Received: 7 May 2021 | Revised: 2 September 2021 | Accepted: 7 September 2021

IET Communications

DOI: 10.1049/cmu2.12291

The Institution of Engineering and Technology WILEY

ORIGINAL RESEARCH PAPER

FANET: Smart city mobility off to a flying start with self-organized drone-based networks

Muhammad Hameed Siddiqi[1] | **Umar Draz**[2] | **Amjad Ali**[2] | **Muddesar Iqbal**[3] | **Madallah Alruwaili**[1] | **Yousef Alhwaiti**[1] | **Saad Alanazi**[1]

[1] College of Computer and Information Sciences, Jouf University, Sakaka, Aljouf, Kingdom of Saudi Arabia

[2] Department of Computer Science, COMSATS University Islamabad, Lahore Campus, Lahore, Pakistan

[3] Division of Computer Science and Informatics, School of Engineering at London South Bank University, London, UK

Correspondence
Umar Draz, Department of Computer Science, COMSATS University Islamabad, Lahore Campus 54000, Pakistan.
Email: sheikhumar520@gmail.com

Funding Information
The authors extend their appreciation to the Deputyship for Research & Innovation, Ministry of Education in Saudi Arabia for funding this work through the project number "375213500". Also, the authors would like to extend their sincere appreciation to the central laboratory at Jouf University to support this study.

Abstract

Due to recent advancements in smart city traffic and transport monitoring industry 4.0 applications. Flying Ad-Hoc Networks (FANETs) ability to cover geographically large areas, makes it a suitable technology to address the challenges faced during remote areas traffic monitoring. The implementation of drone based FANETs have several advantages in remote traffic monitoring, including free air-to-air drone assisted communication zone and smart surveillance and security. The drone-based FANETs can be deployed within minutes without requiring physical infrastructure, making it suitable for mission critical applications in several areas of interests. Here a drone-based FANETs application for smart city remote traffic monitoring is presented while addressing several challenges including coverage of larger geographical area and data communication links between FANETs nodes. A FANET-inspired enhanced ACO algorithm that easily coped with drone assisted technology of FANETs is proposed to cover the large areas. Simulation results are presented to compare the proposed technique against different network lifetime and number of received packets. The presented results show that the proposed technique perform better compared to other state-of-the-art techniques.

1 | INTRODUCTION

The recent decade has seen tremendous advancements towards industry 4.0 revolutionary smart city technologies. Drone-based Internet of Things (IoTs) plays a vital role to transform urban public infrastructure and services including governance and transportation. It provides on-the-fly sensor-based data collection without requiring a physical infrastructure to cover larger geographical areas to support several applications that includes but not limited to disaster management, smart agriculture, smart cities, smart transportation, smart mobility, smart freight, smart waste management, smart housing, smart governance, smart surveillance and security[1–3]. Most of these services heavily rely on integration to a sustainable city transportation system with smart road infrastructure such as adaptive parking, smart traffic navigation and software control signalling and coordination. The smart city transportation systems require self-organised, self-healed and self-managed network and communication infrastructure to cover remote areas outside cities. These remote areas lack basic network infrastructure to support such applications. Recently, the concept of Flying Ad hoc NETworks (FANETs) has gained tremendous attentions for its application in Unmanned Arial Vehicles (UAVs) to over remote and larger geographical areas with its self-organized, self-managed, self-healed nature. FANETs are highly dependent on some intelligent routing algorithm that may be distributed or centralized in nature. Drone-based FANETs successfully capture intention of reliable communication among the Road-Side Units (RSU) and control centres to support smart cities traffic monitoring applications; Due to high mobility, the FANETs are affected by frequently changing topology. Road safety is kept at the heart of any smart urban transportation network and infrastructure

FIGURE 1 FANET-based smart city traffic control and monitoring system

design. Only in Kingdom Saudi Arabia (KSA) alone, the number of people killed in Road Traffic Accidents (RTAs) are extremely high.

According to the world health organization report about 27.4 deaths per 100,000 population were estimated. Moreover, the number of RTAs is continuously increasing and double in the last 10 years. The government of Kingdom of Saudi Arabia (KSA) is looking for a viable solution to overcome this serious issue. Recently, the idea of RTAs monitoring using the drone based FANETs has gained a great attention in both the academia and the industry. This is considered as the most efficient solution to overcome this serious smart urban traffic monitoring challenges as illustrated in the Figure 1. Typically, VANETs consist of vehicular devices, such as car, bikes. Similarly, the FANETs consist of drone-based flying vehicles. Therefore, degree of mobility in VANETs is comparatively low than the FANETs [4]. Due to higher degree of mobility in FANETs, the change of topology is recorded more frequently as compared to VANETs [5, 25]. The VANETs nodes have not much distance for communication; but in FANETs nodes are apart from each other and required a reliable communication. Therefore, the deployment cost in terms of energy in FANETs is higher than the VANETs. The communication range among flying objects in FANETs is higher as compared to VANETs. Therefore, in FANETs, UAVs are used that successfully works in terrestrial and underwater environment. Mobility modes used in the FANETs, such as the RWP, gasser marker, semi random corridor, and mission plan-based models are highly used whereas in the VANETs some of them are used. A lot of deployment methods of FANETs are available, such as directly, satellite based multi-ground stations and Inter-UAV's based FANETs. However, the VANETs lacks above deployment strategies. The contributions of this paper given as follows:

1. We proposed a reliable drone-based RTA monitoring scheme for smart city transportation system using enhanced Ant Colony Optimization (eACO) technique.
2. Extensive simulation results are carried out using NS-2 simulator to compare the performance of the proposed scheme with to other state-of-the-art techniques in terms of different network lifetime and number of received packets.

Due to above motivations and arguments with existing VANETs technology, this paper deals the implementation of FANETs for intelligent traffic control system for the KSA to achieve several health, safety and environmental benefits. Rest of the paper is organized as we cover state-of-the-art in Section 2, proposed algorithm eACO in Section 3. Sections 4 and 5 deal with simulation results and conclusion, respectively.

2 | RELATED WORK

A lot of Routing protocols are already working with improvements of VANETs. Due to recently introduced of FANET; there is much research gap on the working of FANETs [16–20]. FANETs applications usually cover large area's, such as crop's monitoring, and over-surface water activities monitoring like floods and Tsunami. Therefore, moving nodes are needed. For FANETs, drone-base technology and aircraft are mostly used for this purpose. In [7]; the authors use design specific protocol for FANETs that considers the interest characteristics of FANETs; but path for destination sometime is not optimized and creates close-loop routing. Due to fast dynamic nature of nodes the link breakage issue is common in FANETs; for this, the authors purposed a technique in [8] to use combined directional and Omni-directional antenna to improve routing

TABLE 1 Summary of literature

Cataloguing	Related papers	Accomplishments	Confines
Ant Colony Optimization (ACO)	[4, 6–9]	Easily solve complex routing path problems, have interesting result for optimization of path finding, used as traditional benchmark techniques for complex large-scale networks. Overall, its metaheuristic approach to solving hard combinational optimization problem inspired with ant food searching strategy	For P2P networks, the load balancing does not be achieved, further shortest path finding mechanism does not control centralized, lack of hash table, overall, its unstructured method
Inverted/Improved Ant Colony Optimization Algorithm (IACO)	[7] and [13]	Successfully achieved different terms like load balancing, utilization of resources and waiting time calculations	In IACO, as the number of peers is increased, waiting time is increased unstraightforward manner. Due to this number of resources inside the network also increased in exponentially
Improved Co-evaluation Multi Population Ant Colony Optimization (ICMPACO)	[14] and [6]	Multiapplication strategy is used with co-evaluation factor for large complex networks, adjacent regions and pheromone released strategy by ACO is equally improved with pheromone diffusion function, overall results are satisfactory when compared with traditional ACO	The ACO and IACO algorithms are based on swarm intelligence logic and the ICMPACO algorithm use co-evaluation method. Therefore, the path finding and time complexity results of the ICMPACO algorithm are not much improved as compared to the results of the ACO and the IACO algorithms

path selection and try to minimize the Expected Connection Time (EMC) and utility function for path selection. Both these approaches do not cover the routing path which could still lead to closed-loop routing.

Some modifications of legacy self-organized networks for FANETs applications are presented in [10–13], the proposals are evaluated in terms of routing overheads and the communication models in FANETs. Muhammad et al. presented low-cost deployment of FANETs that can be used in future to improve its energy efficiency. Recently artificial Intelligence-based communication model that was developed using Ant Colony Optimization-based clustering and Grey Wolf Algorithm (GWA [14]) is used that focused on saving nodes and routing efficiency. As FANETs [21–24] are basically flying ad hoc therefore they can work in all possible directions, which grow problems also exponentially. Designing efficient routing protocols for FANETs is one of the critical task and still an open challenge [28]. The detailed Taxonomy of FANET based ACO algorithm are listed in Table 1 taken from [4, 6–9]. Some heads are defined to cover the taxonomy like operation strategy, mobility model drone as nodes deployment etc. FANETs are also used for water monitoring purposes in smart-ocean environment by using Unmanned Arial Vehicle (UAVs) therefore; by this reference, the other name of FANETs is considered to be Unmanned Aerial Systems (UAS) from [10, 15]. The next section covers the proposed algorithm that basically is the enhancement of ACO named as eACO. In [37, 38], authors proposed QoS prediction scheme using feature learning for mobile edge computing and provided a collaborative learning-based industrial IoT API recommendations. Optimizing the virtual machine allocation for cloud data centre is discussed in [39]. Offloading decision methods for multiple users with structured tasks in edge computing for smart cities is introduced in [40].

In comparison to traditional best route selection approaches, the ant colony optimization methodology has proven to be of greater dependability and performance. Several modified versions are introduced that directly explain the working and performance in smart city, for example, nature inspired techniques [29], AntHocNet for solving the routing problem in FANETs [30], application of bee colony algorithm [31]. The brief discussion and origin of ant colony optimization is described by some nature inspired technique for data dissemination framework for smart city and solved some routing related problem in FANETs [32, 33]. Some other hybrid bio-inspired approaches solved the different solutions smartly in smart cities, wireless sensor network, and vehicular ad hoc networks [34–36]. As the self-organized nature of all ad hoc networks and their combinations with swarm intelligence function used by the ant-colony, AntHocNet can easily handle mobility in smart cities. Thus, in our proposed eACO technique, ants simply used as drones with its pheromone values for self-driving which aims to improve road safety in smart city. The recent decade has seen tremendous advancements towards industry 4.0 revolutionary smart city technologies. Drone-based Internet of Things (IoTs) plays a vital role to transform urban public infrastructure and services including governance and transportation. It provides on-the-fly sensor-based data collection without requiring a physical infrastructure to cover larger geographical areas to support several applications that includes but not limited to disaster management, smart agriculture, smart cities, smart transportation, smart mobility, smart freight, smart waste management, smart housing, smart governance, smart surveillance, and security.

3 | PROPOSED ENHANCED ANT COLONY OPTIMIZATION SCHEME FOR SMART CITY REMOTE TRAFFIC MONITORING

In this section, we discuss the natural phenomena of nature inspired ant colony optimization technique. The eACO algorithm uses and updates the pheromone values. It is a natural phenomenon used by ants for searching the food and this method has a great tendency to solve the complex problem, such as finding the routing paths [28]. Naturally, ants select an optimized path for selecting, searching, and storing the food (i.e., route history is search by forwarding the route request (RREQ) and selection of path with minimum distance, used in our technique) [29]. One of the criteria for the optimum path is the shortest path which is opted based on the information provided by some random ants; thus, the ants may follow the process of pheromone. When we compare this technique in real time networking, the concept of swarm intelligence appears that is also inspired from the collective behaviour of animals, birds, insects, and other species [30–32]. For living, they make colonies of indirect local communication. Moreover, they also interact with other species colonies (like a Gateway). Thus, they use special mechanisms called "Pheromone" that have special chemical substance used to follow the other ants. Similarly, traversing is possible from vertex to vertex along with the edges of the constructed graph by using the pheromone values to create a solution progressively. Moreover, some other bio-inspired scenario also prompts the new ides of finding the smart solutions in smart city [30] and its collaboration in wireless sensor network, vehicular ad hoc network for different kind of problems is discussed in [31, 32] with its hybrid form [33]. Hence, inspired from it we exploited the eACO in FANETs where the drones behave like ants and uses the pheromone values to handle the problem of interest.

In the same way in networking especially wireless networks we used “Hello Packets” for terrestrial and “Beacon Manage” for underwater wireless sensor network. To optimization of path called shortest path; special behaviour is shown by some random ants that shows there is no kind of any restriction for ants to always follow the process of pheromone. In other words these ants basically follow the local minimum concept of searching of food from animal kingdom. The authors explained the best picture of ants’ colony food searching mechanisms by taking left or right moves. Some of the ants are observed to take immediate concept of local minima of optimization of food’s searching path. Therefore, by above theory we implement this concept of FANETs to cover the area of shortest path selection by dividing the area with different radius information for different purposed like reliable communication. As any smart city covers almost major million hector of land; therefore, the implementation idea of FANETs by enhancement of Ant Colony Optimization (ACO) algorithm is best suited for reliable communication security purposes [11]. Here it is needed to consider that pheromone itself has two important sub-sections knows as “Evaporations and concentration”.

3.1 | Evaporation and concentration

If path is followed or changes with trial of pheromone than the concentration of food searching is increased. That is why their path that is selected on the basis of higher concentration, has increased value of probability of more selected path. On contrary if ants dropped the threshold value of concentration level; it also decreases the pheromone level ultimately path drop which is called ‘pheromone evaporation’. The following equations best describe the relationship of selected or dropping routing path with respect to pheromone levels. We also deal there two sub-functions of enhancement of ACO with security. For example, if evaporation of pheromone and concentration of pheromone are linked together, we easily filter the mechanisms of FANET against types of different attacks as depicted from Equations (1) to (3). The pheromone has two important features known as evaporation and concentration which shows if a path is correctly followed or changed with trial of pheromone. If ants drop the threshold value of concentration level, it also decreases the pheromone level. Consequently, the path is dropped, and this phenomenon is called "pheromone evaporation". Equations (1)–(3) describe the relation of evaporation and concentration in the perspectives of ants’ quantity which is denoted as P1 and its connected phenomenon related to P1 is concentration and evaporation of ant’s quantity denoted as C_p and E_p, respectively.

$$P_l = C_p + E_p \tag{1}$$

$$C_p = P_l - E_p \tag{2}$$

$$E_p = P_l - C_p \tag{3}$$

where P_l shows that different quantity of ants (in FANETs, the ant’s quantity is dealt as number of nodes). Meanwhile both concentrations like pheromone like pheromone (C_p) and Evaporation (E_p) collectively produce and maintain the level of P_l. Furthermore, the selected path of C_p is dealt with below Equation (4).

$$C_p = \frac{n + MD(n)}{Pl - Ep} \tag{4}$$

Similarly, where ‘n’ denotes the total number of nodes that takes parts in networks topology. It further relates with MD (minimum distance) between nodes that calculated among the distance as minimize with help of $C_p + E_p$. Different pheromone levels describe the evaporation quantity against number of nodes. The evaporation of pheromone (that is the function of pheromone chemical substance) denoted with C_p is calculated as follows:

$$E_p = \frac{n + MD(n)}{Pl - Cp} \tag{5}$$

TABLE 2 Simulation settings

Simulation parameters	Values
Number of nodes	80–240
Coverage area	1600 × 1600 × 1600
Radius	500, 1000, 1500, 2000, 2500
Initial energy	800 j
Velocity	2000 m/s
Transmission range	200 m
Data packet size	50 B
Message size	52 B
Data rates	10 kbps

Similarly, if we evaluate the MD (n) further re-arranging the Equation (5) as Equation (6):

$$\text{MD}\,(n) = \frac{\text{Ep} \times \text{Pl} - \text{Cp}}{n} \qquad (6)$$

Usually, the number of nodes is decided according to nature (dynamically) and area (1600 × 1600 × 1600) dimensions) of the deployed network. In this regard the following Equation (7) helps

$$n = \frac{\text{Ep} \times (\text{Pl} - \text{Cp})}{\text{MD}} \qquad (7)$$

Collectively, to calculate both function; for example, pheromone in the form of C_p and E_p; the fundamental Equation (8) works:

$$P_l\,(C_p + E_p) = n \times \text{MD}\,(n) \qquad (8)$$

4 | ENHANCEMENT IN PHEROMONE STRATEGY

For enhancement in ACO to cope with FANETs; we have little bit modification in existing pheromone strategy, to solve complex formed path problems. For this, we improve pheromone

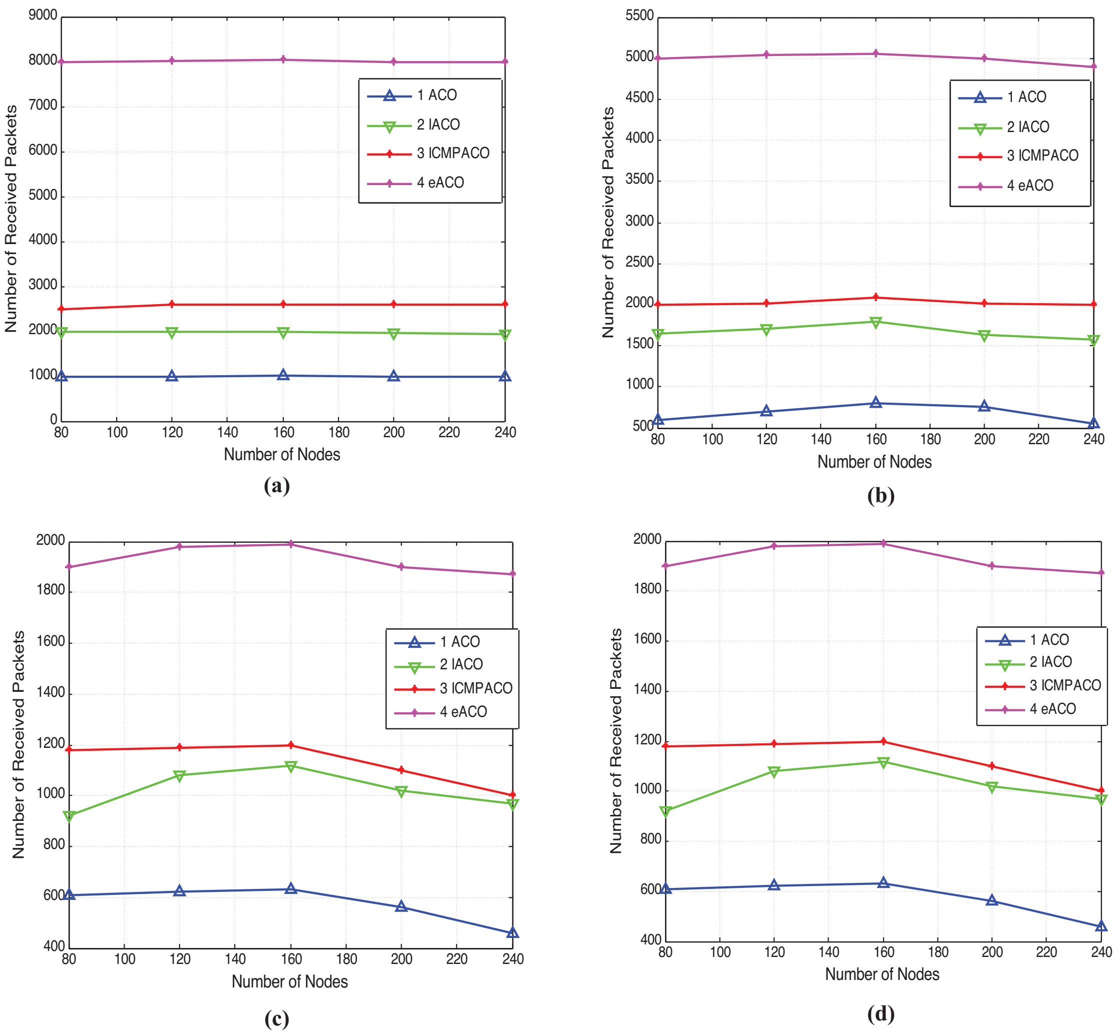

FIGURE 2 Number of received packet under various radius value, (a) when $r = 500$ m, (b) when $r = 1000$ m, (c) when $r = 1500$ m, (d) when $r = 2000$ m

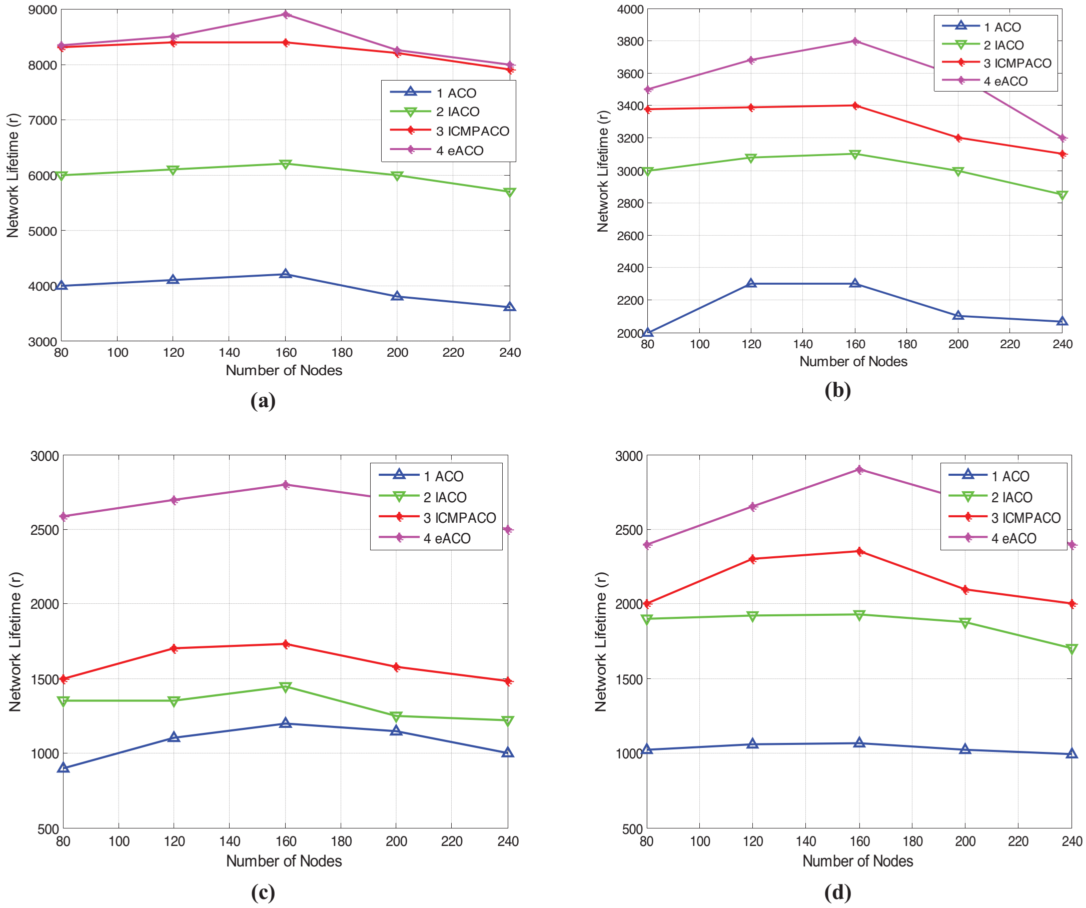

FIGURE 3 Network lifetime under various radius value. (a) Network lifetime when $r = 500$ m, (b) Network lifetime when $r = 500$ m, (c) Network lifetime when $r = 1500$ m, (d) Network lifetime when $r = 2000$ m

and introduce new variable difference pheromone mechanisms. We take the basic equation for these models from ACO-4 in which ant community score is calculated from ($n_1 + n_2$ ……. $+ n_{th}$) of a network such as:

$$\mathrm{CS} = \sum_{i=1}^{n} Score\ (Ci) \tag{9}$$

We update the Equation (9) with difference variable to count the CS. The difference community score is denoted by DCS. It further depends upon Pheromone Residue Factor (PRF) that calculates the initial value of pheromone when ants sniffing for food (like sending of nodes to determine its availability) and when ants successfully reached out the food source (like successfully sends the packets normally know as Packet Delivery Ratio PDR). Both these values are stored in PRF and reported in DCS. Then updating Equation (10):

$$\mathrm{DCS} = \sum_{i=1}^{n} Score\ (Ci \times PRF) \tag{10}$$

In next section, we proposed implementation idea of FANET inspired eACO algorithm in CPEC for sake of reliable air-to-air communication and security purposes with defined different radius areas from 500 m to 2500 m. Our simulation results show that eACO outperformed the above parameters with successfully longest lifetime and total number of received packets as compared to fair proportions techniques like ACO, IACO and ICMPACO, respectively. Nowadays, advanced transport and communication system play an important role in the economic development of any country. The modern communication system is also helpful for the internal and external trading system, economical use of natural resources, vast diversity in markets and the increase in industrial and agricultural products. In CPEC with the improvement in infrastructure, trade, energy sector we also need to create long-distance data communication links between both countries with FANET.

5 | EXPERIMENTAL RESULTS AND DISCUSSION

The simulation parameters and their respective values are given in Table 2. We compare the performance of the proposed scheme eACO compared with the IACO, ACMPACO, and with the conventional scheme ACO using the NS-2 simulator. The comparative analysis is performed against different performance metrics, such as throughput (number of received packets under different radius values), networks lifetime (under different number of nodes).

5.1 | Number of received packets

The total number of received packets (throughput) are measured under different number of nodes and radius information. Remote traffic monitoring is a major land covering application. Therefore, we set a long distance-based radius to deploy drone in FANETs.

5.2 | Network lifetime

For security reasons the network stability is highly demanded in remote monitoring. Therefore, network lifetime is opted as evaluation metric. It is also used to check the stability of networks under increased radius values. Furthermore, we compare our simulation results with the state-of-the-art techniques.

5.3 | Result discussions

In Figure 2a–d, it has been observed that under radius of 500 m about 8000 packets are successfully delivered with 3800 j of network lifetime under the proposed eACO scheme. However, for ICMPACO only 2500 packets are delivered. This is mainly because of optimization scheme opted in it which is travel salesman problem and pheromone updating strategy with co-evolution mechanisms. To divide the overall structure into several sub-problem structure is good but not optimized when the networks is large enough. To do this, long propagation delay and minimum throughput ratio come into existence. Similarly, behaviour shows that traditional ACO and IACO with increasing numbers of nodes receive packets not much exceeding than 3000. The proposed eACO algorithm gives better performance in terms of no. of received packet than the other compared algorithms. About 8000 packets were received that is significant result for remote monitoring applications under larger coverage area. In Figure 2b, when the networks radius is increased up to next further step say radius = 1000 m the same behaviour is seen, even ACO has shown least tendency to receive packets as compared to IACO and ICMPACO, respectively. Only 3000 packets difference is observed with one step higher from $r = 500$ to $r = 1000$ m.

Algorithm 1 starts from the random deployment of nodes. From line 1–3, each node is calculating the MD following the criteria of P1 given in Equations (1)–(3). From lines 4–7, the criterion of pheromone is initialized with its two-sub section C_p and E_p, respectively, with its updating mechanism and nodes are finding the path and its relevant information by receiving update values. Differences Community Score (DCS) is calculated through line 8–9 that further depends on Pheromone Residue Factor (PRF) that calculates the initial value of pheromone when ants sniffing for food (e.g., sending of nodes to determine its availability) and when ants successfully reached out the food source (e.g., successfully sends the packets normally know as Packet Delivery Ratio PDR). From line 10–17, if the DCS does not decide the PRF it again takes another iteration for updating mechanism of evaporation and MD values for nodes. From line 18–22, the coverage procedure is started to cover all the neighbours for path selection.

Proposed Algorithm 1: FANET-inspired eACO for remote traffic monitoring

1. **START**
2. **For** deploy networks of nodes (n) **do**
3. **Set** Each MD (n) w.r.to P_l
4. **Initialize** the **Pheromone Level** (P_l) with its two sub-sections
5. **Call** concentration pheromone action (C_p)
6. **Call** evaporation pheromone action (E_p)
7. **Update** $P_l = C_p + E_p$
8.   **IF** Nodes (n) do not find Path
    i. Set MD (n) and P_l
    ii. **Call** C_p
9.   **Else** Calculate DCS = $\sum_{i=1}^{n} Score\ (Ci \times PRF)$
10.   **Set** MD (n)
11.   **If** Nodes update DCS **do**
12.   **Update** $P_l = C_p + E_p$ **then**
13.   **Else if** $C_p > E_p$
14.   **Call** $C_p = \frac{n+MD(n)}{Pl - Ep}$
15.   **Else if** $C_p < E_p$
16.   **Call** $E_p = \frac{n+MD(n)}{Pl - Cp}$
17.   **End if**
18.   **End if**
19.   **End If**
20. **END IF**
21.   **Until for** all neighbouring nodes
22.   **Until repeat** with stopping criteria
23. **END**

For network lifetime the eACO performs better than the other schemes, for example eACO achieves 3800 s of life. However, the ACO and IACO both tend to decrease the overall network lifetime up to 3000–3200 s as its clear from Figure 3(a). The improved version of ACO is IACO that use local swarm intelligence with local optimal solution is directly based upon location of some environment condition, such as dimensions, variants, and location co-ordinates etc. Therefore, when $r = 1000$ is increased for $r = 1500$ and $r = 2000$ the ACO have only 600 packets received while, 400 and 500 increments of packets are observed in IACO and ICMPACO, respectively. As same as network lifetime is decreased when the radius information is increased as shown in Figure 3(a) and 3(b) for number of received packets and Figure 3(c) and 3(d) for network lifetime, respectively.

The radius gradually increased but still our proposed technique performs better as 700 and 1600 (when $r = 2000$) packets are successfully delivered as shown in Figure 3(d). The least performance is shown by traditional ACO with only 420 packets are delivered with 120 number of nodes. Furthermore, the ICMPACO and IACO comparatively perform better as compared to the ACO. For example, only 100 packets are increased with radius of 2500 and suddenly decreased with rapidly increased iterations. Similarly form Figure 3(d) it has been noted that with $r = 2000$ and 1500, 1200, and 900 for the ACO, the IACO, and the ICMPACO, respectively. In Figure 3(d), the fluctuation behaviour is observed with all routing protocols like the ACO, the IACO, the ICMPACO, and the proposed eACO. Packets transmission is stopped with IACO when the number of nodes reaches at the middle of the network. Increasing trend is observed for ICMPACO performance under 500 nodes but as number of nodes increased beyond 500, performance decreased significantly. Similarly, the decreasing trend is also observed in eACO performance when no. of nodes crossed 650.

6 | CONCLUSION

Drone-based FANETs have emerged and gained tremendous attention as suitable technology towards industry 4.0 enabled smart cities traffic management systems. The implementation of drone-based FANETs have several advantages in remote traffic monitoring, including free air-to-air drone assisted communication zone and smart surveillance and security. The drone-based FANETs can be deployed within minutes without requiring physical infrastructure, making it suitable for mission critical applications in several areas of interests. In this paper, we proposed a reliable remote traffic monitoring scheme using enhanced ant colony optimization technique for self-organized drone based FANETs. The proposed scheme addressed several challenges including coverage of larger geographical area and data communication links between FANETs nodes. We presented experiment results to compare the proposed technique against different network lifetime and number of received packets. The presented results show that our proposed techniques perform better compared to other state-of-the-art techniques.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest to report regarding the present study.

DATA AVAILABILITY STATEMENT

Data available on request due to privacy/ethical restrictions.

ORCID

Amjad Ali https://orcid.org/0000-0002-5346-1017

REFERENCES

1. Draz, U., Ali, T., Yasin, S.: Comparative analysis of different light intensities for implementation idea of Li-Fi for CPEC. In: 2019 International Conference on Frontiers of Information Technology (FIT). Islamabad, Pakistan, pp. 310–3105 (2019)
2. Solanki, D.: Optical Wireless Communication. In: Proceedings of the 24th Annual International Conference on Mobile Computing and Networking. New Delhi, pp. 858–860 (2018)
3. Ali, L., Mi, J., Shah, M., Shah, S.J., BiBi, K.: The potential socio-economic impact of china Pakistan economic corridor. Asian Dev. Policy Rev. 5(4), 191–198 (2017)
4. Parpinelli, R.S., Lopes, H.S., Freitas, A.A.: Data mining with an ant colony optimization algorithm. IEEE Trans. Evol. Comput. 6(4), 321–332 (2002)
5. Draz, U., Ali, T., Yasin, S., Shaf, A., Shakoor, A., Waqas, U.: LI-FI become IOE: A novel architecture for LED. EAI Endorsed Trans. Scalable Inf. Syst. 5(16), e8 (2018)
6. Oubbati, O.S., Lakas, A., Zhou, F., Güneş, M., Yagoubi, M.B.: A survey on position-based routing protocols for flying ad hoc networks (FANETs). Veh. Commun. 10, 29–56 (2017)
7. Khan, M.A., Safi, A., Qureshi, I.M., Khan, I.U.: Flying ad-hoc networks (FANETs): A review of communication architectures, and routing protocols. In: 2017 First International Conference on Latest trends in Electrical Engineering and Computing Technologies (INTELLECT). Karachi, Pakistan, pp. 1–9 (2017)
8. Rosati, S., Krużelecki, K., Heitz, G., Floreano, D., Rimoldi, B.: Dynamic routing for flying ad hoc networks. IEEE Trans. Veh. Technol. 65(3), 1690–1700 (2015)
9. Bujari, A., Palazzi, C.E., Ronzani, D.: A comparison of stateless position-based packet routing algorithms for FANETs. IEEE Trans. Mob. Comput. 17(11), 2468–2482 (2018)
10. Arafat, M.Y., Moh, S.: A survey on cluster-based routing protocols for unmanned aerial vehicle networks. IEEE Access 7, 498–516 (2018)
11. Khelifi, F., Bradai, A., Singh, K., Atri, M.: Localization and energy-efficient data routing for unmanned aerial vehicles: Fuzzy-logic-based approach. IEEE Commun. Mag. 56(4), 129–133 (2018)
12. Khan, M.A., Khan, I.U., Safi, A., Quershi, I.M.: Dynamic routing in flying ad-hoc networks using topology-based routing protocols. Drones 2(3), 27 (2018)
13. Deng, W., Xu, J., Zhao, H.: An improved ant colony optimization algorithm based on hybrid strategies for scheduling problem. IEEE Access 7, 20281–20292 (2019)
14. Sani, N.S., Manthouri, M., Farivar, F.: A multi-objective ant colony optimization algorithm for community detection in complex networks. J. Ambient Intell. Hum. Comput. 11(1), 5–21 (2020)
15. Asghari, S., Navimipour, N.J.: Resource discovery in the peer to peer networks using an inverted ant colony optimization algorithm. Peer-to-Peer Networking Appl. 12(1), 129–142 (2019)
16. Bekmezci, I., Sen, I., Erkalkan, E.: Flying ad hoc networks (FANET) test bed implementation. In: 2015 7th International Conference on Recent Advances in Space Technologies (RAST). Istanbul, Turkey, pp. 665–668 (2015)
17. Chriki, A., Touati, H., Snoussi, H., Kamoun, F.: FANET: Communication, mobility models and security issues. Comput. Networks 163, 106877 (2019)
18. Khan, M.A., Qureshi, I.M., Khanzada, F.: A hybrid communication scheme for efficient and low-cost deployment of future flying ad-hoc network (FANET). Drones 3(1), 16 (2019)
19. Khan, I.U., Qureshi, I.M., Aziz, M.A., Cheema, T.A., Shah, S.B.H.: Smart IoT control-based nature inspired energy efficient routing protocol for flying ad hoc network (FANET). IEEE Access 8, 56371–56378 (2020)
20. Nadeem, A., Alghamdi, T., Yawar, A., Mehmood, A., Siddiqui, M.S.: A review and classification of flying Ad-Hoc network (FANET) routing strategies. J. Basic Appl. Sci. Res. 8(3), 1–8 (2018)
21. Palan, K., Sharma, P.: Fanet communication protocols: A survey. Int. J. Comput. Sci.Commun. 7, 219–223 (2015)
22. Litvinov, G.A., Leonov, A.V., Korneev, D.A.: Applying static mobility model in relaying network organization in mini-uavs based fanet. In: 2018 Systems of Signal Synchronization, Generating and Processing in Telecommunications (SYNCHROINFO). Belarus, pp. 1–7 (2018)
23. Alam, S., Yin, Z., Ali, A., Ali, S., Noor, A., Jan, N.: A comprehensive study of project risks in road transportation networks under CPEC. Int. J. Financ. Stud. 7(3), 41 (2019)

24. Srivastava, A., Prakash, J.: Future FANET with application and enabling techniques: Anatomization and sustainability issues. Comput. Sci. Rev. 39, 100359 (2021)
25. He, C., Yu, B.: Simulation of cooperative positioning flight ad-hoc network. J. Phys.: Conf. Ser. 1813(1), 012009 (2021)
26. Ali, H., Islam, S.U., Song, H., Munir, K.: A performance-aware routing mechanism for flying ad hoc networks. Trans. Emerging Telecommun. Technol. 32(1), e4192 (2021)
27. Vijayakumar, V., Mariyappan, K., Sivakumar, N., Ganesh, S.: A performance analysis study of MANETs routing protocols in FANETs networks environments. Eur. J. Mol. Clin. Med. 7(10), 3007–3020 (2021)
28. Khan, I.U., Qureshi, I.M., Aziz, M.A., Cheema, T.A., Shah, S.: Smart IoT control-based nature inspired energy efficient routing protocol for flying ad hoc network (FANET). IEEE Access 8, 56371–56378 (2020)
29. Leonov, A.V., et al.: The ant-colony-based routing algorithm AntHocNet for solving the routing problem in FANET. Telecommun. Control Syst. 10(1), 7–26 (2017)
30. Leonov, A.V., et al.: Application of bee colony algorithm for FANET routing. In: Proceedings of IEEE 17th International Conference of Young Specialists on Micro/Nanotechnologies and Electron Devices (EDM). Erlagol, Altai, pp. 124–132 (2016)
31. Qureshi, K.N., Ahmad, A., Piccialli, F., Casolla, G., Jeon, G.: Nature-inspired algorithm-based secure data dissemination framework for smart city networks. Neural Comput. Appl. 33, 10637–10656 (2020)
32. Maistrenko, V.A., Alexey, L.V., Danil, V.A.: Experimental estimate of using the ant colony optimization algorithm to solve the routing problem in FANET. In: IEEE International Siberian Conference on Control and Communications (SIBCON). Moscow, pp. 1–10 (2016)
33. Bitam, S., Mellouk, A., Zeadally, S.: Bio-inspired routing algorithms survey for vehicular ad hoc networks. IEEE Commun. Surv. Tutorials 17(2), 843–867 (2014)
34. Sharmin, A., Anwar, F., Motakabber, S.M.A.: A novel bio-inspired routing algorithm based on ACO for WSNs. Bull. Electr. Eng. Inf. 8(2), 718–726 (2019)
35. Azzoug, Y., Boukra, A.: Bio-inspired VANET routing optimization: An overview. Artif. Intell. Rev. 54(2), 1005–1062 (2021)
36. Zhang, Y., Zhao, H., Cao, Y., Liu, Q., Shen, Z., Wang, J., Hu, M.: A hybrid ant colony and cuckoo search algorithm for route optimization of Heating engineering. Energies 11(10), 26–75 (2018)
37. Yuyu, Y., Zengxu, C., Yueshen, X., Honghao, G., Rui, L., Zhida, M.: QoS Prediction for Service Recommendation with Features Learning in Mobile Edge Computing Environment. IEEE Trans. Cognit. Commun. Networking 6(4), 1136–1145 (2020)
38. Honghao, G., Xi, Q., Ramon, J.-.D.B., Hussain, W., Yueshen, X., Yuyu, Y.: Collaborative learning-based industrial IoT API recommendation for software-defined devices: The implicit knowledge discovery perspective. IEEE Trans. Emerging Top. Comput. Intell. (2020). https://doi.org/10.1109/TETCI.2020.3023155
39. Yuzhe, H., Huahu, X., Honghao, G., Hussain, W.: SSUR: An approach to optimizing virtual machine allocation strategy based on user requirements for cloud data center. IEEE Trans. Green Commun. Networking 5(2), 670–681 (2021). https://doi.org/10.1109/TGCN.2021.3067374
40. Li, K., Tao, G., Shuyin, O.-Y., Honghao, G., Shuiguang, D.: Offloading decision methods for multiple users with structured tasks in edge computing for smart cities. Future Gener. Comput. Syst. 105, 717–729 (2020). https://doi.org/10.1016/j.future.2019.12.039

How to cite this article: Siddiqi, M.H., Draz, U., Ali, A., Iqbal, M., Alruwaili, M., Alhwaiti, Y., Alanazi, S.: FANET: Smart city mobility off to a flying start with self-organized drone-based networks. IET Commun. 1–9 (2021). https://doi.org/10.1049/cmu2.12291