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Destination sequenced distance vector routing taking into account signal to noise for flying ad hoc network

Vo Thanh Tu[1], Le Huu Binh[1, *], Phan Dinh Nguyen Vu[2]

[1] *Faculty of Information Technology, University of Sciences, Hue University,*
77 Nguyen Hue street, Hue city, Thua Thien Hue province, Viet Nam

[2] *Hue University of Medicine and Pharmacy Hospital, 41 & 51 street, Hue city,*
Thua Thien Hue province, Viet Nam

[*] Email: *lhbinh@hueuni.edu.vn*

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Abstract. Flying ad hoc networks (FANET) are becoming increasingly popular in both military and civilian applications. The primary characteristic of FANET is their high mobility, which results in a frequently changing topology. This is a significant challenge for protocols that control data transmission from nodes to base stations. Consequently, many research groups have recently been attracted to the study of data transmission control protocols in FANET, typically routing protocols. This paper presents an application of Destination Sequenced Distance Vector (DSDV) routing protocols for FANET. We improved the DSDV routing protocol by considering the signal-to-noise ratio (SNR) when discovering new routes. Simulation results show that the improved DSDV algorithm outperforms the traditional DSDV algorithm in terms of network throughput, end-to-end delay, and SNR.

Keywords: Flying ad hoc network, DSDV, SNR.

Classification numbers: 4.5.1, 4.5.2

1. INTRODUCTION

Unmanned aerial vehicles (UAVs) are becoming more modern and widely used in a variety of fields owing to recent remarkable advancements in wireless communication technology and intelligent control systems. A multi-UAV system is much more efficient than a single UAV because it is suitable for multitasking applications and wide and complex terrains. In this case, UAVs must connect and collaborate to form a network known as a UAV network or flying ad hoc network (FANET). Figure 1 shows an example of a FANET, where there are 13 UAVs and one base station (BS). The UAVs in each other's coverage areas are connected to each other by a wireless link, forming a mesh topology. In the current state, U_1, U_6 and U_{10} are covered by the BS and can transmit data directly to the BS. The other UAVs are not covered by the BS; they must pass through some intermediate UAVs to transmit data to the BS. For example, the $U_4 \rightarrow U_8 \rightarrow U_5 \rightarrow U_1 \rightarrow$ BS transfers data from U_4 to the BS.

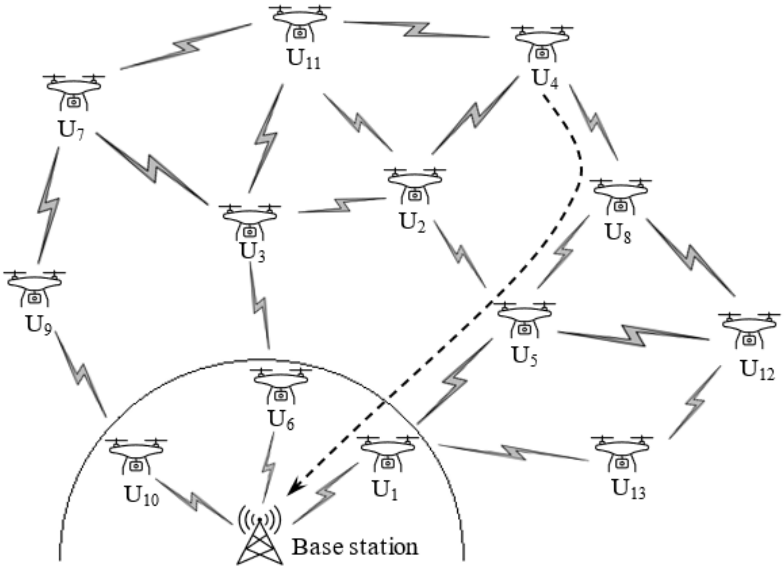

Figure 1. An example of flying ad-hoc network.

Control protocols, such as routing, switching, and signaling, are used in FANET to transmit data between UAVs. However, the effective implementation of these protocols is a major challenge because of the unique characteristics of UAVs, such as high mobility, sparse node density, and being heavily influenced by environmental noise. Therefore, the study of control protocols in FANET is a fascinating subject that has recently attracted the attention of numerous research groups, in which routing is a key issue. In [1], the authors conducted a thorough analysis of cluster-based routing protocols (CBRPs) for FANET, examining their strengths, drawbacks, particular applications, approaches, cluster head selection, routing metrics, and potential future improvements of CBRPs. The authors of [2] have studied the use of ad hoc on-demand distance vector (AODV), dynamic source routing (DSR), and DSDV protocols for FANET. The simulation method on NS-3 was used to compare the performance of these protocols in terms of network delay, received traffic, dropped packet ratio, and throughput. The use of AODV and DSR routing protocols for FANET was also studied in [3], where the authors used a highway mobility model to evaluate how well these routing protocols were performed in the FANET environment. It can be concluded from an experimental study utilizing NS-2 under a constant bit rate (CBR) and transmission control protocol (TCP) traffic sources that AODV performs better than DSR in nearly all aspects. In [4], the Optimized Link State Routing (OLSR) protocol was used for a FANET. The authors investigated OLSR under various mobility models to improve OLSR performance in FANETs. In addition, to evaluate the performance of routing protocols in the FANET environment, the authors of [5] compared AODV and DSDV protocols in terms of delivery rate, end-to-end delay, and throughput. According to the simulation results, the AODV protocol outperformed the DSDV protocol in terms of delivery rate and throughput. However, the DSDV protocol has lower latency than the AODV protocol.

The routing metric is another area of FANET routing that has recently attracted the interest of numerous research groups. The authors of [6] investigated reliability-based routing metrics for UAV networks and presented a metric that considered the relative speeds of UAVs. The AODV routing system with this metric becomes effective in high-mobility scenarios according to the simulation results using NS-2. In [7], the authors proposed a routing metric called I2R, which considers inter-flow interference for flying multi-hop networks. When compared to the state-of-the-art routing metrics of the Expected Transmission Count (ETX) [8] and some other metrics, the simulation results demonstrate the I2R's improved performance, with appreciable benefits in throughput and end-to-end delay.

Routing metrics have a significant impact on routing protocol performance in a FANET environment. It is crucial to develop a routing statistic that considers link quality. In this study, we suggest a routing metric for the DSDV protocol in the FANET environment that accounts for both hop count and SNR. The SNR metric is considered in the improved DSDV routing protocol for FANET for the following reasons:

(i) SNR is an important metric that reflects the QoT of a wireless link. SNR-based routing enhances the QoS of the data transmission routes.

(ii) In a FANET environment, nodes frequently move quickly, causing the SNR of the links to change quickly. Long-distance links can exist at times, causing the SNR to decrease. To guarantee QoT, the SNR must be considered in the routing metric.

The remainder of this paper is organized as follows. In Section 2, the proposed routing metrics are presented. Section 3 describes the application of the new routing metric to the DSDV protocol in a FANET. The simulation results and discussion are presented in Section 4. Finally, concluding remarks and promising future study items are presented in Section 5.

2. HOP COUNT AND SNR AWARE ROUTING METRIC (HCS)

2.1. SNR of a route in FANET

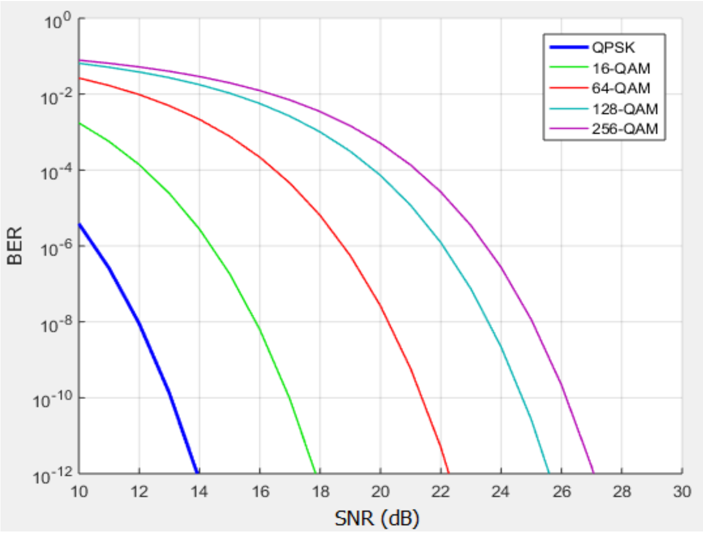

Figure 3. Bit error ratio (BER) versus SNR characteristics for quadature phase shift keying (QPSK) and quadrature amplitude modulation **(**QAM).

The SNR is a crucial metric for evaluating the effectiveness of data channels in communication networks, including wired and wireless networks, as calculated by [9]:

$$\beta = 10\log_{10}\left(\frac{P_s}{P_n}\right) \qquad (dB) \qquad (1)$$

where P_s and P_n are the signal and noise powers, respectively. For each data-transmission route, if the SNR is high, the BER is small. As shown in Figure 3, we determined the theoretical curve of BER versus SNR for various modulation techniques using BER tool in MATLAB software [10]. The modulation techniques considered were quadrature amplitude modulation (QAM), which includes QPSK, 16-QAM, 64-QAM, 128-QAM, and 256-QAM. As the SNR increased, the BER decreased exponentially. For example, in the case of 256-QAM, if the SNR is 15 dB, then the BER is 0.0198. When SNR is increased to 20 dB and 25 dB, BER drops to 5.05×10^{-4} and 1.14×10^{-8}, respectively.

When data are transferred over numerous intermediary nodes in a FANET, the noise power that accumulates along the route increases. As a result, the SNR of the route decreases. The relay type of the intermediate nodes affects the SNR. Intermediate nodes in a multi-hop wireless network have two options for data forwarding: amplify and forward (AF) or decode and forward (DF). These forward types affect the SNR of routes, which is calculated by [11, 12, 15]:

$$\beta_{s,d} = \begin{cases} \underset{\forall h_{i,j} \in r_{s,d}}{Min} (\beta_{i,j}) & if\ DF \\ \left(\sum_{\forall h_{ij} \in r_{sd}} \frac{1}{\beta_{i,j}} \right)^{-1} & otherwise \end{cases} \tag{2}$$

where $\beta_{s,d}$ and $\beta_{i,j}$ are the SNR of routes $r_{s,d}$ and hops $h_{i,j}$, respectively.

2.2. HCS routing metric

Because nodes in the FANET move frequently, the SNR of the links also changes. Furthermore, the SNR difference between the links is significant. Consequently, hop-based routing is inefficient, as is the case with traditional routing protocols. In this paper, we propose HSR, a routing metric for FANET that considers both hops and SNR, which is defined as follows:

$$w_{s,d} = \alpha \frac{\beta_{min}}{\beta_{s,d}} + (1-\alpha) \frac{h_{s,d}}{h_{max}} \tag{3}$$

where $w_{s,d}$ is the metric of route r_{sd}, β_{min} is the minimum SNR of all links in the FANET. $\beta_{s,d}$ is the SNR of route $r_{s,d}$ which is determined using (2). $h_{s,d}$ is the number of hops in route $r_{s,d}$, h_{max} is the number of hops in the longest route in the network. In a network topology, the longest route passes through all nodes, that is, n - 1 hops, where n is the number of nodes. Therefore, h_{max} was set as n - 1. α is a coefficient in the range [0,1], which is used to control the effect degree of the metrics SNR and hop count.

To clearly observe the effect of SNR, hop count, and coefficient α on the HCS metric, consider a FANET with 20 nodes and a minimum SNR of 25 dB. Because the number of nodes is 20, $h_{\max} = 19$. The results of the calculation of the HCS metric according to the SNR, hop count, and α other parameters are shown in Figure 4. We can see that when α equals 0.2, $w_{s,d}$ is primarily determined by the number of hops, and less by the SNR. When α is 0.5, $w_{s,d}$ is affected by both SNR and hop count parameters. When α is large (0.7 and 0.9), $w_{s,d}$ is primarily determined by the SNR, with little influence from the hop count. Because the goal of the HCS metric is to consider both SNR and hop counts, we chose α to be 0.5.

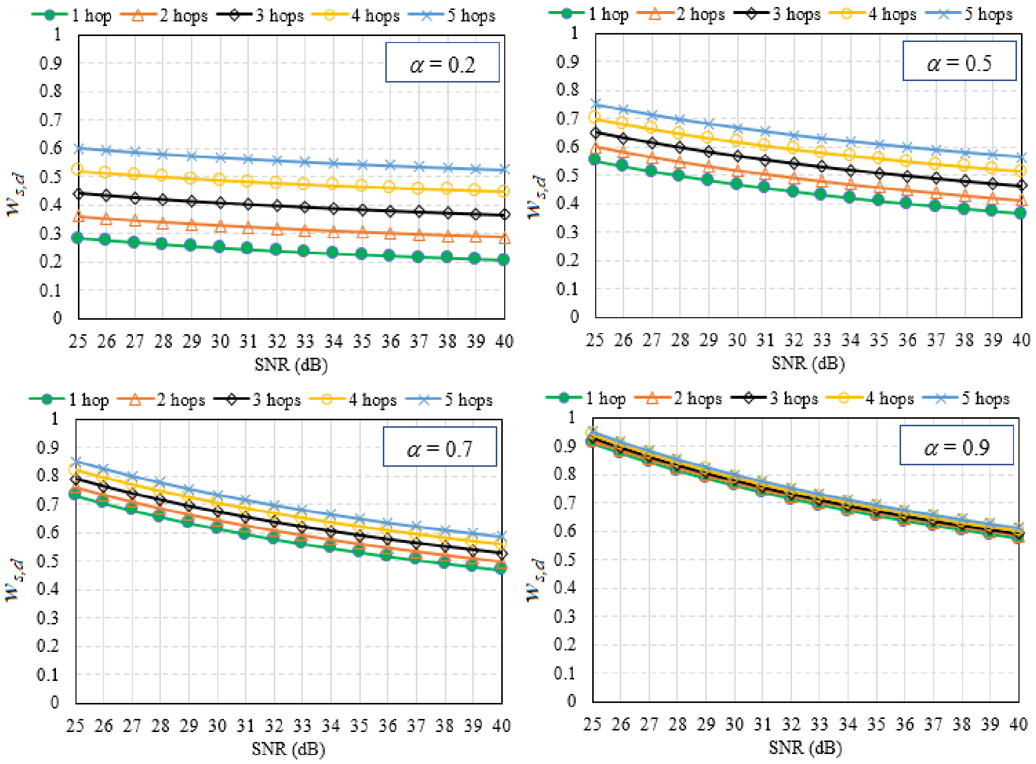

Figure 4. Impact of parameters SNR, hop count and coefficient α on the HCS metric.

3. DSDV-HCS ROUTING ALGORITHM FOR FANET

In this section, we demonstrate the application of the proposed HCS metric to the DSDV routing protocol in a FANET. The DSDV protocol, which employs the HCS metric, is named the DSDV-HCS.

Table 1. Description of the notation used for DSDV-HCS algorithm.

Notation	Description
G_{hello}	The node that generates the hello packet
S_{hello}	The node that sends the hello packet
I	The node that receives the hello packet
w_{hello}	Metric from node S_{hello} to node G_{hello}
N_{rc}	Next node of a route in route cache (RC)
w_{rc}	Metric of a route in RC
$w_{I,S_{hello}}$	Metric of route from node I to node S_{hello}
seq_{hello}	Sequence number of a route in the hello packet
Seq_{rc}	Sequence number of a route in RC
$R_{I,G_{hello}}$	Route from node I to node G_{hello} in RC of node I

Figure 5 depicts the hello packet processing process at each FANET node using the DSDV-HCS algorithm, and the meanings of the symbols are listed in Table 1. The DSDV-HCS algorithm differs from the original DSDV algorithm in that it computes a metric to update the routing table at each node whenever a node receives a hello packet. Because the DSDV algorithm discovers routes based on hop count, every time a node broadcasts a hello packet to update the routing information, the hop count increases by one. The routing metrics utilized by the DSDV-HCS method are the SNR and hop count; therefore, each time a node needs to update its routing table, the SNR must be calculated from it to the destination node.

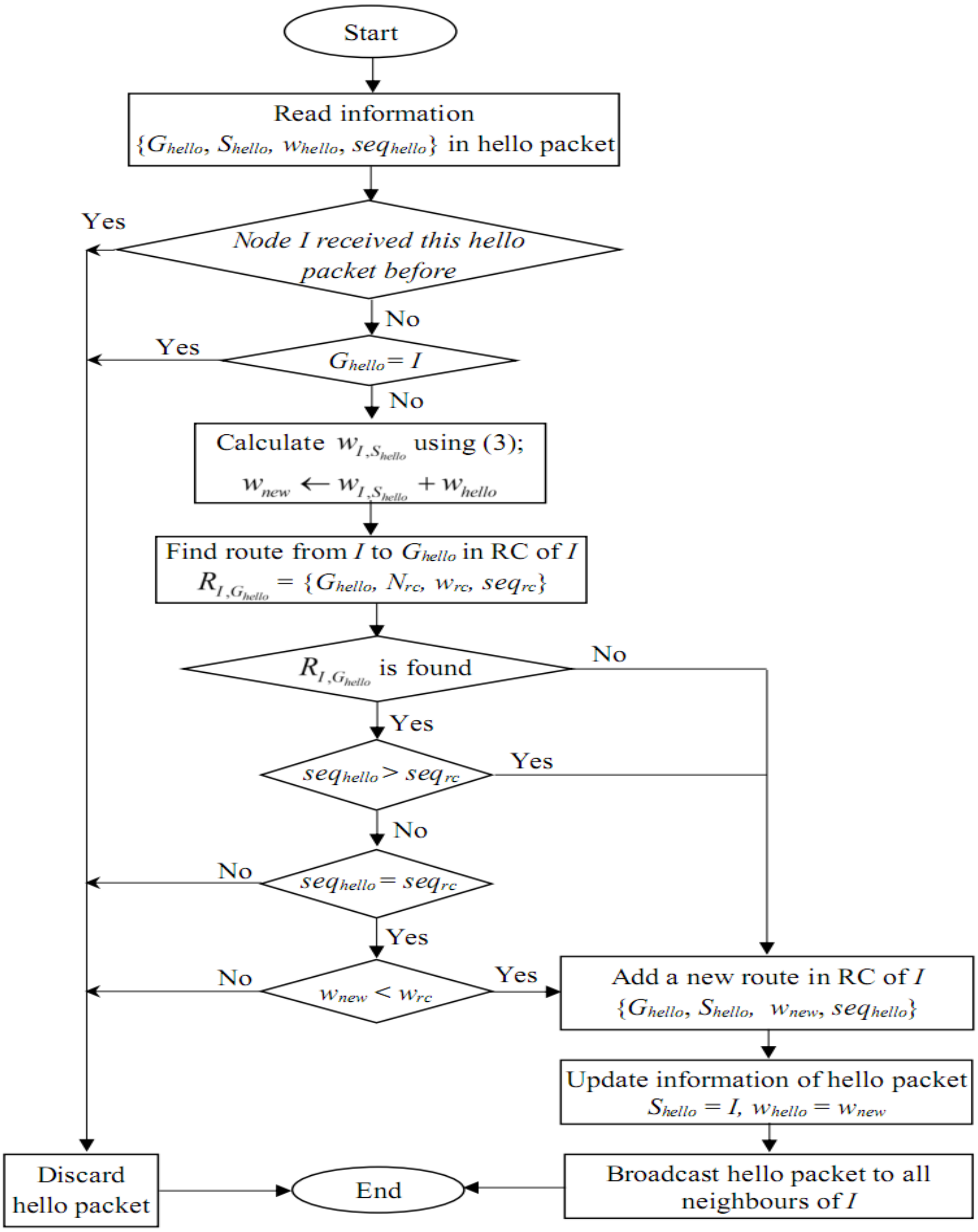

Figure 5. Flowchart of DSDV-HCS algorithm for FANET.

4. PERFORMANCE EVALUATION BY SIMULATION

The performance of the DSDV-HCS algorithm was evaluated by a simulation method using OMNET++ [13] and the INET Framework [14]. The DSDV-HCS algorithm was compared with the traditional DSDV algorithm in terms of network throughput, end-to-end delay, and SNR. The simulation assumptions are listed in Table 2. Figure 6 shows a snapshot of the interface while running the FANET simulation.

Table 2. Simulation parameters.

Notation	Description
Simulation area	1000 × 1000 × 1000 meters
Radio range	250 meters
Noise model	Thermal noise
Movement speed	5 - 30 m/s
Mobility model	Mass mobility
Number of nodes	30
Number of base stations	1
Path loss model	Free space
Simulation time	2000 seconds

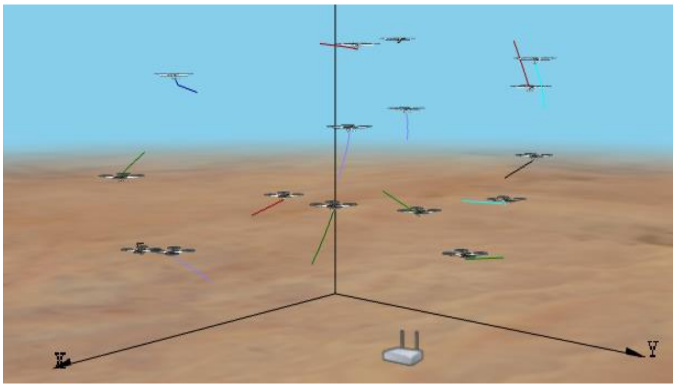

Figure 6. A snapshot of the interface when running the FANET simulation using OMNET++ and INET Framework.

The results obtained in Figure 7 show the difference in throughput received at the base station (BS) when using the DSDV and DSDV-HCS routing algorithms. In this case, FANET nodes moved at an average speed of 10 m/s. We can observe that when the simulation time is less than 600 s, the throughput of both algorithms changes significantly because at this time, the network is unstable. When the simulation time was greater than 600 s, the throughput of the two algorithms started to stabilize, with an average of approximately 120 kbps and 100 kbps for the DSDV-HCS and DSDV algorithms, respectively. Thus, the DSDV-HCS algorithm outperformed the DSDV algorithm in terms of throughput. The result when the nodes move at a higher speed of 15 m/s is shown in Figure 8. The average throughputs of the DSDV and DSDV-HCS algorithms were 105 and 112 kbps, respectively. Thus, the DSDV-HCS algorithm also provides a higher throughput than the traditional DSDV algorithm.

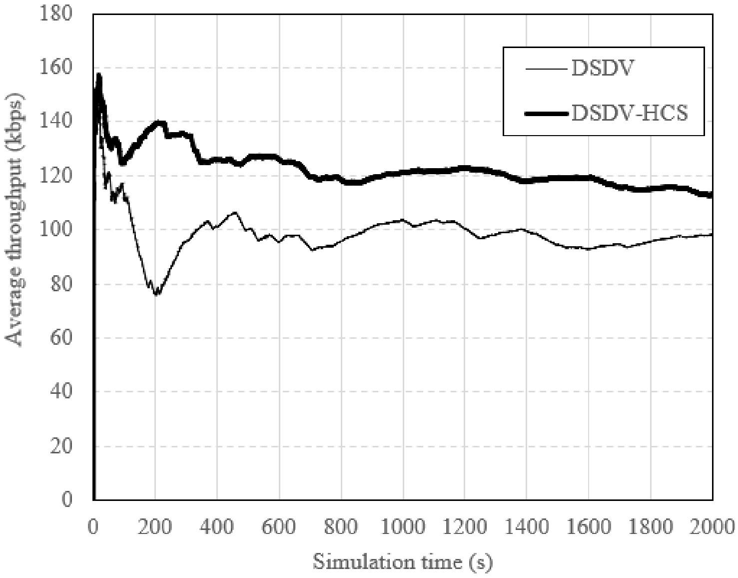

Figure 7. Comparison of the throughput of DSDV and DSDV-HCS algorithms in case the average moving speed of the nodes is 10 m/s.

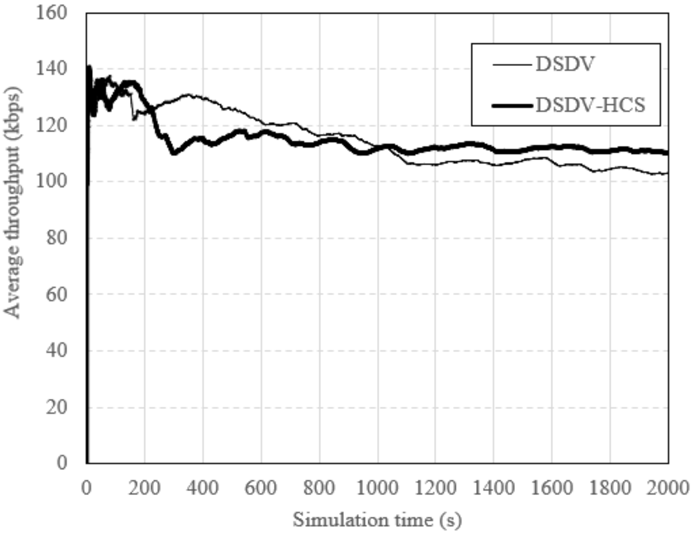

Figure 8. Comparison of the throughput of algorithm DSDV and DSDV-HCS in case the average moving speed of the nodes is 15 m/s.

The dependence of throughput on the movement speed of the nodes is clearly shown in Figure 9, where we plot the average received throughput at the BS as a function of mobility speed. We can observe that when the mobility speed of the nodes is less than 20 m/s (equivalent to 72 km/h), the DSDV-HCS algorithm is more efficient than the DSDV algorithm. When the mobility speed was greater than 20 mps, the performances of both the algorithms were similar. Thus, in terms of throughput, the DSDV-HCS algorithm is highly efficient when the moving speed of the nodes is moderate.

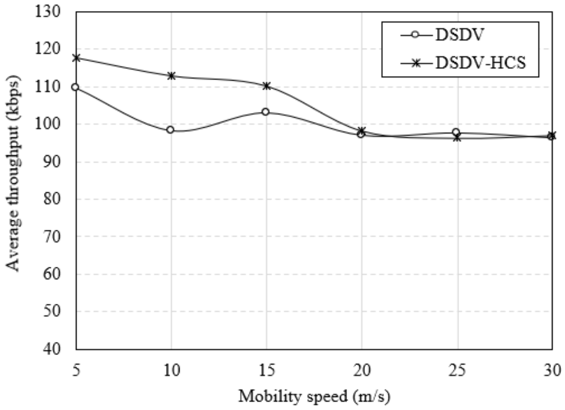

Figure 9. Comparison of the throughput of algorithm DSDV and DSDV-HCS versus mobility speed of nodes.

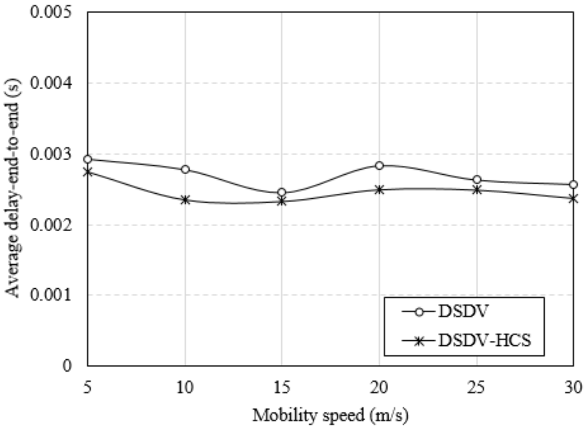

Figure 10. Comparison of the end-to-end delay of algorithm DSDV and DSDV-HCS versus moving speed of nodes.

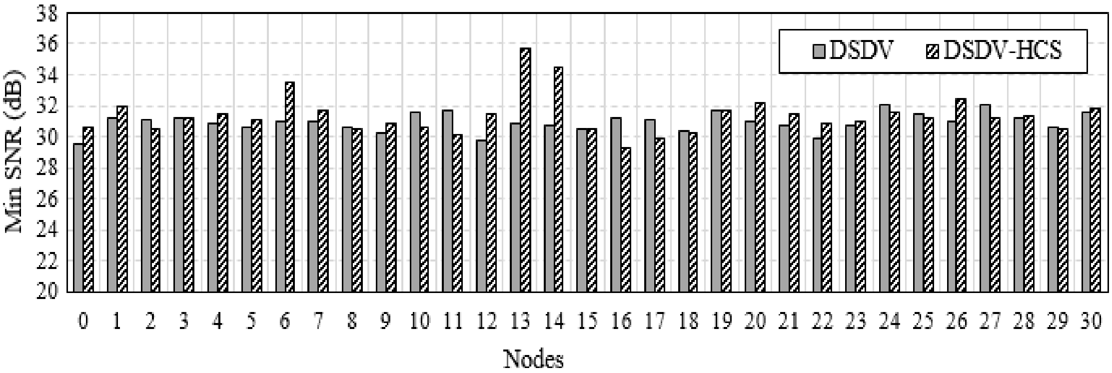

Figure 11. Comparison of the minimum SNR at the nodes of algorithm DSDV and DSDV-HCS.

The findings of our analysis of the end-to-end delay are shown in Figure 10. We can see that the DSDV-HCS algorithm always has a shorter end-to-end delay than the DSDV algorithm. The end-to-end delays of the DSDV-HCS and DSDV algorithms are 2.4 ms and 2.8 ms, respectively, when nodes are moving at a speed of 10 mps. In comparison to the DSDV algorithm, the DSDV-HCS algorithm can reduce end-to-end delay by a value of 0.4 ms. The end-to-end delay of the DSDV-HCS algorithm, with an average value of roughly 0.35 ms, is always smaller than that of the DSDV method for the other situations.

Next, we analyzed the SNR at the nodes. This is an important metric that significantly affects the quality of the data signals in the network. The histograms in Figure 11 show the minimum difference in SNR at all nodes. We can see that the DSDV-HCS algorithm outperforms the DSDV algorithm in terms of the SNR.

5. CONCLUSION

The use of flying ad hoc networks - FANET in both military and nonmilitary applications is growing. High mobility, the main feature of FANET, leads to a frequently changing topology. Protocols that regulate data transit from nodes to base stations present substantial difficulties. As a result, the study of data transmission control protocols in FANET, typically routing protocols, has recently attracted many research groups. The application of the Destination Sequenced Distance Vector - DSDV routing protocols for FANET is discussed in this work. By considering the signal-to-noise ratio - SNR when finding new routes, we enhanced the DSDV routing protocol. The simulation results demonstrate that, in terms of network throughput, end-to-end delay, and SNR, the revised DSDV algorithm performs better than the conventional DSDV algorithm.

In future work, we will continue to improve this algorithm by introducing new constraints to increase the reliability of data transmission from the nodes to the base stations.

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Declaration of competing interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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