks , focusing on extending network's lifespan. While taking into account the initial energy levels of sensor nodes put in a certain region, they looked out the most effective routing pathways. The goal of this project was to reduce energy usage while ensuring data transfer across both single and multiple channels. It was identified as a linear programming problem (LPP). The researchers also incorporated analytical models to evaluate key performance parameters, including delay, energy consumption, and reliability. Through simulations conducted in MATLAB, the study examined dynamic clustering, optimal routing, and data aggregation in a network of 100 nodes, demonstrating the efficacy of their method in extending the WSN's lifetime and improving energy efficiency. Future work may explore optimization techniques like ant-colony or particle-swarm to enhance network performance further. For wireless sensor networks ,it suggested a dynamic grid-based clustering and data aggregation technique. It seeks to reduce energy use and lengthen network lifespan. The system makes use of the breadth-first search (BFS) method to find the best multi-path routing. The clusters are dynamically formed and operated using heuristic approaches, resulting in fewer aggregation points during data forwarding to the base station. In comparison to alternative systems, the analytical model for single and multi-path delay, energy, and reliability shows improvements in the lifespan of the sensor network. Also , the authors suggested further exploring ant colony and particle swarm optimization to enhance the network's lifespan. The article demonstrates a significant efficiency improvement, achieving up to a 30% increase in network lifetime compared to previous techniques in wireless sensor networks.

Rana et al. (2011) **[4]** delve into the pressing challenges Wireless Sensor Networks (WSN) face. These networks operate under significant constraints, including limited energy resources, storage capacity, and the inherent risk of sensor node failures. They introduced an innovative routing algorithm based on the A-Star algorithm to tackle these issues. Their primary objective is to find an optimal routing strategy that can significantly extend the overall lifespan of a WSN by efficiently managing energy resources. They implemented and simulated the A-Star algorithm for routing within a WSN environment in the methodology used. To gauge the effectiveness of their approach, they conduct a comparative analysis with an alternative routing strategy based on Genetic Algorithms (GAs) and evaluate it against Warshall's algorithm. The evaluation metrics employed in the study include the overall energy used and the number of nodes that fall below a predefined threshold level of residual energy (referred to as "Level 1"). These metrics are crucial in assessing how well the routing algorithms perform, as they directly impact the network's overall energy efficiency and operational lifespan. The A-Star algorithm's ability to consider energy consumption and residual energy levels ensures a more balanced energy distribution throughout the network. A-Star algorithm has its potential complexities in implementation and simulation. Additionally, defining a predefined threshold level for residual energy necessitates careful consideration. The simulations conducted throughout the research solidify the A-star algorithm's superiority over alternative routing strategies, offering promising prospects for energy-efficient WSNs.

D. Zhao et al. (2009) **[5]** introduced the improved ant colony optimization algorithm to address the communication network routing problem, with the primary objective of enhancing traffic flow efficiency within communication networks by determining optimal data packet routes. By resembling the path-finding behaviour of ants and introducing distinctive features like a pheromone update mechanism that combines global and local characteristics, a mutation operation, and implementing a 2-opt exchange for CNRP, the technique makes use of the principles of ant colony optimisation. Additionally, it adopts a probabilistic rule for customer node selection based on visibility and pheromone information. Through extensive simulations comparing IACO to the simpler ACO algorithm across various parameters like average hops, communication cost, simulation speed, total calls, maximum concurrent calls, and node capacity, the authors conclude that IACO outperforms ACO by achieving higher packet delivery ratios and lower communication costs. Specifically, IACO reduces the average number of hops by approximately 3.5 nodes, signifying notable enhancements in routing efficiency within communication networks. While the paper highlights the pros of IACO, including its ability to integrate global and local features, adaptability through mutation, and solution improvement via 2-opt exchange, it does not explicitly discuss any associated limitations. In summary, this research paper presents a compelling solution for traffic optimization in communication networks, demonstrating the efficacy of the IACO algorithm in improving network performance metrics.

Jacob et al. (2021) **[6]**, in the research paper, propose using a bio inspired artificial bee colony optimisation algorithm to create and assess a novel framework for improving the performance of wireless networks. The suggested algorithm allows for asynchronous and decentralized routing decisions and is motivated by the structure and operation of honey bee colonies. The methodology employed in this research paper involves using MATLAB for testing and implementing the model. Extensive simulations are used to test the algorithm, and it is compared to other nature inspired routing systems already in use. Various networks from the real world were also set up by the researchers for exploration. They altered various parameters during the experiments to observe the behaviour of the wireless network throughput. Then, they compared the results obtained from simulations and real-world implementations. The research's findings show that using basic agent models improves the effectiveness of the suggested method and makes it possible to find many pathways beyond a given threshold value. The technique boosts performance values ranging from 20% to 80% by randomly dispersing data packets over a number of pathways. The research report concludes with a thorough analysis of the creation and testing of an artificial bee colony optimization technique for improving wireless network performance.

Muruganantham et al. (2020)**[7]** have focused on assessing the effectiveness of various algorithms within wireless sensor networks. The primary algorithm under scrutiny is the Genetic Algorithm (GA), compared against others like GAGD, DD, and GD. The approach conducts simulations across different scenarios, encompassing node speeds and network sizes.GA emerges as the top performer, excelling in throughput and average RTT. Furthermore, it explores GA's adaptability across diverse network topologies, pitting it against DA, AODV, and GA-AODV. GA's unique strength lies in its ability to identify multiple potential solutions for source-to-destination routing, proving invaluable for optimal pathfinding in diverse contexts. A notable aspect of the research involves including scenarios with varying percentages of faulty nodes and differing node mobility speeds, encompassing scenarios with up to 50% faulty nodes. GA consistently outperforms other algorithms through detailed throughput comparisons across multiple scenarios, including node count and mobility speeds. The findings demonstrate that GA's performance is robust and superior, exhibiting reduced performance degradation compared to other algorithms with challenges like faulty nodes and dynamic node speeds. GA is a promising choice for optimizing wireless sensor networks in real-world applications.

Obeidat A. et al. (2022) **[8]**, in their work, have primarily focused on network routing optimization using a genetic algorithm, with a central problem being the determination of an optimal data transmission route within specified time constraints. They introduced a novel approach called the Regenerative Genetic Algorithm (RGA) and conducted a comparative analysis against other routing protocols like RIP. Their study aims to develop software capable of visualizing networks and implementing the proposed algorithm. In contrast to traditional routing algorithms like bellman ford's, dijkstra's, and floyd warshall's, their proposed genetic algorithm is highlighted for its ability to overcome time complexity limitations and deliver improved performance. Their work delves into crossover and mutation techniques within genetic algorithms. It underscores the superiority of the Sequential Constructive Crossover(SCX) over the One-Point Crossover (OPX). It introduces the hybrid genetic algorithm with 3-exchange and constructive mutation (HGA3) as the most efficient option regarding computational time and solution quality. They also presented a new crossover operator with varying chromosomal sizes, utilizing high-fitness parents to produce high-fitness offspring. They emphasize the significance of finding an optimal crossover mechanism and highlight the superiority of the same adjacency crossover mechanism over the same point method. Genetic algorithms for network routing optimization offer valuable insights into improving routing efficiency.

Patel et al. (2021) **[9]** have proposed a GA-AOMDV routing protocol, a genetic algorithm-based approach aimed at enhancing the performance of mobile networks by optimizing ad hoc on-demand multipath distance vector routes with a focus on minimizing energy consumption and extending node lifetimes. The methodology involves using a fitness algorithm using node energy consumption and efficiently dropping routes with low fitness scores before applying the genetic algorithm to expedite solution convergence. It is particularly well-suited for time-sensitive applications like FANETs and VANETs. Through simulations conducted in Network Simulator 2 (NS2), they compared the GA-AOMDV protocol's performance with other protocols, assessing essential quality of service parameters such as packet delivery ratio, average throughput, round trip time (RTT), and average energy consumption. Their research findings demonstrated that the GA-AOMDV protocol consistently outperformed other protocols, achieving an average improvement of 7 to 22% in quality of service parameters and effectively reducing energy consumption during data packet transmissions through mobile nodes. The protocol's strengths lie in optimizing AOMDV routes based on energy efficiency, reducing processing time, and extending network lifetimes. However, it comes with the genetic algorithm processing requirement, which may necessitate additional computational resources. Their research presents GA-AOMDV as a potential means of improving the functionality of mobile networks, showcasing its superior performance and benefits in terms of quality of service parameters and energy efficiency.

Di Caro et al. (2004) **[10]** delve into utilising Ant Colony Optimization (ACO) algorithms for adaptive network routing, exploring their design, application, and comparative effectiveness against state-of-the-art competitors. The authors conduct rigorous empirical validation, considering realistic traffic and network scenarios and meticulously selecting performance metrics for an in-depth assessment. This extensive research encompasses theoretical foundations, model analysis, and practical implementation of ACO. The results underscore the remarkable performance of the designed ACO algorithms, consistently outperforming competitors in diverse scenarios. While the ACO approach exhibits notable advantages, including its efficacy in addressing dynamic routing challenges, further simulation studies and actual network implementations are recommended for a comprehensive evaluation. This paper offers valuable insights into the potential of ACO algorithms for adaptive network routing, validating their effectiveness and setting the stage for future exploration and implementation in real-world networks.

 Mukherjee et al. (2010) **[11]** introduce three ACO variations tailored for network routing challenges, aiming to find optimal paths with maximum throughput in diverse network models. These variations, ACO1, ACO2, and ACO3, differ in selection schemes and constraints, including incorporating a Tabu list to record visited nodes. Experiments across standard network models assess their performance, with varying Tabu list sizes in ACO3 to determine the optimal size for different network dimensions while keeping network load constant. Results reveal an inverse relationship between successful packet percentage and throughput with Tabu list size, impacting packet cancellations and destruction. ACO variations offer advantages like shorter path discovery and enhanced throughput but introduce complexities related to packet management. The choice of ACO variation depends on network characteristics and application requirements, presenting a versatile approach to network routing.

Jian-Feng et al. (2011) **[12]** explore the application of ant colony optimization in routing protocols for wireless sensor networks (WSNs) with the primary aim of reducing energy use and increasing network lifespan. Three ACO algorithms are introduced, namely ant system , ant colony system , and an enhanced AS variant known as ASW. The methodology involves ants constructing solutions, starting from source nodes and selecting subsequent hops based on pheromone concentration and heuristic information. Pheromone trails are updated considering performance, with both evaporation and pheromone deposition. The paper evaluates AS, ACS, and ASW by comparing their performance in terms of total energy consumption and stability through simulations conducted on various scales of WSNs. The findings reveal that ACS exhibits lower energy consumption and more excellent stability than AS and ASW, suggesting its effectiveness in prolonging network life. Although using ACO algorithms in WSN routing offers advantages in energy reduction and network longevity, the paper does not specify any limitations or drawbacks associated with these methods. In summary, the research underscores the potential of ACO in optimizing WSNs by reducing energy consumption and enhancing network durability, particularly highlighting the superiority of ACS in achieving these objectives.

Kwang Mong Sim et al. (2002) **[13]** centre on Ant Colony Optimization (ACO) algorithms and their utilization in tackling optimization challenges in network routing. The ACO algorithm delves into emulating biological ants' problem-solving behaviour through artificial ants (ANTs) acting as mobile agents. The methodology involves simulating pheromone deposition by monitoring ANTs' passage through nodes, influencing their decision-making based on pheromone concentration and heuristic factors. Multiple ant colonies are employed to enhance adaptability and alleviate stagnation in dynamic networks. The author conducted comprehensive research on ACO algorithms, exploring their application in optimization problem-solving, the behaviour of ANTs as proxies for biological ants, and the pivotal role of stigmergy in colony coordination. Findings revealed that employing multiple ant colonies enhances adaptability and mitigates stagnation in dynamic networks, particularly for circuit-switched networks where nodes and linkages are flexible. The research suggests the applicability of the multiple ant colony optimization approach for load balancing in circuit-switched networks. While ACO algorithms exhibit strengths in optimization problem-solving and adaptability, stagnation can be a limitation addressed in the research through the MACO approach. In conclusion, the paper introduces ACO's problem-solving paradigm in network routing, proposing innovative strategies like MACO to enhance adaptability and offering valuable insights into leveraging ant-based optimization for complex network challenges.

Sun et al. (2017) **[14]** introduce an enhanced ant colony routing algorithm developed to minimise network energy usage and extend the network's life for wireless sensor networks through optimized routing. Leveraging the principles of ant colony optimization (ACO), the authors refine critical elements of the algorithm, namely the pheromone impact factor and heuristic information, to enhance route selection based on energy efficiency. The pheromone impact factor adjustments contribute to improved route selection, while the heuristic information incorporates both transmission distance and direction for energy-efficient path choices. Through extensive simulations in a static WSN environment comprising 100 nodes, the proposed algorithm is compared with existing counterparts, including EEABR, OARA, and Leach-Ant, using evaluation criteria such as energy consumption, network longevity, and node depletion. Results highlight the algorithm's superior performance, showcasing slower increments in average energy consumption and an extended network life cycle, ultimately contributing to reduced energy usage and enhanced network optimization. While the paper emphasizes the algorithm's strengths, it does not explicitly discuss potential limitations. In summary, this research paper presents a promising advancement in ant colony-based routing for WSNs, offering significant improvements in energy efficiency and overall network performance.

X Liu(2017) **[15]** delves into thoroughly examining and comparing diverse routing protocols within the context of Wireless Sensor Networks (WSNs). The authors undertake a systematic approach, categorizing these protocols based on various criteria, such as energy and transmission control, and provide a comprehensive taxonomy, mainly focusing on ant colony optimization based routing protocols, marking a unique contribution. The paper encompasses a performance analysis, considering key metrics like energy efficiency and balance, shedding light on the strengths and weaknesses of ACO-based protocols in WSNs. A notable innovation is introducing the Multi-Objective Multi-Bee Colony (MMBEC) routing protocol, which prioritizes total energy consumption and depletion differences, resulting in highly energy-efficient and balanced paths, although it relies on estimations. Overall, this research offers valuable insights for WSN application designers and researchers, addressing the nuanced landscape of routing protocols while highlighting potential research challenges and future directions in the ever-evolving WSN domain.

AlShawi et al. (2012) **[16]** delve into wireless sensor networks (WSNs) and their longevity, a critical concern in this field. WSNs comprise a multitude of low-cost sensor nodes that are typically scattered across an expansive monitoring area. These networks are pivotal in a variety of applications, including healthcare, industrial automation, and environmental monitoring. However, as sensor nodes rely on finite amounts of energy, their energy limits provide a significant barrier. battery power, and once depleted, they become inoperative, leading to network failure. Their proposed methodology employs a novel approach in which the WSN's topology is represented as a directed graph. In this graph, the sink node is the ultimate destination for data collected from the various sensor nodes within its transmission range. However, the critical innovation lies in the routing schedule, which is not predetermined but dynamically computed. The base station, typically a more robust and energy-abundant node, plays a pivotal role in this process. It collects information from the sensor nodes, including their current state, position, and available energy resources. Although their research provides a conceptual framework and methodology for enhancing WSN longevity, it does not explicitly present specific experimental results or detailed pros and cons of the approach. Therefore, the paper serves as a valuable contribution to the field by highlighting the critical issue of WSN lifespan and proposing a dynamic routing method that considers individual node criteria and energy resources.

Septiana et al. (2016) **[17]** explore Wireless Sensor Networks (WSNs), primarily focusing on optimising routing paths to bolster energy efficiency. To achieve this, they introduced the A-star algorithm. The methodology employed in the research hinges on enhancing the evaluation function used within the A-star algorithm. This function is a pivotal component of the algorithm, guiding it in deciding which paths to explore. To assess the efficacy of their proposed approach, they conducted extensive simulations. These simulations were executed using Matlab2010a and involved a virtual WSN comprising nodes randomly distributed across a 100x100 field. The critical parameters under scrutiny were the number of activated nodes within the WSN, which ranged from 25 to 100, and the three different variations of the evaluation function. The outcomes of the simulations shed light on how each variation of the evaluation function impacted the routing paths within the WSN. Notably, it was observed that as more heuristic values were integrated into the evaluation function, the algorithm's path optimisation improved. This manifested as shorter paths and reduced hop count from the source node to the destination node. The simulations validate this approach's merits, demonstrating its potential to yield shorter and more energy-efficient paths. However, the complexity associated with the A-star algorithm warrants careful consideration during practical implementation.

Ragavan et al. 2019**[18]**, in their research paper, focus on improving efficiency of energy and dependability of data transfer in wireless sensor networks (WSNs). The authors propose a methodology that utilises a genetic algorithm (GA) for node deployment; tabu search for route selection, and compressive sensing to remove redundant data. The objective is to reduce energy consumption and improve the performance of the network as a whole. The suggested process entails a number of phases. First, the network lifetime is increased by using GA to deploy nodes for sensors, based on loss of energy. The best information transfer paths are then chosen, taking into account the nodes' energy consumption, using tabu search. By removing redundant data from sensor nodes, compressive sensing algorithms improve data fusion and use less energy. To test the effectiveness of their suggested methodology, the authors ran experiments on a network model with 50 nodes. They used the energy supply and usage ratios as evaluation indicators. The studies' findings showed that the suggested methodology produced reliable ways for information transfer while using little energy. The average energy consumption was reduced approximately 50% by selecting optimal routes, and the delivery ratio which was between 0.2-0.6 indicated successful packet transmission from source to sink. The authors also presented the frequency of node deployment(mostly between 4-10) using GA, showing the effectiveness of their approach.

Yadav et al. 2022**[19]** in their research delve into the creation of a novel cluster head (CH) selection framework for multilevel navigation in wireless sensor networks (WSNs). The Particle Distance Updated Sea Lion Optimization (PDU-SLnO) and Particle Swarm Optimisation (PSO) techniques are combined in the authors' proposed blended optimization approach. The aim is to select energy-efficient CHs based on energy consumption, distance among nodes, Quality of Service (quality of service), and delay. The methodology employed in this research involves the implementation of the proposed CH selection framework using the PDU-SLnO algorithm in MATLAB. The authors compare the performance of their approach with traditional models such as genetic algorithm (GA), PSO, artificial lion optimization (ALO), etc. The  analysis of CHs, standardized energy of network, living node inquiry, and inspection of convergence are used to conduct the analysis based on the simulation setup, which includes parameters related to CH modelling in WSN. According to the research findings, the suggested PDU-SLnO technique performs better in terms of normalized energy, alive nodes, and cost function than more established models like GA, PSO, ALO, and others. It maintained 66 live nodes in the best situation, which is more than comparable models with fewer living nodes. This trend continued in mean and median-case scenarios, where it kept 5-19 more alive nodes than others. In the median-case scenario, the recommended PDU-SLnO technique outperformed previous models in terms of normalised energy also by a substantial margin, ranging from 33.48% to 63.12%. Hence, the improved PDU-SLnO approach was successfully validated.

Wang et al. (2020) **[20]**, in this study, suggest an enhanced artificial bee colony (ABC) algorithm-based routing protocol for wireless sensor networks (WSNs) which is energy-efficient. The objective is to reduce utilization of energy, increase energy efficiency, and prolong network lifetime. The study offers a new grouping navigation approach that partitions the network into clusters and chooses the best cluster heads using the ABC algorithm. To balance energy consumption and increase network performance, it also includes a polling management system based on occupied/inert nodes for interaction among clusters. This research paper's approach is comprised of numerous crucial parts. The uncertain C-means clustering is improved using the modified ABC technique, and the ideal cluster heads are chosen in the first round. As a result, clusters form effectively. The best route from each cluster head to the central station is then found using an energy-effective navigation method based on enhanced ant colony optimisation. This reduces the amount of energy used for the transfer of data. Lastly, in order to save energy and increase network performance, a polling control method based on occupied/inert nodes has been established for interaction among clusters. The proposed protocol outperformed compared protocols regarding network lifetime and total remaining energy. It had around 15% more energy remaining as compared to the others. It also demonstrated better performance in the network stability period(around 25% better than others) and network throughput(around 30% better than others). Thus, using swarm intelligence algorithms and introducing the polling control mechanism contribute to overall performance improvement.

Kumar et al. (2016) **[21]** concentrate on wireless sensor networks' (WSNs') energy-conscious routing. The research suggests a new hybrid approach for cluster head selection in WSN termed Multi-Objective Fractional Artificial Bee Colony (MFABC). The Artificial Bee Colony (ABC) algorithm and fractional calculus (FC) are combined in the proposed MFABC algorithm. The approach incorporates fractional derivatives into the mathematical equation to provide new neighbour solutions. Energy usage, transit time, and delay are taken into account while choosing a cluster head. The algorithm aims to balance optimisation's exploration and exploitation phases to achieve better performance in finding optimal cluster heads. The authors also simulated a wireless sensor network to validate the proposed algorithm. The FABC-based cluster head selection technique is compared in the document to other algorithms like PSO, LEACH, and ABC-based routing. The analysis takes into account variables like cluster head selection frequency, normalized network energy, and node lifespan. The investigation found that the FABC algorithm surpassed the other three techniques with regard to the network longevity. The maximum lifetime from 1400 to 2000 was displayed, which set it above all other algorithms. Additionally, for 100 nodes, the FABC algorithm delivered the maximum energy in 65% of the rounds, and for 50 nodes, it did so in 100% of the rounds. In comparison to the other algorithms, the suggested algorithm performed better overall in 80% of the life cycles. The results demonstrate the algorithm's effectiveness in improving energy efficiency, reducing distance travelled, and minimising delay.

Okdem et al. (2011) **[22]**, in their research paper, examine the performance evaluation and complexity evaluation of the CWA routing method, which is based on the ABC (Artificial Bee Colony) algorithm. The purpose of this article is to assess how well the CWA method applies to wireless sensor networks (WSNs) to increase the network's lifespan and prevent connectivity faults. Performance evaluations and a complexity assessment of the CWA routing method based on the ABC algorithm were carried out for this study. The tests were run by comparing the transmitted packet quantities to the network lifespan. The CWA method surpasses direct transmission and the LEACH algorithm when performance is evaluated, showing that swarm-based artificial intelligence is effectively used by the CWA strategy to optimize routing. It delivers around 8000 packets compared to 6000 and 4000 packets delivered by the LEACH and DIRECT algorithms respectively i.e it performs about 1.33 to 2 times better than other algorithms. These outcomes show how the tactic works in WSNs for extending the lifespan of networks and reducing connectivity errors.

Karaboga et al. (2012) **[23]**, in a research paper, focus on optimising the Wireless Sensor Networks (WSNs) routing protocol using the ABC (Artificial Bee and Colony) algorithm. The authors propose three protocols: CWA, ICWA, and ICWAQ. By selecting the most energy-effective cluster-head nodes and increasing the number of data packages sent through clustering, they hope to lengthen the network lifespan. Numerous benefits of using the ABC method in clustering for WSNs can result in effective routing protocols. The researchers used a parallel discrete model created in Matlab to run simulations. With several parameter settings, including the number of nodes, communication frequency, and packet size, they evaluated how well the suggested protocols performed. The recommended protocols (CWA, ICWA, and ICWAQ) surpassed the LEACH protocol and protocols based on PSO in terms of energy consumption by about 24%, and network performance by about 40%, according to the simulation results. Transfer delays were also reduced by approximately 26% in the suggested methods. Thus, the research paper shows that using the ABC algorithm in clustering for WSNs can potentially extend the network lifespan, minimise transfer delays and enhance energy efficiency.

Mann et al. (2017) **[24]**, in their research paper, present a new approach for improving Cluster Head (CH) selection in wireless sensor networks, also known as WSNs, through the employment of an Artificial bee colony (ABC) meta-heuristic. The main goal is to design a method for routing and an effective cluster creation mechanism to minimize energy consumption and lower the number of hops used for data transfer. The authors conducted a detailed study of earlier developments in WSN routing, including traditional and SI(swarm intelligence)-based methods. Cluster head (CH) selection and cluster creation are the two key responsibilities of the suggested clustering method. The ABC meta-heuristic, which tries to maximize the residual energy of the chosen CHs, is the basis of the CH selection method. Additionally, they provided notations for their suggested algorithms as well as a thorough system description. Their results, based on comprehensive simulations and comparative analysis against existing SI-based hierarchical protocols, revealed the superior energy efficiency of the ABC meta-heuristic as it consumed 40% lesser energy as compared to others, even in densely populated networks. The method's strengths lie in its ability to select CHs with maximum residual energy, thereby extending network lifespan by about 25% and optimizing data aggregation by about 50%.

M. Conti et al. (2014) **[25]** explore the wireless sensor network ant-based routing algorithm. Considering energy consumption and network lifetime factors, the suggested technique aims to determine the ideal route for data transmission between nodes and the base station. The algorithm utilizes three types of ants: Frontward, Bfrontward, and Backward ants, along with a tree Breadth First Search (BFS) algorithm. These ants search for the shortest and most efficient pathway to transfer data packets to the base station. The simulation outcomes show that the suggested method leads to higher energy preservation , more successfully transmitted data packets, and a more extended network lifetime than other ant-based multi-path protocols. The algorithm also addresses the issue of starvation in WSNs, which occurs when nodes fail to find the right path for data transfer. Overall, the ant-based routing algorithm is an effective choice for raising the effectiveness and performance of WSNs. It is clear through study and simulated observation that the article significantly improves network effectiveness. The ANT-BFS method, after 800 rounds of simulation, exhibits a substantial 30% improvement in the amount of data successfully transmitted and notably superior energy preservation compared to alternative methods. This observed percentage highlights how well the suggested method works to improve network performance and energy efficiency, constituting a major development in wireless sensor network routing algorithms.

B. Vukojevic et al. (2000) **[26]** introduce an innovative approach to address efficient data packet routing in Wireless Sensor Networks (WSNs). They explore three critical routing approaches: depth-first search (DFS), location-based localized routing, and quality of service (quality of service) routing. DFS, a well-known algorithm, is adapted to enhance data transmission within wireless networks, offering a systematic way to explore potential routes. Location-based localized routing leverages the geographical positions of nodes to make routing decisions, reducing overhead and improving network performance. Additionally, the authors discuss the quality of service routing, which aims to ensure specific service requirements, such as minimum bandwidth or low latency, are met during data transmission. By investigating these routing strategies, the paper provides valuable insights into optimizing wireless network performance, reducing congestion, and enhancing the overall quality of communication. This research holds significance in today's wireless communication demands, where efficient routing plays a pivotal role in meeting user expectations and delivering seamless connectivity. This article presents valuable routing strategies that can potentially enhance the efficiency of wireless networks, although specific numerical efficiency metrics are not provided.

Q. Shi et al. (2019) **[27]** present a safe routing model for wireless sensor networks (WSN's) when dealing with potentially malicious nodes. Its core goal is to enhance the delivery of data packets and reduce packet loss in these networks. To accomplish this, the authors created a network model enabling multi-hop communication between sensor nodes and a central sink node, even while malicious nodes are present. They developed a safe routing model and provided a trust calculation approach based on the attack likelihood of each node. This model takes into account a cost function that is based on node information and chooses the route with the lowest cost to relay packets to the sink node. They used a modified version of the dijkstra algorithm for routing to make this possible. Through extensive simulations with varying proportions of malicious nodes, the study revealed that the enhanced dijkstra algorithm significantly outperforms the traditional version, resulting in lower data loss. Furthermore, it was observed that as the number of malicious nodes grows, so does the packet loss ratio within the WSN. The proposed secure routing method, directed by sensor nodes that are aware of information, demonstrated improved packet delivery and loss ratio performance while steering clear of malicious nodes. Further research avenues might explore the inclusion of transmission delay as a parameter for choosing pathway to bolster the method's practicality and effectiveness. The improved algorithm is better at avoiding malicious nodes, resulting in less energy consumption by these nodes. However, the document does not provide specific numerical values to quantify the efficiency difference between the two algorithms.

D C. Lee (2006) **[28]** introduces a tailored solution to address the challenges posed by networks featuring deterministically time-varying links. By presenting and proving the correctness of a modified Dijkstra algorithm, this research contributes significantly to network optimization. The algorithm's ability to compute the shortest-delay paths within interplanetary, orbital satellite, and sensor networks is promising to improve communication and data transmission in such dynamic and critical contexts. This work underscores the importance of adapting established algorithms to suit the unique characteristics of specialized network environments, opening new avenues for enhancing network performance and reliability. The proposed algorithm demonstrates significant improvements in data transfer efficiency, reducing delays and ensuring faster communication in networks with time-varying links, with up to a 30% reduction in data transfer times compared to traditional methods.

J. Barbancho et al. (2007) **[29]** explore wireless sensor networks (WSNs), which use small, affordable sensors to collect environmental data. While these sensors have limitations in power and processing, our study looks into how artificial intelligence (AI), specifically neural networks, can improve how data is routed in these networks, making them more efficient and reliable. We tested traditional routing methods like Directed Diffusion and Energy-Aware Routing, comparing them to our new routing approach called SIR. SIR is unique because it includes neural networks in every sensor node. Our main goal was to keep data transfer quality high while using energy wisely, which is a big concern in WSNs. We used simulations in the OLIMPO wireless sensor network simulator to see how well SIR performed, even when some nodes did not work. Surprisingly, SIR showed promise in improving network performance and quality of service (quality of service), which is essential for applications like monitoring and recognizing activities. Julio Barbancho, who is deeply involved in this research, has a telecommunications engineering degree and is pursuing a Ph.D. in computer science. He focuses on WSNs and applying AI techniques. To sum it up, our research suggests that AI, mainly neural networks, can enhance routing in wireless sensor networks. SIR, our algorithm, can reduce delays and improve WSNs, which has important implications for their future development. The article's method proposes a significant improvement in efficiency, with about a 30% reduction in data transfer.

P. Mohan et al. (2022)**[30]** discuss the strengths and weaknesses of the proposed MCR-UWSN method. The strength lies in its two-stage approach, which includes the CEPOC-based cluster building and the MHR-GOA-based routing method. The CEPOC method divides the sensor network into clusters and selects cluster heads, while the MHR-GOA method optimizes multi-hop routing. However, the suggested system has a shortcoming in collecting data and underwater monitoring approaches. The authors suggest that future research should concentrate on overcoming these challenges via the use of hybrid protocols for energy-efficient data collection and object identification in sensor networks. It concludes that the MCR-UWSN technique, which incorporates CEPOC and MHR-GOA, presents a promising and highly efficient solution for addressing the energy challenges faced by Underwater Wireless Sensor Networks (UWSN). It highlights that this technique outperforms existing methods in terms of network lifetime and the number of surviving nodes, demonstrating its effectiveness. The report invites further research in the area to investigate developments in data collection and underwater object monitoring methods for UWSNs, which might improve their overall performance and efficiency even more.

Lorenzo et al. (2012) **[31]** have optimised relaying topologies within mobile cellular networks (MCNs) to achieve high link throughput while minimising energy consumption. Their proposed solution employs a genetic algorithm-based approach, specifically GA-TSL, which evolves a population of potential solutions through genetic operators like crossover, mutation, and selection. The fitness of each solution is evaluated based on its ability to maximise link throughput and minimise energy consumption. They extensively researched network optimisation theory, topology control, radio resource management, and quality of service provisioning in various network types. They also reviewed existing literature on evolutionary algorithms and dynamic environments. They presented numerical results demonstrating the effectiveness of the GA-TSL algorithm, showcasing its convergence and superiority over exhaustive search methods in terms of generating optimal relaying topologies for MCNs.

Bhardwaj et al. (2020) **[32]** have introduced an AOMDV-FFn protocol, a novel multipath routing solution for mobile ad hoc networks (MANETs). It leverages a genetic algorithm to optimise route selection, targeting critical issues such as energy optimisation, route efficiency, and data loss. AOMDV-FFn extends the ad hoc on-demand multipath distance vector routing protocol, incorporating a genetic algorithm that considers factors like energy consumption, congestion control, and the impact of node mobility on data loss. They assessed the protocol's performance across various scenarios through comprehensive simulations, including node counts, simulation durations, faulty nodes, and node mobility rates. Key performance metrics evaluated include packet delivery ratio and throughput. Results indicate that AOMDV-FFn excels in energy efficiency, data traffic reduction, and network lifetime extension compared to existing protocols. However, the genetic algorithm-based approach may entail additional computational demands and could be better for real-time applications with stringent latency requirements. Their work presents a promising solution to enhance MANET efficiency by addressing energy, routing, and data loss challenges. However, further research is needed to evaluate its applicability in real-world scenarios, scalability, and adaptability to diverse network conditions.

**3. CONCLUSION**

In our study, we learnt about the significant potential of hybrid metaheuristics and search algorithms in enhancing network routing efficiency and reliability. These metaheuristic search algorithms are very useful in solving complex optimization problems. By combining diverse techniques such as depth first search (DFS), breadth first Search (BFS), ant colony optimization (ACO), bee colony optimization (BCO), genetic algorithm (GA), A\* algorithm, and some others, we have been able to tackle the complex challenges associated with network routing. Through the study of the research papers and extensive experimentation and analysis in them, we have learned a lot about the advantages and disadvantages of these algorithms in addition to their synergistic effects when combined in hybrid approaches. However, like any optimization technique, their performance should be carefully evaluated and fine-tuned to suit the specific requirements of the network routing problem at hand. These algorithms are motivated by the principles of genetic evolution and natural selection to repetitively enhance solutions.

The algorithms under study have yielded a plethora of notable outcomes in the realm of network routing. Their findings cover a number of significant areas, including the capacity to choose the best data packet paths, maximise throughput in various network models, reduce energy consumption for extended network longevity, and simplify load balancing in circuit-switched networks. Additionally, these algorithms have demonstrated their prowess in achieving optimal pathfinding across various contexts, enabling the determination of data transmission routes within predetermined time constraints, and enhancing energy efficiency, route effectiveness, and data integrity. Furthermore, they have been essential in preventing connectivity errors, optimising cluster head selection, and enhancing the Quality of Service (QoS) while concurrently lowering latency. Collectively, these successes highlight the revolutionary potential of hybrid metaheuristics and search algorithms in developing network routing as a subfield of artificial intelligence.

We learned about genetic algorithms, a class of metaheuristic algorithms that excel in solving complex improvement problems, particularly in the context of network routing. Genetic algorithms have been widely applied in network routing because they can handle large-scale, dynamic, and complex routing problems effectively. They can address various routing problems, including single-objective and multi-objective optimization, with the flexibility to simultaneously consider different constraints and objectives.

One of the critical strengths of genetic algorithms in network routing is their adaptability to different scenarios. They can optimize routing decisions while considering factors like network topology, traffic demands, and quality of service requirements. Genetic algorithms also have the advantage of exploring a diverse solution space, which can contribute to the quick discovery of ideal or flawless solutions.

Through careful analysis, it became clear that while each algorithm has certain advantages, Genetic Algorithms are the best method for streamlining network routing. They stand out because of their capacity to imitate the concepts of natural development and adjust to shifting network circumstances. Therefore, we plan on using Genetic algorithm as it is a powerful tool for solving network routing problems. Their ability to handle complex optimization tasks, adapt to different scenarios, and optimize multiple objectives makes them valuable for addressing challenges in modern network design and management. Their exceptional performance emphasizes how crucial it is to use evolutionary methods in order to solve challenging routing challenges.

## GRAPHICAL TIMELINE



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