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Delay tolerant data forwarding topology aware routing protocol for multi-UAVs empowered VANETs

Mujahid Hamood Hilal Alzakwani[1], Shaima Miqdad Mohamed Najeeb[2], Mohammed Ahmed Jubair[3], Zakaria N. M. Alqattan[4], Rabei Raad Ali[5*]

[1]*Centre for Language and Foundation Studies, A'Sharqiyah University (ASU), 400 Ibra, Oman.*
[2,4,5]*Technical Engineering College for Computer and AI, Northern Technical University, 41000, Mosul, Iraq.*
[3]*Department of Computer Technical Engineering, Al-Maarif University College, Al-Ramadi, 31001, Iraq*

Corresponding author: Rabei Raad Ali (*Email: rabei@ntu.edu.iq*)

Abstract

Vehicular Ad hoc Networks (VANETs) are recognized for their special properties, such as dynamically varying topology, high speed, unpredictable mobility, and recurrent link failures. Unmanned Aerial Vehicles (UAVs) have recently been proposed in VANETs to protect the network from ground-level obstacles and provide instant communication among the vehicles. Even though many earlier studies exist on UAVs in VANETs to perform effective communication and create stable communication links between the source and the destination, enhancements are needed. To address this, the paper presents the Delay Tolerant and Data Forwarding Topology Aware Routing Protocol (DTDF-TARP) for Multi-UAV empowered VANETs. This protocol is segmented into three sections: topology-aware routing protocol, delay tolerant model, and data forwarding process. Through the topology-aware routing protocol, routing disconnections are identified and neglected, mobility prediction is performed through a delay tolerant model, and the data forwarding process conducts the final verification for the selected paths. The proposed DTDF-TARP protocol is implemented in OMNET++, where the parameters used for measurements and analysis are Energy Efficiency (EE), Packet Delivery Rate (PDR), End-To-End (E2E) delay, and Routing Overhead (RO). The outcomes of the proposed DTDF-TARP protocol are compared with earlier works, such as CLO-MFG and RDJ-EDC methods.

Keywords: Ad hoc network, Delay-tolerant model, DTDF-TARP protocol, Greedy forwarding routing, Routing protocol, UAVs, VANETs.

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Transparency: The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.
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1. Introduction

An ad hoc network is a wireless network that enables wireless client devices in the same physical location to join easily without the need for an infrastructure component, like a base station or access point [1-7]. Nonetheless, unmanned aerial vehicles, or drones, have revolutionized several industries and uses and are now a crucial component of contemporary technology. The use of UAVs to strengthen Vehicular Ad-Hoc Networks is one such application that has attracted a lot of interest lately [8]. Additionally, VANETs are a kind of mobile ad hoc network in which automobiles use wireless technology to connect with infrastructure (V2I) and with one another (V2V). Real-time route planning, collision avoidance, and traffic monitoring are just a few of the many services that these networks are expected to offer. The possibility of improving VANETs' capabilities through the integration of UAVs could open new applications and solve current issues. The possibility of improving VANETs' capabilities through the integration of UAVs could open new applications and solve current issues. Furthermore, the potential of UAVs to offer dynamic and adaptable communication infrastructure is one of the main benefits of utilizing them in VANETs [9].

To accomplish activities that are usually too complicated or large for a single UAV to manage, as well as to achieve efficient performance in intelligent transmission systems, VANETs are integrated with UAVs, which refers to the coordinated usage of several UAVs. VANETs equipped with UAVs are widely utilized in several real-time applications, including disaster management, agriculture, and industry. To address real-time VANET issues including link failure and frequent topology changes, many UAVs are built into the network [10-15]. Transmissions between vehicles, vehicles, and UAVs, and UAVs and UAVs are the three forms of network communication models carried out in this type. Path prediction becomes extremely complex in this network because of its great mobility, and it is still an open study topic [16-18]. During periods of frequent topology changes, routing is essential to network management. Adhoc On-Demand Distance Vector (AODV), Dynamic Source Routing (DSR), Optimized Link State Routing (OLSR), Greedy Forwarding Protocol (GFP), and Predictive Optimized Link State Routing (P-OLSR) are some of the routing protocols that were previously utilized in UAV-based VANET networks [19, 20].

There are issues with all these protocols, including poor communication, data loss, and link failure, among others. Therefore, to obtain effective performance in VANETs, the routing protocol in UAV-based VANET networks must be improved. This paper describes the research contribution and proposes a delay-tolerant data forwarding topology-aware routing system. Unmanned aerial vehicles (UAVs) are included in VANETs to enhance communication efficiency. A novel routing protocol, known as a delay tolerant data forwarding topology aware routing protocol, is presented to create stable communication in UAV-enabled VANETs. This protocol is primarily utilized to get over the previously mentioned problems. This routing protocol is based on a data forwarding mechanism, delay tolerance model, and topology-aware routing protocol. This procedure uses data forwarding for efficient routing, mobility prediction, and validation. Energy Efficiency (EE), Packet Delivery Rate (PDR), End-To-End (E2E) delay, and Routing Overhead (RO) are some of the metrics used to gauge performance. A list of the forthcoming sections is provided.

1.1 Related Work

In Wang, et al. [21] A GPSR routing protocol was proposed by the authors using a flooded path-finding stage and greedy routing stage. The PSO approach has resolved the suboptimal choice problem. This approach causes communication overhead and delays. The authors of Song, et al. [22] suggested a novel routing protocol for swarm UAV networks. The proposed protocol is based on random network coding (RNC). The first protocol was created using a unique RNC, and if a UAV network was in place, the original data was decrypted. The efficiency is increased by the second routing protocol, which requires a fresh generation of UAVs for every transmission; this could result in a rise in routing overhead during communication.

To find the connection time between nodes, the inventors of Du, et al. [23] created a probabilistic routing system. This protocol considers the dependability and efficiency of connected nodes. According to the data, the suggested protocol lowers latency during communication but falls short of achieving a high delivery rate. The Skeleton-based Swarm Routing (SSR) protocol was introduced by the authors in Saravanan and Thillaiarasu [24]. The first of SSR's three modules, geometric addressing, allocates geometric coordinates to each node according to SSR. Second, the shortest path is determined using a leaf-like routing pipe. Despite distributing packets throughout the network to achieve load-balancing, the third intelligent low-complexity learning model is unable to produce improved efficiency during data transmission.

A more realistic simulation of a UAV communication network was described by the authors in Tan, et al. [25]. This suggested work is implemented in the OPNET tool and contrasted with other routing protocols, including DSR, GPR, and AODV. Although this approach produces mediocre results, it needs to be improved to manage the high-speed routing of VANETs. The inventors of Peng, et al. [26] created the new network topology-aware routing (FNTAR) protocol. The new topology uses future location data to determine the best route choices. Depending on the future network structure, the suggested protocol transfers the messages to the next node, after which UAVs transmit the message more quickly to its target. Although this approach reduces delays, it does not increase delivery rates.

An effective trajectory-based multicast routing strategy for UAV networks was put out by the authors in Peng, et al. [27]. UAVs calculate the trajectory data that TBM has used. In UAV, the priority metric is utilized to determine the destination node. The suggested approach can take timeliness and stability into account when creating a priority encounter graph. The authors of Du, et al. [28] introduced a novel routing protocol that uses the connection time between mobile nodes to compute each encounter while taking encounter probability into account. The suggested system can precisely locate the stable communication link and choose the route based on persistent connection time.

To minimize the energy drain, the authors of Tong, et al. [29] successfully suggested a novel adaptive hello interval system depending on the volume of the permitted airspace, the number of UAVs, and the speed of the UAVs. The proposed method defined the UAV's distance before transmitting the message. During communication, this method results in a moderate routing overhead. Using a novel mean field game methodology and a cross-layer optimization strategy, the authors of Mokhtari, et al. [30] created multi-hop communication networks for UAVs. This approach uses energy efficiently and transmits data in the best possible way, which lowers communication overhead and delay, but it falls short of achieving maximum density.

A NOMA proposed uses a Poisson stochastic process and a fast global K-means method by Du, et al. [31] as an efficient UAV-based vehicular technology to reduce power consumption and boost delivery rate. However, this approach resulted in communication overhead. Furthermore, in highway settings, where the UAVs efficiently pass data packets between automobiles, the work in Qasim, et al. [32] tackles the challenges of utilizing VANETs in UAVs. tackling emergencies where there aren't enough fixed infrastructures accessible. The main objective of the work is to minimize power consumption and maximize the overall data rate under specific situations to decrease latency and increase energy efficiency [33].

1.2. Proposed DTDF-TARP Protocol

The proposed Delay Tolerant Data Forwarding Topology Aware Routing Protocol (DTDF-TARP) is mainly to develop multi-UAVs empowered VANETs with effective communication. DTDF-TARP is subdivided into two segments. They are (i) topology aware routing protocol, (ii) delay tolerant model and (iii) data forwarding process. The structure of multi-UAVs empowered VANETs are shown in Figure 1.

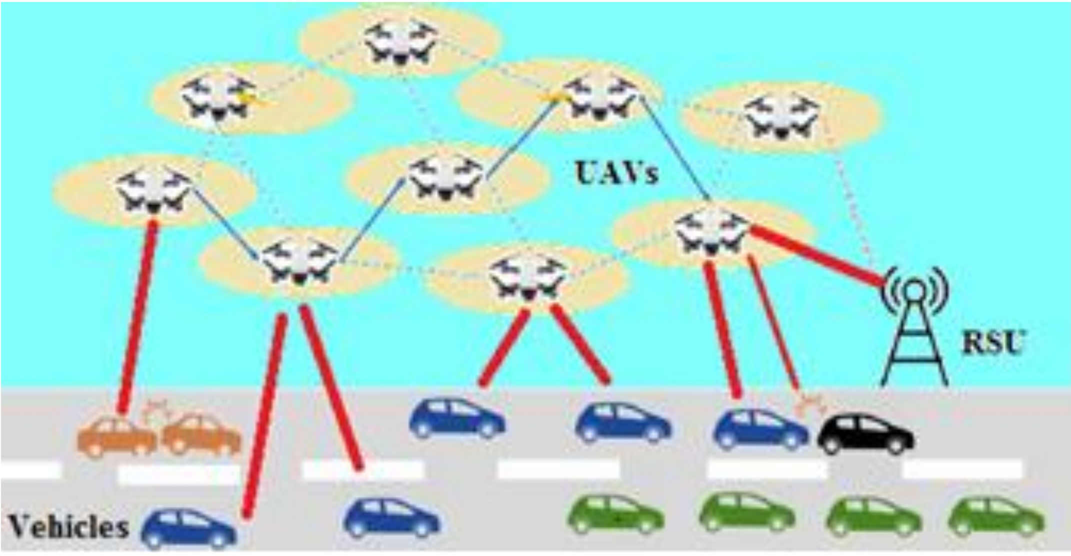

Figure 1.
Multi-UAVs Empowered VANETs.

1.3. Topology Aware Routing Protocol

To understand the mobility conditions of VANETs, this topology-aware routing is obtained, which is a combination of the Greedy Forwarding Routing (GFR) and the Ad hoc On-Demand Routing Protocol (AODV). In general, UAVs are equipped with positioning devices; using that device, they transmit messages in a flooding manner to understand their neighbors as well as to update their routing tables. Once they find their neighbors, data transmission is initiated, and at that time, GFR routing is performed to communicate the data to the destination UAV using the greedy policy. The transmission is preceded using the routing table of the neighbors. According to the current scenario, two intermediate hops are employed to transfer the data from the source to the destination. If any intermediate nodes fail to maintain the line of sight to the destination, the AODV routing protocol's route discovery process continues, which helps avoid disconnection during data transmission. The principle behind the AODV routing protocol is neighbor identification through HELLO messages in a flooding manner. Then the source transmits the route request; once the destination receives the broadcast, it replies to the source. In case any link failure occurs, the route error is sent to the source. According to the process, route discovery is performed, ensuring that the data can reach the destination with the least number of hops. This principle is followed during the occurrence of a routing hole in the data transmission path. The routing hole occurs between any two intermediates; at that time, the source hop receives the GFR packets and then broadcasts the RREQ to the next intermediate, which is the shortest distance with the line of sight to the destination. Once it receives the reply from the next neighbor, it transmits the packets to it.

1.4. Delay Tolerant Model

The major drawback in VANETs-based networks is the frequently changing topology. For example, if the current data path is "S→A→B→C→D" where S is the source, D is the target and A, B, and C are the transitional nodes. Once the data is transmitted from the source to vehicle A the next vehicle moves away from the track. At the time, a delay occurs in finding the next best hop which is present at the line of sight to the destination. To overcome such drawbacks multiple UAVs are used, and they consist of larger transmission ranges so that they can be able to create flexible communication among vehicles. As well as improving the vehicle communication encounter connection time factor is measured between the vehicles to select the best hop nodes using the prediction method. The expression for the calculation of the encounter connection time factor $ECT_{(h,d)}$ between the hop (h) to the destination (d) and it is shown in the Equation 1.

$$ECT_{(h,d)} = \frac{\sum_{i=1}^{n} T_{hd}(L) * T_{hd}(E)}{T_0} \quad (1)$$

Based on Equation 1 the terms T_{hd} (L) implies the time taken for the connection of hop to the destination T_{hd} (E) energy consumed for the data transmission in the path and T_0 implies the fixed time for the transmission. Approximately the $ECT_{(h,d)}$ lies between (0, 1), and using this calculation the mobility prediction is performed, and it is expressed in Equation 2.

$$MP_{(h,d)} = \left(\alpha * P_{(h,d)}\right) + \left(\beta * ECT_{(h,d)}\right) \quad (2)$$

Based on Equation 2 the term implies the general probabilistic function of the hop to the destination and the terms α and β are the experimental constants. Through this mobility prediction model, the network delay is reduced, and a stable path is established between the source and the destination.

1.5. Data Forwarding Process

In the proposed DTDF-TARP method the effective data forwarding process is used to decrease the routing overhead occurrence through communication. At the time of making routing decisions initially, the UAVs analyze the location of the vehicles and other UAVs as well as the path consideration for the vehicles to reach their destination optimally [33]. At the time of data transmission vehicles to UAVs and UAVs to UAVs communication is handled. The optimal path is selected by choosing the best intermediate hop using the mobility prediction process and it is verified in this section using Dijkstra's algorithm path verification is performed. Once after receiving the data from the vehicle the UAVs search for the destination. In case the vehicle is not present in the coverage area of the UAVs the Inter UAVs communication takes place to transfer the data to the destination. Hence the UAVs maintain high bandwidth and coverage area they can be able to transmit a huge number of messages at each instant of time with low delay and overhead in the network. The workflow of the DTDF-TARP method is illustrated in Figure 2.

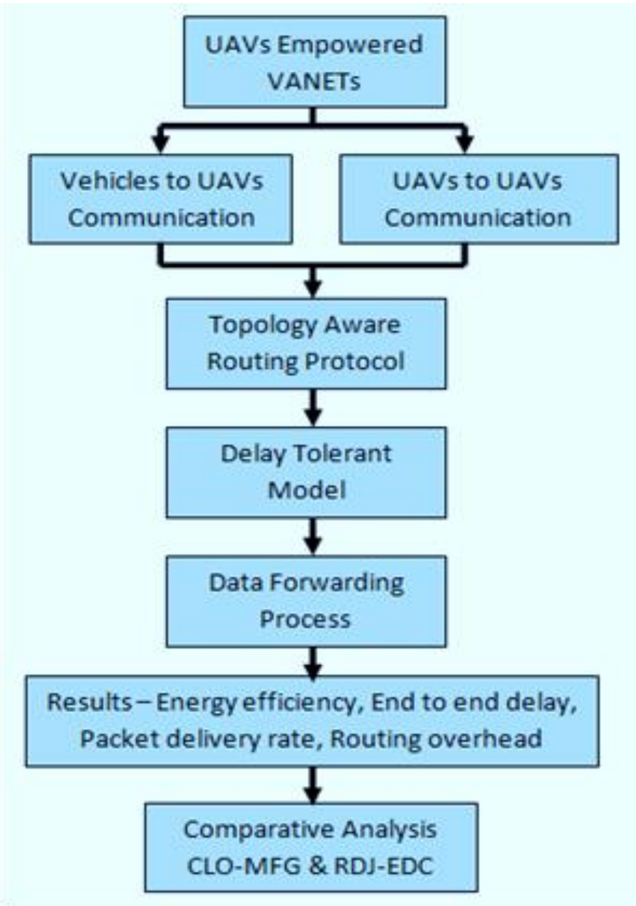

Figure 2.
Workflow of the proposed DTDF-TARP method.

1.6. Experiments and Evaluation

The DTDF-TARP method is implemented in the UAVs-empowered VANETs, effective performance is achieved in terms of EE, PDR, E2E, and RO to achieve virtual analysis those calculated results are compared with the CLO-MFG [29] and RDJ-EDC [28] techniques. In general, energy is the only parameter that is considered to transfer data in VANETs. To improve that in the proposed DTDF-TARP method delay tolerant data forwarding technique to introduced in the topology-aware routing protocol. The software used to perform simulation experimentation is OMNET++. Table 1 shows the setting of the simulation.

Table 1.
Simulation setting.

Parameters	**Values**
Running time	200 ms
Receiving power	0.050 Joules
Area	2000m*2000m
Vehicles number	1000
No of UAVs	5 UAVs
Vehicle transmission range	150m
UAVs transmission range	500m
Network bandwidth	1 Mbps
Transmission power	0.500 Joules

1.7. Energy Efficiency (EE)

Figure 3 shows the outcomes of the simulation experimentation of methods such as CLO-MFG, RDJ-EDC, and the DTDF-TARP method. During simulation, each UAV can cover around 250 to 300 vehicles which are connected in the wireless medium. The UAVs are dynamic, and the vehicles are also in movement. So, it is essential to achieve high EE during communication. For that purpose, delay tolerant model and data forwarding technique in UAVs empowered VANETs. Based on Figure 1, it is declared that the EE of the DTDF-TARP method is higher than the CLO-MFG and RDJ-EDC methods.

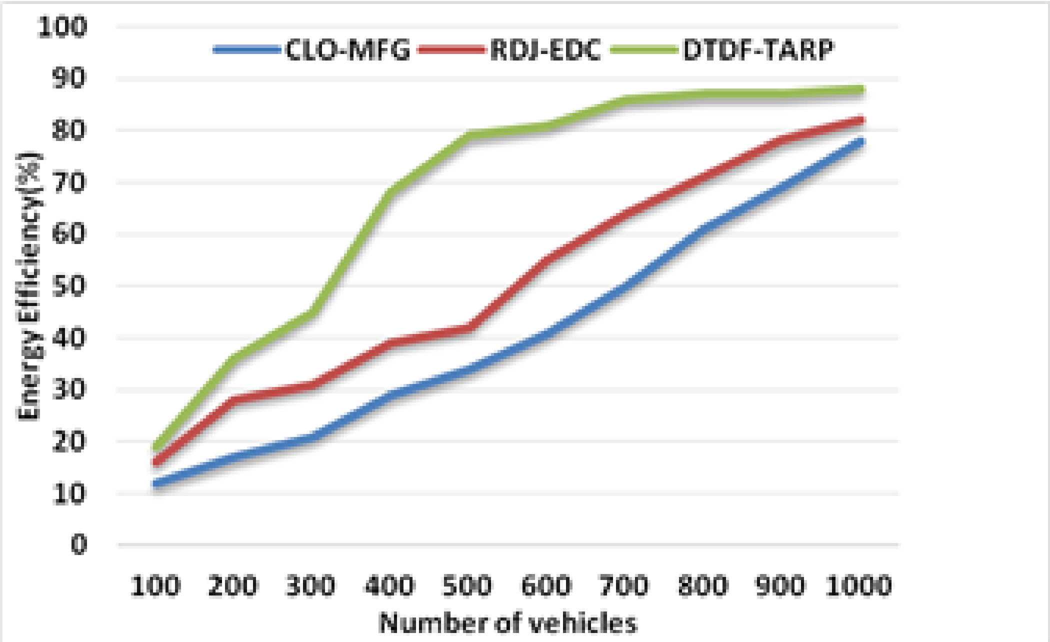

Figure 3.
EE calculation.

1.8. Packet Delivery Ratio (PDR)

To verify the PDR performance of vehicles and UAVs in the DTDF-TARP method simulation is performed. the result of PDR is compared with techniques like CLO-MFG, and RDJ-EDC. Due to the introduction of delay tolerance and data forwarding in the topology-aware routing protocol of VANETs and UAVs, the data forwarding delay is reduced as well as maximum of the packets are received by the destination from the source. Based on Figure 4, it is observed that the DTDF-TARP method gets performance when associated with the previous method in terms of PDR.

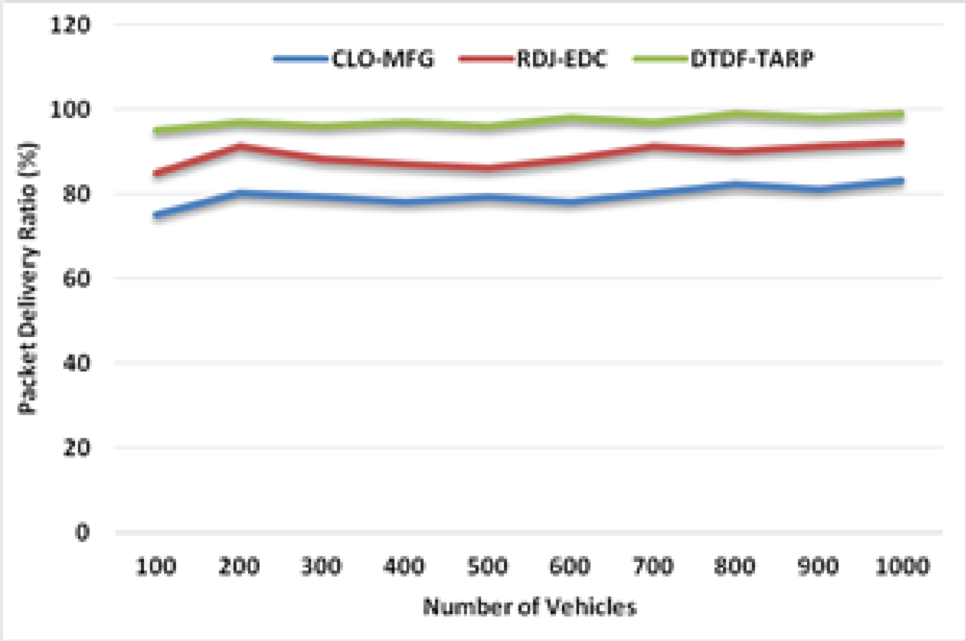

Figure 4.
PDR Calculation.

1.9. End-to-End (E2E) Delay

Figure 5 displays the E2E outcome of the CLO-MFG, RDJ-EDC, and the DTDF-TARP methods. The main aim of the DTDF-TARP is to reduce the delay during the process of communication in the network. It is observed that the E2E values of the DTDF-TARP method are lower than the CLO-MFG, and RDJ-EDC methods. In the delay tolerant model, the mobility prediction is performed to reduce the E2E that occurs during link failures.

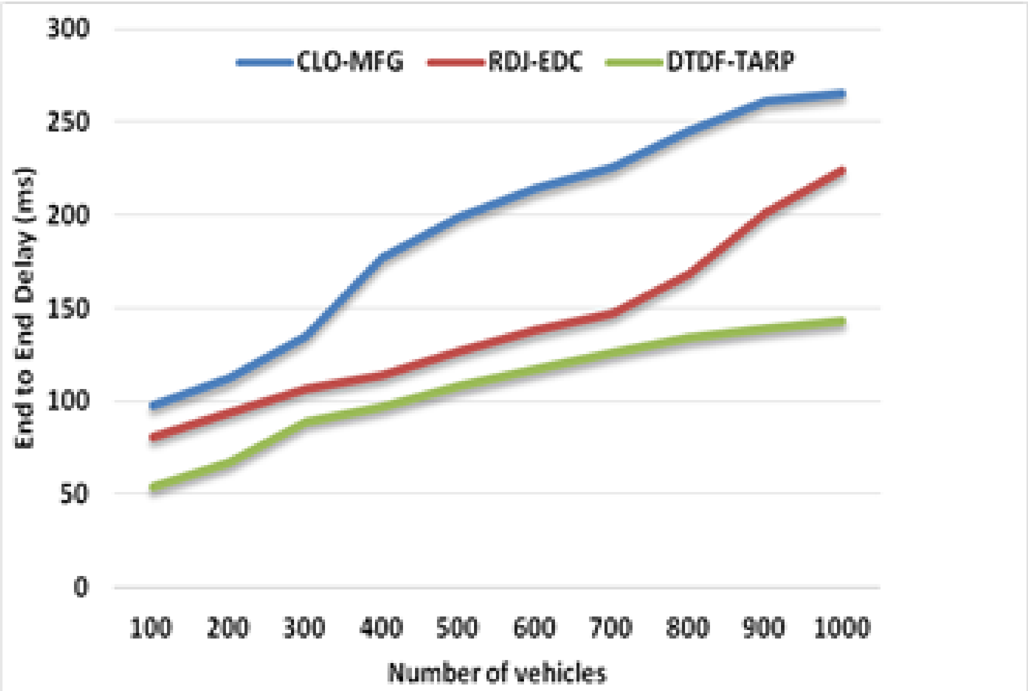

Figure 5.
E2E Calculation.

1.10. Routing Overhead (RO)

Figure 6 presents the RO of the CLO-MFG method, RDJ-EDC method, and DTDF-TARP. As a result of using the effective data forwarding model, the RO of the network is reduced which helps to achieve effective performance in UAVs empowered VANETs. Based on Figure 6, it is understood that the RO of the DTDF-TARP is lower than the CLO-MFG, and RDJ-EDC methods. Both the mobility prediction and data forwarding process present in the proposed DTDF-TARP concentrated on reducing the RO in the network.

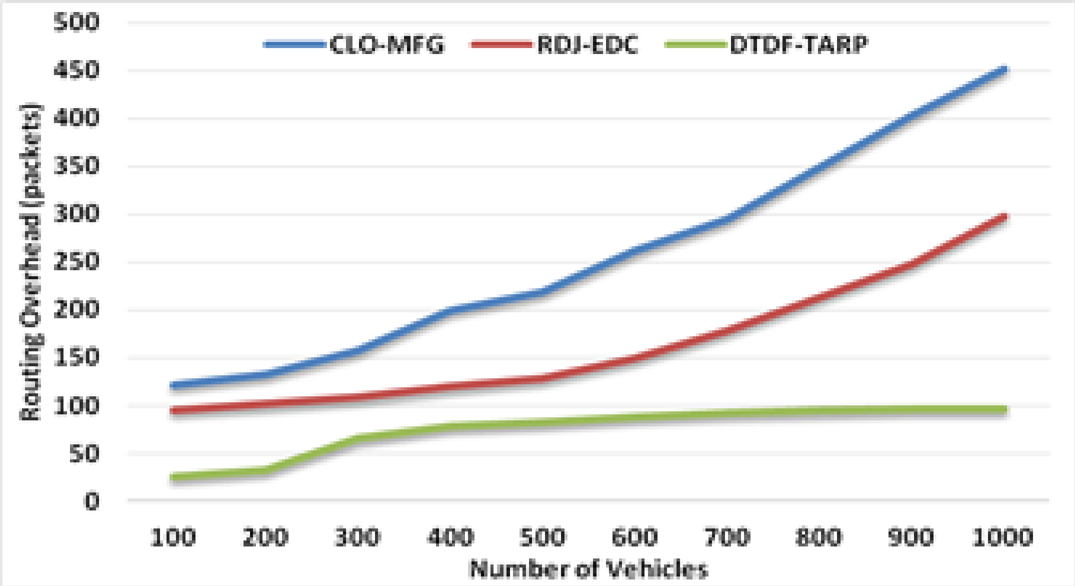

Figure 6.
Routing overhead (RO) calculation.

2. Results and Discussion

The results of the DTDF-TARP are compared with the CLO-MFG and RDJ-EDC methods, and the discussion is performed in terms of the calculations of the parameters such as EE, PDR, E2E, and RO. Table 2 shows the values of those methods.

Table 2.
Results analysis and measurements.

Parameters	CLO-MFG	RDJ-EDC	DTDF-TARP
EE	78%	82%	88%
PDR	83%	92%	99%
E2E	265ms	224ms	143ms
RO	451 packets	297 packets	96 packets

The EE achieved by the DTDF-TARP method is 88% whereas for the CLO-MFG, and RDJ-EDC methods it reaches up to 78% and 82% respectively. So, the EE of the DTDF-TARP method is 10% greater than the CLO-MFG method and 6% greater than the RDJ-EDC method. The PDR reached by the proposed DTDF-TARP method is 99% whereas for the CLO-MFG, and RDJ-EDC methods it reaches up to 83% and 92% respectively. So, the PDR of the DTDF-TARP method is 16% greater than the CLO-MFG method and 7% greater than the RDJ-EDC method. The E2E produced by the DTDF-TARP method is 143ms whereas for the CLO-MFG, and RDJ-EDC it produced up to 265ms and 224ms respectively. So, the E2E of the DTDF-TARP method is 120ms less than CLO-MFG and 80ms less than RDJ-EDC. The RO produced by the DTDF-TARP method is 96 packets whereas for the CLO-MFG and RDJ-EDC methods, it produced up to 451 packets and 297 packets respectively.

3. Conclusion

UAVs are presented to enhance the performance of VANETs. In the paper, the Delay Tolerant and Data Forwarding Topology Aware Routing Protocol (DTDF-TARP) is suggested to achieve stable communication in multiple UAV-powered VANETs. This method reduces latency and overhead while increasing the data delivery rate and energy efficiency. The suggested DTDF-TARP protocol combines data forwarding, mobility prediction, and topology-aware routing. The simulation program OMNET++ is used to carry out the implementation. The network performance is measured using four parameters: EE, PDR, E2E, and RO. It is also compared to previous efforts termed CLO-MFG and RDJ-EDC. According to the results, the suggested DTDF-TARP protocol outperforms the previous works in terms of EE by 6% to 10%, PDR by 7% to 16%, E2E delay by 80 to 120 ms, and RO by 375 to 500 ms. Satellite-assisted UAV-powered VANETs are being launched in the future to boost the network's density.

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