ANT COLONY OPTIMIZATION IN AD HOC NETWORKS: A COMPREHENSIVE SURVEY

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ABSTRACT

In the interlinked globe of present-day, rapid transformation of technology presents numerous challenges. The development of smart cities, equipped with intelligent appliances, is essential for efficient management of communication between machines and humans. Networking plays a pivotal role in building smart cities with advanced devices, and optimizing performance remains a critical concern. In this review article, We concentrate on a specific type of wireless network - ad hoc networks and analyze current research on a nature-inspired algorithm, Ant Colony Optimization (ACO), to enhance their efficiency. This paper provides an extensive review of the use of Ant Colony Optimization or ACO applied to MANETs, and VANETs, moreover FANETs from 2021 to 2024. Additionally, it examines the characteristics and applications of various ad hoc networks, provides a detailed discussion on the Ant Colony Optimization algorithm, and highlights key challenges along with future research directions. It is hoped that this paper will be a useful resource for scholars in this area.

KEYWORDS

Smart city, MANET, VANET, FANET, ACO, Optimization, Ant, Routing

1. INTRODUCTION

By 2050, the global population is expected to rise by 70%, leading to migration into small towns and abandoned cities. To support this growth, smart cities will integrate electronic devices like connected sensors, intelligent transport, cloud/fog technologies, service-based middleware for sustainability and efficiency [1]. Safer, connected, and eco-friendly cities through efficient management [2]. Mobile Ad Hoc Networks (MANETs), despite their initial design for military communications, now play a key role in seamless connectivity and resource optimization in urban environments [3][4]. Additionally, Vehicular Ad Hoc Networks (VANETs) enhance autonomous driving and traffic management, improving road safety and congestion [5]. Flying Ad Hoc Networks (FANETs) utilize UAVs for aerial coordination, emergency response, and surveillance. Together, these decentralized networks address challenges in pollution, transportation, and safety, helping smart cities evolve into more connected, efficient, and eco-friendly urban ecosystems [4][6].

1.1. Purpose and Challenge Statement

Issues with MANETs, particularly VANETs, include restricted capacity, mobility, congestion, and security risks. In FANETs, optimized routing enhances data transfer despite high UAV

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mobility [7][8]. Nature-inspired algorithms, especially Ant Colony Optimization (ACO), are frequently used for route selection in dynamic networks like MANETs due to their flexibility and QoS guarantee [9]. 6G wireless technology will revolutionize MANETs, VANETs, and FANETs with terabit speeds, ultra-low latency, and high reliability, enabling advanced smart city applications like machine communication, AR/VR, and the tactile Internet [1] [4] [6].

1.2. Objective

Considering an analysis of the issues The other part of this investigation is structured as follows: summary is given in Section 2 about Ad Hoc Networks. Fundamental principles of ACO are presented in Section 3. In Section 4, ACO-Based Routing Algorithms for MANET, VANET, and FANET are compared. Section 5 outlines open challenges and potential avenues for future research, while Section 6 concludes.

2. Overview of Ad Hoc Network

A prototypical anarchic network made up overhead with no prior infrastructure is called an ad hoc topology [10]. I's possible which categorize ad hoc types networks into four varieties based on the application domain: MANETs, VANETs, FANETs, and UANETs.

2.1. Mobile Ad-Hoc Networks (MANETs)

MANET, or mobile ad hoc network, seems a sort of wireless system where points engage to one other entirely lacking require permanent facilities or an authoritative centre. MANETs to function every member acts as both a gateway along with a server, enabling it to send and receive messages from other nodes. It is very adaptable, flexible, and offers many benefits, which is helpful when more conventional networks cannot be formed [11][12].

MANET properties

(1) Because of their mobile nodes, their topology is erratic and rapidly shifting. (2) Because of open media and free space, the wireless channel has both variable capacity and limited bandwidth. (3) Every node in the network functions independently and forwards data by acting as both a host and a router. (4) MANET that usually up of different kinds of appliances, resources, signal strengths, as well communication technologies (like Bluetooth or Wi-Fi). Therefore, both short-range and long-range devices can be a part of a MANET. (5) MANETs must employ congestion control techniques to boost network throughput since using shared media might cause data transmission bottlenecks [13].

MANET Applications

Typical applications include (1) military battlefields (2) natural disasters (3) educational institutions (4) healthcare facilities; and (5) commercial and civilian settings. Because MANETs may establish a network without the need for fixed infrastructure in locations that are risky or difficult to reach, they are essential for military operations. Natural catastrophes are estimated to kill 45,000 people annually on average throughout the world. Quality education is the fourth goal among the seventeen objectives to earn sustainable growth that the UN set. The strategies for achieving this objective, however, may be difficult to implement in rural or isolated locations and in underdeveloped nations [13]. Applications for chat and e-commerce, databases, traffic sharing, and more are included in this.

2.2. Vehicular Ad Hoc Networks (VANETS)

VANET, mobile entities (vehicles) and stationary entities (roadside units) work together to exchange vital information about the condition of roads and other transportation. Between vehicles (V2V), between vehicle and infrastructure (V2I), vehicle and Sensor (V2S), Intra-Infrastructure (I2I), vehicle to the structure of a cellphone network (V2CN), and from vehicle toward personal Device (V2PD) are the six wireless ways to communicate that are typically found in this kind of network.

VANET properties

(1) VANETs work in a constantly shifting atmosphere, with rapid setting changes due to varying vehicle speeds and frequent node connections/disconnections. (2) GPS enables easy road information access, estimating vehicle positions via speed and trajectory. (3) As vehicles move around, the topology is always changing. (4) Unlike traditional networks, VANETs face no power constraints as vehicles have powerful batteries supporting onboard units. (5) Additionally, modern vehicles come equipped with high computational capabilities, including GPRS, memory, sensors, storage, internet connectivity, and advanced antennas, enhancing network performance and communication efficiency [14].

VANET Applications

VANETs are frequently used in the following areas: (1) Ad-Hoc Enabled Car Communities (2) Ad-Hoc Facilitated ITS Vehicle Navigation (3) Stolen Vehicle Tracking (4) On-the-Go Traffic Management and Automatic Identification of Traffic Rule Offenders (5) Warning of Accidents at Intersections.

2.3. Flying Ad Hoc Networks (FANETS)

FANETs represent like a specialized form of mobile ad hoc networks also VANET, here UAVs function as network nodes. FANETs are characterized by frequent topology changes, three-dimensional environmental conditions, diverse mobility patterns, and varying terrain structures [15].

FANET properties

(1) FANETs typically feature a lower concentration of UAV nodes in comparison with other types of networks such as MANETs and VANETs (2) FANETs exhibit significantly higher node mobility than VANETs and MANETs (3) FANET topology changes frequently due to UAVs' fast movement (4) The radio propagation model is key in designing and simulating communication systems (5) FANET power consumption depends on UAV size, communication range, hardware, and link obstacles [16].

FANET Applications

MANETs lack the performance needed for disaster and warzone tasks like floods, earthquakes, and rescue missions. Thus, FANETs are mostly utilized for (1) target detection, (2) emergency scenarios, (3) civilian and public applications, (4) data packet delivery, and (5) route guidance.

2.4. Differences between MANETs, VANETs and FANETs

Table 1 provides a brief of the comparisons between FANET, VANET, and MANET regarding certain criteria.

Table 1 Comparison of Networks [17][18]

Parameters	MANETs	VANETs	FANETs
Node Density speed	Low as 6 km/h	Modest to fast speed that 20 to 130 km/h average	Very Less From slow toward fast (6 -460 km/h)
Mobility	Identical two dimensions, as well random paths, Little	Identical two dimensions, as well random paths,Large	Free, three dimensuional, Frequentor predetermined paths, extremely large
Model of transmission	Ground level	Ground level	Air
Band of frequencies	From 30 MGHz to 5 GHz	5.9 GHz	UAV 2-5GHz, 2-2.4 GHz
Change in design	Altering and hard to predict	Straight motion that is much advanced	Slow, fast, and stationary
Technology that lacks wires	IEEE standard 802.11a/b/g/n and 802.16	IEEE standard 802.11p	IEEE standard 802.11a/b/ac/g/s/n/p
Power Consumption	Effective Use of Energy	Not required	Mini UAVs are required.

3. Overview of Ant Colony Optimization (ACO)

3.1. Biological Inspiration

Research in computer science, mathematics, engineering, power, and business has frequently drawn inspiration from biology [19]. Meta-heuristic algorithms offer optimal or nearly optimal answers in a reasonable amount of computational time for networks of any size. For pathfinding and optimization problems, Particle Swarm Optimization or PSO, Ant Colony Optimization or ACO, and Genetic Algorithms or GA is currently extensively employed. Specifically, ACO called a biologically inspired method that is based upon ant while foraging. It is useful for resolving challenging combinatorial issues and is a member of the optimization meta-heuristic family [20].

3.2. Ants in the Real World

With over 8,800 species known to date, ants are gregarious insects that have been around for more than 100 million years. There are various castes in a colony, and each has a specific function: (1) Workers: Sterile females in charge of maintaining the nest, foraging, and tending to the queen and her young. (2) Queens: The fertile females who lay eggs and establish colonies. (3) Drones: Male ants that are only present during the mating season to reproduce. (4) Soldiers: In certain species, these larger, more powerful workers protect the colony from intruders [21].

3.3. Ant Colony Optimization

Ant Colony Optimization known as idea offered from Marco Dorigo made dealing with a variety of combinatorial difficulties with efficiency. Let's explore the working of ants in ACO technique through a flowchart.

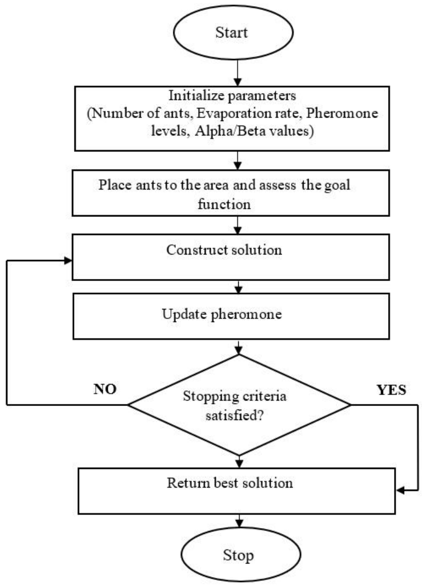

Figure 1. Workflow of Ant colony optimization (ACO)

Ants can find optimal or near-optimal paths by balancing exploration and exploitation; evaporation and heuristic parameters (such as α and β) encourage exploration, while high pheromone concentrations encourage exploitation. In ACO, pheromone update rules refine solutions through reinforcement (depositing pheromone on successful paths) and evaporation (diminishing pheromone over time). The iterative pheromone updates drive convergence, with the convergence rate indicating the algorithm's effectiveness in finding solutions [20][21][22].

ACO is combined with various techniques for improved routing, including fuzzy logic for secure path selection (FTAR), ML for adaptive routing (Q-learning, NSGA-II), and meta-heuristics like ACO-FDRPSO for energy efficiency. Security protocols like SAR-ECC and S-AMCQ integrate ACO with ECC and attack defense, while ABPKM detects Sybil attacks. Network models like MAR-DYMO and MAZACORNET use the Nakagami Fading Model, QoRA estimates QoS with SNMP, and HOPNET combines ACO with ZRP. Additionally, pheromone-based mobility models guide UAV movements and optimise coverage via pheromone maps [18] [21-23].

For better routing, ACO is integrated with a number of methods, such as meta-heuristics like ACO-FDRPSO for energy efficiency, fuzzy logic for secure path selection (FTAR), and machine learning (ML) for adaptive routing (Q-learning, NSGA-II). While ABPKM identifies Sybil attacks, security protocols such as SAR-ECC and S-AMCQ combine ACO with ECC and attack defence. The Nakagami Fading Model is used by network models such as MAR-DYMO and MAZACORNET, QoRA uses SNMP to estimate QoS, and HOPNET combines ACO and ZRP. Furthermore, pheromone-based movement models use pheromone maps to optimise coverage and direct UAV motions.

3.4. Connecting ACO to Ant Behavior

One of ACO's main tenets is (1) Positive Feedback: Over time, effective solutions are reinforced. Distributed Computation: Several agents operate concurrently without centralized control. Stochastic Decision Making: Premature convergence is avoided and exploration is guaranteed by randomness. ACO algorithms are frequently employed to solve routing, scheduling, and optimization issues in dynamic and complex contexts by mimicking these natural tendencies [21][22].

3.5. Early Ant-Based Algorithms that were Developed

Numerous routing methods have been put forth thus far for ad hoc networks, with an emphasis on factors like scalability, load balancing, and effective routing. These algorithms fall into one of three categories: hybrid, proactive, or reactive. Ant-Colony Based Routing Algorithm (ARA) and AntNet are two variety of proactive ACO-based protocols that keep continuous routing information, guaranteeing lower latency but at the expense of increased overhead. Ant-Based Control (ABC) and PACONET for MANETs are examples of reactive ACO-based protocols that create routes only when necessary, lowering overhead but raising initial delay. HOPNET and AntHocNet are examples of hybrid ACO-based protocols that optimize routing efficiency and adaptability by combining the benefits of proactive and reactive techniques [22][23].

However, this study highlights recent applications of ACO in various ad hoc networks to guide researchers on emerging trends and future contributions. A systematic paper selection process, illustrated through a diagram, ensures focused and relevant literature coverage.

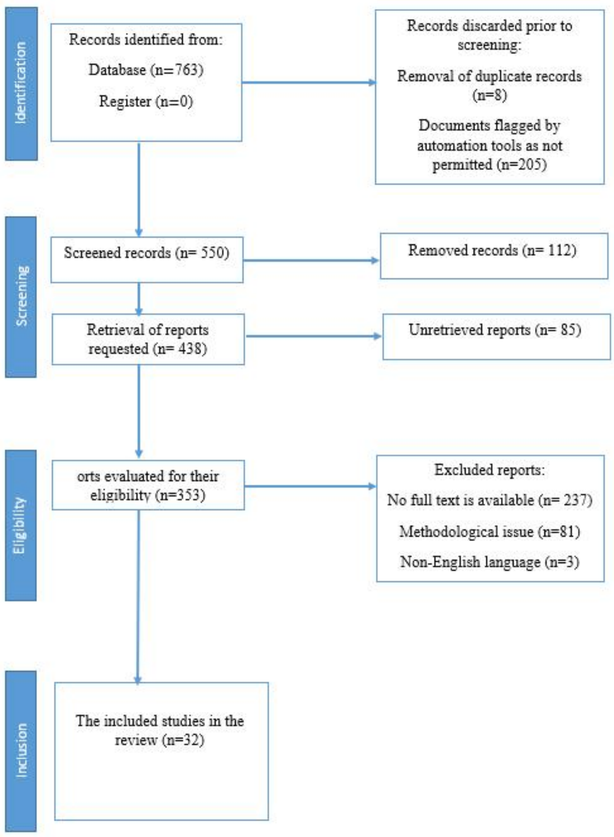

Figure 2. PRISMA Study Selection Process Flow Diagram

Table 2 : Existing work on integrating ACO-based routing algorithms in MANET, timeframe (2021-2024)

References	Algorithms/mechanisms	Performance metrics	Simulation tools
[12]	ACO with Delay Aware Energy Efficient (ACO-DAEE)	PDR, E2E Delay, Throughput	NS-2.34
[24]	ANN with ACO	Energy consumption, Network lifetime, PDR, Routing overhead, E2E delay	NS-3
[25]	Deep learning in space and time with enhanced ACO	PDR, Throughput, E2E delay, True Positive Rate (TP)	SimPy library in Python
[26]	Enhanced Manhattan Mobility Model (EMMM) and ACO	PDR, Throughput, Dropped packets, Average e2e delay, and packet overhead	NS-2.35 Bonnmotion-3.0.1
[27]	Quantum-inspired ACO (QACO)	Discovery Time, Routing & Gateway Overhead, Protocol Tracing	MATLAB 9.1 (R2016B)
[28]	MyANT	PDR, E2E delay, Throughput	Glomosim
[29]	Cross-layer routing that respects energy system utilising ACO (AOERP)	E2E delay, Dead nodes, Reliability, Energy factor	NS-2.34
[30]	Game theoretic approach with AntHocNet	E2E delay, Packet Loss Ratio, Throughput	NS-2.34
[31]	Fuzzy logic and ACO	Packets Diffused, PDR, Avg. Delivery Ratio	NS-3
[32]	ACO based MAODV	PDR, E2E delay, Throughput, Overhead	NS-2.34

With a cross-layer strategy, author Uppalapati Srilakshmi et al. [12] set out to design an energy-efficient military routing framework. Overcoming the shortcomings of current methods, such as PDO-AODV, which prevent optimal path selection, is one of the principal goals. Their results demonstrate that ACO-DAEE performs better in PDR, delay, and throughput than PDO-AODV and N-CRS together. Because the Forwarder Selection Functioning employs a probability-dependent procedure to determine the best next hop by taking into account important variables like Pheromone Trail, Link Quality, Node Energy Level, also Trust Rating, the authors chose this approach.

Hande and Sadiwala [24] propose an energy-efficient MANET routing method using ANN and ACO. ANN enables intelligent, adaptive routing based on factors like energy, mobility, and congestion, outperforming AODV and DSR. ACO enhances link selection, boosting PDR, reducing energy use and delay. Future work includes optimizing ANN scalability, reducing computational costs, and integrating real-time mobility and hybrid models.

The aim of JIAMIAO ZHAO et al. [25] is to formulate a cross-layer design for directional multicast that uses DI-prediction. The suggested solution outperforms the competition and avoids packet loss due to node mobility by proactively managing directional interference (DI) with ST-ResNet, an ANN version that predicts DI patterns spatiotemporally. The improved ACO+ algorithm then uses these predictions to maintain optimal multi-tree routing that avoids interference. Compared to reactive methods such as AODV and AMRoute, this cross-layer approach improves DI prediction accuracy (81.33% true positive), enhances packet delivery ratio

(82% recovery), boosts throughput (10.7 Mbps, 25% improvement), and decreases End-to-End Delay.

Satveer Kour et al. [26] predominant objective is to use mobility-aware ACO to improve MANET performance. Because of its integration with the Enhanced Manhattan Mobility Model (EMMM) and distinctive link selection method, the suggested ACBBR technique, a variant of ACO, performs better than another ACO variant known as AMBRLB. Compared to multi-path techniques, EMMM guarantees smoother node motions, while ACBBR cost of packets. In mobility experiments, these elements result in notable gains in throughput, missed packets, average pdr and e2e delay. One area for future development, according to the authors, is choosing a dynamic threshold for identifying significant relationships. Although they admit that this could be dynamic, they now classify links using a fixed threshold of 80% of the deposited pheromone. Additionally, they propose that the ACBBR approach be employed for future improvements in network load balancing by applying it to multipath ACO algorithms.

Jamal Khudair Madhloom et al. [27] for the goal of Quantum-Inspired Ant Colony Optimization (QACO) method to enhance internet access in MANETs through improved gateway detection. QACO reduces network overhead, accelerates gateway discovery, and maintains stable paths by leveraging quantum parallelism to avoid premature convergence and efficiently explore solution spaces addressing the limitations of classical ACO. It outperforms protocols like AODV, OLSR, ZRP, and AntHocNet in speed and overhead reduction. However, challenges remain, including the need for better internal network discovery, adaptive link thresholds, and improving search efficiency limited by fixed lookup-based quantum rotation angles.

MyANT, a revolutionary ACO dependent routing algorithm, is the principal objective of the authors Pimal Khanpara and Sharada Valiveti [28] for ad hoc networks. Because of its hybrid, bio-inspired ACO methodology, which adjusts to the dynamic features of ad hoc networks, the MyANT routing scheme performs better. It allows for ongoing improvement and path optimisation by fusing proactive route maintenance with reactive path discovery. By rebuilding pathways or generating backups, MyANT also effectively manages link failures. Consequently, MyANT achieves higher throughput than conventional protocols such as AODV, DSR, and AntHocNet. Although its packet delivery is comparable to AntHocNet's, its delay is greater than that of AODV and DSR. Reducing the routing overhead brought on by proactive ants is the primary task for next development in the MyANT routing system.

Researchers Shaik Shafi and D. Venkata Ratnam [29], introduce a novel ACO dependent energy concern cross layer AOERP with the main objective of enhancing route consistency and network longevity in MANETs. By choosing Adaptive Relay Nodes (ARNs) according to Energy Factor and Nearby Node Proportion and utilising ACO with Stability Factor, LET, Congestion, and Hop Count to determine the optimal path, the protocol's cross-layer design optimises routing. Regarding reliability and energy efficiency, eed latency, and node longevity at different densities and speeds, AOERP performs better than EPAAODV and K-means AODV ACO. Analysing the suggested plan from a variety of angles to enhance security and defend against threats in MANETs is the main focus for future research.

By dynamically adjusting its pheromone evaporation value online, the authors Marwan A. Hefnawy et al. [30] mainly aim at enhancing ACO routing strategies for MANETs. The recommended game-theoretic method for adjusting AntHocNet's pheromone evaporation rate enhances performance through adaptive, inexpensive tuning. By dynamically modifying the evaporation parameter, it lowers overhead. In bigger networks, this produces better results than AntHocNet regarding eed latency, packet loss, and throughput. In some areas, it performs better than AODV as well. The primary obstacles are the requirement for more thorough experimental findings and the incorporation of additional Quality of Service (QoS) measures linked to the gamers.

Fuzzy ant colony networking safety, or OFACA-5G, was proposed by R. Nithya et al. [31] OFACA-5G: 5G MANETs with improved routing via fuzzy logic. For 5G-MANETs utilising mmWave technology, the OFACA-5G algorithm performs very well with an enhanced ACO hybrid routing solution and security-aware fuzzy logic to identify rogue nodes. It provides lower overhead, lower latency, improved Packet Delivery Ratio (PDR), and strong fault tolerance. OFACA-5G performs better than AODV and is more resilient than ANT, particularly when it comes to Sybil and black hole assaults. A significant obstacle to further research is the need for increased caution in selecting suitable parameters for the fuzzy framework.

The authors, Mallikarjuna Anantapur and Venkanagouda Chanabasavanagouda Patil [32], introduced an ACO-based MAODV for safe MANET transmission. By employing ACO to counteract blackhole attacks, the MAODV-ACO algorithm improves secure data transmission in MANETs and achieves a 99.66% packet delivery ratio for 100 nodes. It minimises overhead, cuts down on delay, and increases throughput. The authors draw attention to issues with MANETs, such as routing complexity, security flaws, and restrictions in protocols including AODV, TSQRS, and CARP.

Table 3: Existing work on integrating ACO-based routing algorithms in VANET, timeframe (2021-2024)

References	Algorithms/mechanisms	Performance metrics	Simulation tools
[5]	GyTAR, E-IFTIS, Dijkstra's algorithm and ACO	PDR, E2E delay, and Bytes overhead	NS-3 and SUMO
[8]	Enhanced Location-Aided Ant colony Routing (ELAACR)	Throughput, Packet Loss Rate, PDR, Overhead, E2E delay	NS 2.35, MOVE, SUMO 0.22.0
[22]	ACO	Waiting Time, Route Diversity, Fuel Convergence, Trip Standard deviation	MATLAB
[33]	ACO-AODV	Packet dropping rate, Overhead, Expected delay, Throughput	MATLAB
[34]	AODV as well ACO	Ratio for packet loss, Delay Throughput, Total Overhead, Energy loss	MATLAB
[35]	VANET-ACO	Connection Prob., PDR, Delay, Latency Var., Throughput, QoS, Segment Connection, Tx Rate, Vehicle Density	Omnet++
[36]	ACO technique and the AODV	Delay, Packet Loss Throughput	NS-2
[37]	ACO with Distance-Based Source Routing	PDR, PLR, E2E delay, Throughput, Routing Overhead	NS-2.34
[38]	ACO, Fuzzy logic, TCP and UDP	PDR, E2E delay, Network Overhead, PSNR	NS-2.34, EvalVid, VanetMobiSim
[39]	Genetic Algorithm (GA) into ACO	PDR, Average throughput, E2E delay, Packet loss	NS-3.26 and SUMO

The evaluation of multiple junction oriented traffic awareness navigation, or MJTAR, for urban VANETs is the primary aim of this study conducted by Seung-Won Lee et al. [5]. Ant Colony Optimisation (ACO) and a two-hop junction technique are used by MJTAR to optimise VANET routing in order to avoid closed roads, decrease latency, and increase packet delivery. It reduces routing overhead through the Enhanced Infrastructure-Free Traffic Information System and performs better than GyTAR and GSR. The limitations of MJTAR include the requirement for a hybrid RSU approach, the difficulty of obtaining traffic information in low-density areas, and more computation at intersections. Future research will concentrate on enhancing forwarding node selection, investigating collision avoidance for multi-source transmissions, and using machine learning to traffic prediction.

The investigation, which was composed by Raghu Ramamoorthy [8], suggests using ELAACR for exchanging data on VANETs in a seamless and secure manner. In highway settings, the protocol performs very well by integrating an Ant Colony Routing (ACR) algorithm for effective, secure pathfinding with Location-Aided Key Management (LAKM) for safe vehicle authentication. By giving priority to high pheromone routes, it lowers the Packet Loss Rate, EED, and increases PDR. In addition, ELAACR provides faster convergence and less routing overhead than EHACORP and F-ANT. Because of different speeds and impediments that raise processing overhead, ELAACR is best suited for highways and is not appropriate for urban settings. Future research should incorporate a congestion strategy and modify it for metropolitan environments.

The authors of the research, Amar Partap Singh Phrawaha et al. [22], aim to improve transport performance by establishing an intelligent route strategy. The suggested approach uses a decentralised, adaptive algorithm inspired by Ant Colony Optimisation (ACO) to optimise transportation networks. Because it can modify pheromone levels in response to real-time congestion, it performs well in dynamic network scenarios and changing conditions, resulting in resource-optimized, time-efficient, and cost-effective transportation with a lower environmental impact. The difficulties of maintaining big networks, finding suboptimal solutions, and fine-tuning parameters are highlighted in the paper. For greater adaptability, future research will concentrate on combining the algorithm with machine learning and smart cities.

In order to create a quantum-secure IoV protocol with optimal routing for 5G intelligent cities, Tannu Sharma et al. [33] take the initiative. By employing ring learning with mistakes to provide post-quantum security and ACO for hostile vehicle identification and optimised routing, this approach performs exceptionally well. With lower overhead, higher throughput, and fewer packet drops, it performs better in IoV contexts than SE-AOMDV and elliptic curve cryptography. IoV issues that cause delays and excessive cost in current frameworks are highlighted in the paper, including privacy, security, and ineffective routing without malicious vehicle detection.

The intent of this study, which was prepared by Payal Kaushal et al. [34], was to compare the real-time applications of AODV and ACO. The sources examine and contrast ACO and AODV, two reactive routing techniques. When it comes to throughput, packet loss ratio, and delay, ACO outperforms AODV. The reason for this is that ACO's route-finding technique is dynamic and scalable since it is a self-organization system that takes into account of fitness measurements like latency and distance, and vehicle velocity. The current routing protocols need to be optimised. This leads to the recommendation that hybrid protocols be created in order to improve VANET performance even more.

Ali M. Ali et al. [35] talk about how to optimize routing for UGV communication during firefighting. The ACO-based protocol uses throughput to choose the best routes, outperforming GSR and CAR in Quality of Service metrics including latency, packet delivery ratio, and connection probability. The study draws attention to the erroneous pathways and incapacity of the current VANET routing protocols to adjust to network changes. Subsequent investigations will examine the influence of VANET weight variables and contrast ACO with alternative optimisation methods.

Manoj Sindhwani et al. [36] composed this research, which is about how to improve VANET routing by cutting down on traffic. The suggested ACO-AODV protocol performs better than AODV by increasing throughput, decreasing packet loss and delay, and using optimal path selection to minimise congestion and bandwidth use. By choosing routes with the least distance, the ACO algorithm accomplishes this. The constraints of AODV in dynamic VANETs, specifically congestion and inefficient bandwidth, are discussed in the study. In order to maximise dependability and efficiency, future research will test the protocol with more nodes in locations with high traffic.

Raghu Ramamoorthy and Menakadevi Thangavelu [37] proposed EHACORP: Enhanced Hybrid ACO for VANETs. EHACORP improves packet delivery and throughput while lowering latency, packet loss, and routing overhead by utilising a source-based ACO and the Distance Calculation Method to determine the best routes. It performs better in urban road settings than F-ANT, AODV, ARA, and AntNet. The focus on urban topologies and the lack of extensive testing on highways are the study's limitations. EHACORP will be expanded to highway scenarios in future research to assess performance more broadly.

This paper, published by Mohammad Vafaei et al. [38] design a QoS adaptive ACO-Fuzzy multi-path routing for VANETs. The suggested technique performs exceptionally well in urban VANETs by utilising fuzzy logic for intelligent next-hop vehicle selection and ACO for multi-path QoS route selection, which enhances packet delivery, throughput, and lowers overhead and latency. It is more efficient than the UDP, MSLND, VACO, and AQRV protocols. With little testing on highways, the study's focus on urban topologies is one of its limitations. In the future, the protocol will be expanded to highways to meet more QoS requirements, such as security and privacy.

Gagan Deep Singh et al. [39] proposes and evaluates GAACO routing for VANETs. By integrating GA and ACO for optimised routing, increasing packet delivery and throughput, and decreasing delay and packet loss, GAACO (Genetic Algorithm in Ant Colony Optimisation) performs exceptionally well in urban VANET traffic situations (basic, complicated, and Dehradun). It performs better than the AODV, ACO, and PSO protocols. The study's focus on urban traffic is one of its limitations; future research will try to expand GAACO to other VANET scenarios and investigate other metrics, such as intra-satellite communication and FANET.

Table 4: Existing work on integrating ACO-based routing algorithms in FANET, timeframe (2021-2024)

References	Algorithms/mechanisms	Performance metrics	Simulation tools
[6]	MFA, ACO, EFA, IABC	PDR, E2E delay, Routing, Overhead and Throughput	NS-3.26
[15]	EALC, CACONET, GWOCNETs	Clusters count, build time, lifetime, energy use	EALC matches clusters, outperforms ACO & GWO
[16]	Ant-Hocnet with fuzzy logic	PDR, E2E delay, Throughput	MATLAB
[40]	Hybrid ACO-Physarum Foraging Model	Avg. E2E delay, PDR, energy, routing time	OMNeT++
[41]	ACO, PSO, GA, DE	Collision avoidance, communication range, and accuracy	Real-world applications
[42]	ACO, OLSR	PDR, Throughput, E2E delay	NS-2
[43]	ACO, PSO, RAODV and Dijkstra algorithm	PDR, between hosts delay, Overhead of routing, Networks, Throughput	NS-2
[44]	Enhanced ACO	Throughput, Network Lifetime	NS-2
[45]	AntHocNet	Clusters: Count, Build Time, Lifetime, Energy Use	NS-2
[46]	AntHocNet	Throughput, Bandwidth Use, Packet Loss, QoE	NS-2
[47]	ACO with trust-aware algorithm	Latency, Packet delivery ratio, as well as Routing overhead	OMNET++
[48]	MAA and BCO	Throughput, Scalability, PDR, and E2e delay	MATLAB

Amrita Yadav's paper [6] aims to improve FANET routing algorithms so they may be used in real time. The Modified Firefly Algorithm outperforms ACO, IABC, and EFA regarding throughput, packet delivery(98%) and E2e delay (0.9 ms) across node densities (10-50 nodes). ACO serves as a reference point for comparison. With node densities greater than 20, the MFA's performance deteriorates, indicating the need for alternative nature-inspired algorithms (NIAs) for certain uses. New NIAs, energy-efficient routing, and moving to hardware for real-time FANET applications will all be investigated in future research.

Farhan Aadil and others expressed it [15]. Its goal is to address important problems related to effective clustering and modifying the power of UAV transmissions. Because of its simpler, less complicated methodology, the Energy Aware Link-based Clustering method performs better in cluster construction time and energy usage than ACO-based CACONET and GWO-based clustering. ACO is used as a standard by which to compare. Although EALC only roughly rivals CACONET in cluster lifetime, it overcomes ACO's high computational complexity and sluggish convergence. In order to increase routing efficiency, future research will concentrate on integrating high node mobility.

The intent of this study, authored by Saifullah Khan et al. [16], is to improve FANET routing utilising Ant-HocNet and fuzzy logic. FAnt-Hocnet uses fuzzy logic to analyse wireless network status, including bandwidth, node mobility, as well quality of link, and improves throughput, end-to-end delay, also packet delivery proportion. The Ant-Hocnet method, that is founded on ACO, is improved. The study does not address congestion control in FANETs, security against rogue nodes, or packet drop likelihood. These topics, which include congestion reduction techniques, priority-based communication, packet drop monitoring, and security, will be the focus of future research.

The goal of the research carried out by Siwei Yang et al. [40] is to present a new ICRP for scalable, adaptive UAV routing. In high-speed node mobility scenarios, the Inter-Cluster Routing Protocol (ICRP) performs better than AODV, FL-AODV, and Enhanced Ant AODV in terms of packet delivery rate and EED. It is based on ACO and overcomes its slow convergence by using a Physarum polycephalum-inspired heuristic and improving pheromone updates. Wireless communication information leakage is not covered in the study. Future research will concentrate on secure routing, authentication, encryption, and network adaptation for 5G/6G and IoT.

Yunus Alqudsi and Murat Makaraci [41] discuss the latest progress in swarm aerial robots. The review study highlights ACO's convergence and optimal performance in limited search spaces as a heuristic search algorithm for path planning, task allocation, and resource management in Swarm Robotics. It highlights issues with swarm aerial robots, such as scalability, fault tolerance, and algorithmic complexity. Future research will concentrate on creating adaptive, energy-efficient algorithms, combining AI and metaheuristics, and tackling moral dilemmas.

Shiyar Karbooz et al. [42] suggested the INT-OLSR routing protocol in their study. By selecting more reliable routes based on node speed and distance-factors that OLSR's hop-count measure does not account for—the Intelligence-OLSR (INT-OLSR) protocol performs better than OLSR. Although it increases throughput and the data delivery ratio, it performs similarly to entire delay of OLSR.

This study, produced by Hayder A. Nahi et al. [43], aims to introduce MOHOQ-FANET for improving QoS. Throughput, packet delivery rate, delay, as well overhead are all improved by the Multi-Objective Hybrid Optimisation for QoS Assisted Flying Ad-Hoc Network (MOHOQ-FANET), which performs better than CSPO-FANET and OSNP-FANET. ACO is utilised for dependable routing using RAODV and shortest path selection. Future research will concentrate on employing clustering to improve FANET energy efficiency.

Muhammad Hameed Siddiqi and others [44] come up with a drone-based FANET for keeping an eye on traffic in smart cities. The Enhanced Ant Colony Optimisation approach outperforms conventional ACO, IACO, and ICMPACO in terms of network longevity and performance, particularly in bigger areas. By altering the pheromone technique, eACO improves data communication and route selection in dynamic FANETs. But when there are more than 650 nodes, it performs worse.

Inam Ullah Khan et al. [45] wrote this study with the goal of addressing important concerns and suggesting effective clustering. The AntHocNet method excels in FANETs by achieving optimal throughput, balanced packet delivery ratio, reduced loss, and low delay, outperforming protocols like DSR, ZRP, M-DART, DSDV, and AOMDV. Future work will focus on deploying additional mobility models for UAVs.

The aim of Sadoon Hussain et al. research [46] is to create an innovative ant-based routing system for networks that fly securely. In terms of end-to-end delay, overhead, and data forwarding, the AntHocNet approach performs better than protocols such as i-ACO, LEACH, ZRP, M-DART, DSR, DSDV, also AOMDV. It achieves 93% optimised packet drop rate, 90% increased bandwidth, and 95% enhanced throughput. Pheromone updates are used for data encryption and security, and it is based on ACO. Future research will investigate hybrid mobility models for FANETs, particle swarm-based routing, and the integration of computational intelligence, AI, and machine learning to enhance communication standards.

Sahabul Alam et al. [47] proposed a bio-inspired strategy with ACO for safe, energy-efficient routing and trusted leader selection inside clusters, the suggested algorithm, a Trusted Fuzzy Routing Scheme, performs very well in FANETs. In FANETs, it works better than current protocols like SecRIP and UNION, demonstrating gains in latency, packet delivery ratio, also less routing overhead.

Author Altaf Hussain et al. [48] work with both Moth-and-Ant (MAA) alongside Bee Colony Optimisation (BCO) routing protocols outperform DSR, AODV, and DSDV in FANETs due to their superior throughput, scalability, PDR, and decreased End-to-End Delay. Future research will concentrate on creating more effective routing algorithms for interaction betweenUAVs and the ground as well as between UAVs, tackling issues like link stability and energy consumption in high-speed UAVs.

4. Open Challenges and Future Research Directions

4.1. Current Challenges in ACO-Based Routing

While ACO shows promise in addressing routing concerns in ad hoc networks, challenges remain. In MANETs, ACO must adapt to the network's extremely dynamic nature while maintaining energy efficiency and security. Furthermore, developments in parameter tuning, QoS support through cross-layer designs, and scalability via methodologies such as Quantum-Inspired ACO (QACO) are crucial for performance optimization. Modifications to VANETs are aimed at enhancing convergence speed, flexibility to network dynamics, decreased overhead, increased security, and more optimal routing in diverse vehicle contexts. From complex also continuous changing nature of UAV-based infrastructures, FANETs require improvements in ACO versatility, convergence speed, efficiency, and overall performance. Addressing these problems with enhanced optimization techniques and new technology is critical for maximizing ACO's promise in next-generation ad hoc networks [49][50].

4.2. Possible Research Areas

For energy efficiency and adaptability, future MANET research should concentrate on intelligent cross-layer routing using AI and swarm techniques like ANN+ACO [12, 24, 25, 29]. Security should be improved through fuzzy logic and trust models [31, 32], and scalability should be improved through quantum-inspired techniques and dynamic parameter tuning [27, 30]. For improved QoS and performance in VANETs, it is crucial to address congestion, security, and dynamic topologies [33, 36, 39], enhance support for both urban and highway environments [8, 37, 38], and integrate machine learning with ACO for adaptive routing and traffic prediction [5, 22]. With a focus on enhancing clustering, real-time hardware deployment, and secure communication under 5G/6G frameworks [43, 44, 45, 47, 48], future research on FANETs should prioritise energy-efficient, secure, and adaptive routing using AI, fuzzy logic, and hybrid metaheuristics [6, 15, 16, 40, 46]. These developments will be essential for creating ad hoc networks that are resilient, scalable, and next-generation.

5. CONCLUSION

Although integrating ACO into ad hoc networks for suggesting smart city applications presents several challenges, survey results highlight its potential. This survey present that, research increasingly focuses on hybridization with techniques like fuzzy logic, PSO, genetic algorithms, security mechanisms and others to enhance routing efficiency. As smart cities depend on advanced communication networks, ACO-based solutions can improve traffic management, energy optimization, and real-time data exchange. However, according to this investigation's analysis, the majority of works concentrate on PDR, latency, and throughput, ignoring important metrics such buffer occupancy, load balancing, and jitter that are essential for real-time performance insights. In conclusion, this study identifies three key research directions: (1) Advancements in ACO (2) Diverse ad hoc network applications and (3) Emerging research trends offering valuable insights for future smart city communication systems.

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