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RGIM: An Integrated Approach to Improve QoS in AODV, DSR and DSDV Routing Protocols for FANETS Using the Chain Mobility Model

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Flying *ad hoc* networks (FANETs) are a collection of unmanned aerial vehicles that communicate without any predefined infrastructure. FANET, being one of the most researched topics nowadays, finds its scope in many complex applications like drones used for military applications, border surveillance systems and other systems like civil applications in traffic monitoring and disaster management. Quality of service (QoS) performance parameters for routing e.g. delay, packet delivery ratio, jitter and throughput in FANETs are quite difficult to improve. Mobility models play an important role in evaluating the performance of the routing protocols. In this paper, the integration of two selected mobility models, i.e. random waypoint and Gauss–Markov model, is implemented. As a result, the random Gauss integrated model is proposed for evaluating the performance of AODV (*ad hoc* on-demand distance vector), DSR (dynamic source routing) and DSDV (destination-Sequenced distance vector) routing protocols. The simulation is done with an NS2 simulator for various scenarios by varying the number of nodes and taking low- and high-node speeds of 50 and 500, respectively. The experimental results show that the proposed model improves the QoS performance parameters of AODV, DSR and DSDV protocol.

Keywords: FANETs; random waypoint model; Gauss–Markov model; routing protocols; QoS parameters

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1. INTRODUCTION

Flying *ad hoc* networks (FANETs) represent a special kind of mobile *ad hoc* network. In FANETs, the *ad hoc* network is between unmanned aerial vehicles (UAVs), which fly independently without carrying any human pilot. All the UAVs form an *ad hoc* network, but the only subset of UAVs communicates with the base station or satellite as shown in Fig. 1 [1]. UAVs are used in various applications like emergency support, border surveillance, disaster monitoring and rescue operations [2–4]. In comparison to other *ad hoc* networks, change in the node's mobility in FANETs is considerably high and change in topology is also very frequent [5]. Mobility models are used to develop these mobility scenarios in the wireless *ad hoc* network, and different routing protocols are implemented using various mobility scenarios. In FANETs, the routing protocols are categorized as topology-based, swarm-based and position-based. In topology-based routing, the various protocols proposed as proactive are OLSR (optimized link state routing) and DSDV (destination-sequenced distance vector), as reactive are AODV (*ad hoc* on-demand distance vector) and DSR (dynamic source routing) and as hybrid are HWMP (hybrid wireless mesh protocol), HRPO (hierarchical routing protocol), ZRP (zone routing protocol) and TORA (temporarily ordered routing algorithm) [6]. In swarm-based routing, the proposed protocols are

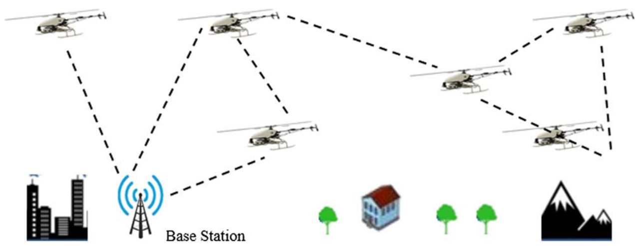

FIGURE 1. Flying *ad hoc* network [1].

APAR (ant colony optimization-based polymorphism-aware routing) and BeeAdHoc. The position-based routing has protocols categorized on a single path, which are GLSR (geographic load share routing), MPGR (mobility prediction geographic routing), LAROD (location-aware routing for delay-tolerant networks), GRAA (geographic routing protocol for aircraft *ad hoc* network), UVAR (UAV-assisted VANET routing protocol) and P-OLSR (position-based OLSR), and others based on multi-path are ARPAM (*ad hoc* routing protocol for aeronautical mobile *ad hoc* networks), RGR (reactive-greedy-reactive), PASER (position-aware, secure and efficient mesh routing) and LCAD (load carry and deliver routing) [6]. The mobility models for FANETs are random waypoint mobility model, random movements, Gauss–Markov, pheromone repel, semi-random circular movement and paparazzi mobility model [6].

1.1. Our contributions

The quality of service (QoS) parameters that are considered for effective routing in FANETs demand delay and jitter to be minimized whereas the packet delivery ratio (PDR) and throughput to be increased. In the wireless *ad hoc* network, the chain mobility model is formed by integrating the Manhattan Grid model and the random waypoint model [7, 8]. This motivates to propose a new chain mobility model i.e. RGIM (random Gauss integrated model) using existing models with a specific goal to improve the performance of routing protocols.

The main objective is to identify the existing mobility models that can be integrated to form a chain. In FANETs, the QoS parameters are mostly evaluated by using the Random waypoint [9,10] and Gauss–Markov models [11,12]. These two models are selected to form a chain as they are widely accepted to evaluate the QoS parameters for FANETs. In this paper, a new chain mobility model combining random waypoint and Gauss–Markov is proposed for better performance of FANET routing protocols. The proposed chain mobility model creates mobility scenarios using BonnMotion [13] and is simulated using the NS2 simulator [14]. The purpose of this work is to optimize delay, PDR, jitter and throughput for AODV, DSR and DSDV protocols in FANETs.

The paper is organized as follows. Section 2 presents existing mobility models and the related work. The proposed chain model is described in Section 3. Section 4 discusses the implementation details and presents the experimental results. The conclusions and future scope are presented in Section 5.

2. RELATED WORK

The mobility model is devised to define the movement pattern of a node, and it also represents how the node changes its location, acceleration and velocity over time [35]. A realistic simulation environment created using the mobility model plays a major role to evaluate various *ad hoc* routing protocol's performance [36]. The performance of protocols varies significantly by applying diverse mobility models. The routing protocol performance is analyzed by using various mobility models as covered in the literature.

The random waypoint mobility model is used to perform simulations in the *ad hoc* network for various routing protocols given by following authors: Sharma and Yadav [15] performed simulation in improving reactive-greedy-reactive (RGR) protocol under the random waypoint model over a FANET network. The results show that RGR protocol gives better performance for the like metrics delay and throughput in comparison with original RGR and AODV protocol. Leonov [9] experimentally analyzed AntHocNet and BeeAdHoc protocols to provide a solution to the problem of routing in FANETs. The simulation is done under the random waypoint model using the NS2 simulator. The performance of protocols is examined using throughput, delay and routing overhead parameters. The results show that AntHocNet and BeeAdHoc are more efficient when compared with AODV, DSDV and DSR protocols. Gankhuyag *et al*. [16] proposed a novel directional hybrid routing scheme with enhancement of the AODV routing protocol for FANETs. The proposed hybrid routing uses both unicast and geocast routing. The proposed routing is compared with the traditional AODV routing by applying the random waypoint model for success of route setup and lifetime of active path. The results show that the enhanced AODV routing performs better than traditional AODV. Biomo *et al*. [10] optimized the RGR routing protocol for a recovery strategy in an unmanned aerial *ad hoc* network. The performance is evaluated using OPNET under the random waypoint model for PDR, delay and control overhead. The results show that optimized RGR performs better for PDR when compared to modified RGR. Gupta and Gupta [17] evaluated the mobility effect on the AODV, DSDV, OLSR and DSR performance with the random waypoint model. The simulation is done using the NS2 simulator to get PDR, delay and routing load. The results show that AODV gives better performance in comparison with other protocols. Kout *et al*. [18] defined AODVCS, a protocol based on the cuckoo search method in MANETs. AODVCS is implemented with NS2 using the random waypoint model. The comparison of AODVCS is done with AODV, DSDV and AntHocNet for PDR and delay. From the result, AODVCS is considered better in terms of PDR and delay. Zheng *et al*. [19] proposed a hybrid communication protocol i.e. PPMAC (position prediction-based directional MAC protocol) and RLSRP (self-learning routing protocol based on reinforcement learning). The proposed protocols are implemented using MATLAB and NS2 with the random waypoint mobility model and provide an intelligent communication in FANETs. Gankhuyag *et al.* [20] proposed a routing scheme with directional and dynamic angle adjustment for FANETs. The simulation is done using C++ to evaluate route setup success and data delivery ratio. From the outcomes, it is concluded that the proposed scheme performs superior to the AODV scheme.

The Gauss–Markov mobility model is used to perform the simulation of various routing protocols given by the following authors: Biomo *et al.* [11] proposed the enhanced Gauss–Markov (EGM) model for UAVs. The EGM model eliminates rapid pause and quick turning of mobile vehicles. The OPNET simulator is used to evaluate the performance in terms of PDR. The results show that EGM produces significantly more network partitions in comparison with the random waypoint model. Lin *et al.* [12] proposed an MPGR protocol for *ad hoc* UAVs. The results obtained from simulation using the Gauss model show that MPGR performs superior than AODV and GPSR (greedy perimeter stateless routing) for PDR and delay. Chenghao [21] improved DSR protocol with the Gauss–Markov model for reducing the impact of node movements in the simulation area. The results calculated using QualNet shows an improvement in the improved DSR routing protocol's performance for PDR, throughput, delay and jitter when compared with the original DSR routing protocol. Alenazi and Sahin [22] modified the implementation of the 3D Gauss–Markov model. The results show that mobile nodes follow smooth movements in an improved model by avoiding reaching the boundaries of the simulation area. Jung *et al.* [23] proposed a QGeo routing protocol for unmanned robotic networks. The simulation is done using the NS3 simulator with the Gaussian–Markov model. In results, QGeo performs better as compared to GPSR and QGrid for PDR and network overhead. Wang *et al.* [24] presented the semi-random circular movement (SRCM) model for UAVs in MANETs. The simulation is done using NS2 simulator. The SRCM model performs better as compared to the existing random waypoint model in MANETs for the curved movement scenarios. Bahloul *et al.* [25] proposed a BR-AODV, flocking-based protocol for routing purposes of UAVs. In the proposed protocol, AODV is used for on-demand routing and Boids of Reynolds (BR) mechanism is used for route connection and maintenance for dynamic topology. The simulation is done using the NS2 simulator, and results show that BR-AODV performs better than AODV for throughput, delay and packet loss parameters.

The chain mobility model is proposed and used in the simulation of routing protocols by Bhasin and Kumar [7] and evaluated the DSR and AODV protocol performance using the chain mobility model. The simulation is done using NS2 to evaluate throughput, PDR and delay performance parameters. AODV and DSR give equal throughput using the chain test random and chain campus models. In the chain test random model, DSR protocol results in more delay as compared to AODV. AODV gives a steady PDR using a chain campus model and also PDR of DSR is reduced. Shukla and Jha [8] compared the chain mobility model (Manhattan Grid model and random waypoint model) with the random waypoint model. The various parameters like throughput, delay and PDR are evaluated for DSR routing protocol. The simulation is done using the NS2 simulator. The results show that the chain model gives better performance compared to the random waypoint mobility model. Huan *et al.* [26] compared the performance of the reference point group mobility model, random waypoint, Manhattan and freeway models for sparse networks. From the simulation, it is concluded that these four models are not relevant for a sparse network. Therefore, the authors proposed a chain mobility model for efficient communication between nodes, which performed better in a sparse network. Table 1 compares the proposed model RGIM with routing protocols using existing mobility models. In these research works, the chain mobility model is formed by integrating the random waypoint and Manhattan Grid models, but no chain model is formed with the random waypoint and Gauss–Markov models.

3. RGIM: THE PROPOSED CHAIN MOBILITY MODEL

To analyze routing protocol performance in FANET, a new chain model is proposed. The proposed model is formed by integrating two mobility models, i.e. random waypoint and Gauss–Markov. In the proposed chain mobility model, the random waypoint and Gauss–Markov are selected for integration because existing research finds huge acceptance and usage of these two mobility models for simulation of routing protocols in FANETs [5, 9, 10, 11 12, 15, 16]. The random waypoint model allows nodes to move randomly in any direction with random speed within the simulation area. Using this model, the nodes decide their movement based on fixed probabilities. This model uses pause time before changing the node speed or direction. The random waypoint model is one of the simplest and easiest models to use. In the Gauss–Markov model, every node is given a particular speed and direction at starting which is updated at a fixed interval of time. It states that the speed and direction at some instance (*n*th) of time depends upon previous instance (*n*-1st) of time.

3.1. Problem formulation

To improve various QoS performance parameters like delay, PDR, jitter and throughput are the main areas of concern in FANETs. The mobility model is used to evaluate the performance of the routing protocols in the wireless *ad hoc* network. The purpose of this work is to implement an effective mobility model using chaining of selected mobility models, i.e. random

TABLE 1. Comparison of RGIM with existing mobility models.

Technique	Mobility model	Ad hoc network	Simulator	QoS parameters	Routing protocols	Result
Improved RGR [15]	Random waypoint	FANET	NS2	Delay, throughput	AODV, RGR	RGR performs better for the delay and throughput
AntHocNet and BeeAdHoc [9]	Random waypoint	FANET	NS2	Throughput, routing overhead and delay	AODV, DSR, DSDV, BeeAdHoc and AntHocNet	AntHocNet and BeeAdHoc are more efficient
Enhanced AODV [16]	Random waypoint	FANET	Programming language (C++)	Route setup and lifetime of an active path	AODV	Enhanced AODV routing performs better than traditional AODV
RGR [10]	Random waypoint	Unmanned aerial *Ad hoc* network	OPNET	PDR, delay and control overhead	RGR	Optimized RGR performs better for packet delivery ratio
AODV, DSDV, OLSR and DSR [17]	Random waypoint	MANET	NS2	Routing load, delay and PDR	AODV, DSR, OLSR and DSDV	AODV gives better performance compared to other protocols
EGM [11]	Enhanced Gauss–Markov, random waypoint	Unmanned aerial vehicles	OPNET	PDR	Optimized-RGR	EGM produces a large number of network partitions compared to the random waypoint
MPGR [12]	Gauss mobility model	UAVs	–	Delay and PDR	MPGR, AODV, and GPSR	MPGR outperforms AODV and GPSR
Improved DSR [21]	Gauss–Markov mobility model	Adhoc Network	QualNet	Packet delivery ratio, throughput, delay and jitter	DSR	Improvement in performance of improved DSR routing protocol
SRCM [24]	semi-random circular movement, random waypoint	MANET	NS2	Node distribution	–	SRCM outperforms Random waypoint
AODV, DSR [7]	Chain model (random waypoint, Manhattan)	MANET	NS2	Throughput, PDR, delay	AODV, DSR	AODV gives a steady PDR, and PDR of DSR is reduced
DSR [8]	Chain model (random waypoint, Manhattan Grid)	Adhoc Network	NS2	Throughput, end-to-end delay, packet delivery ratio	DSR	Chain model gives better performance compared to the random waypoint mobility model
RGIM (this work)	Random waypoint and Gauss–Markov	FANET	NS2	PDR, end-to-end delay, throughput, jitter	AODV, DSR, DSDV	RGIM gives more packet delivery ratio, less end-to-end delay, less jitter and better throughput than individual random waypoint and Gauss–Markov mobility model

Algorithm 1: Random Waypoint Model (RWPM)

```
Input: Movement duration parameter of node (i), identification parameter of node (j), speed of node (V), movement vector (P), pause time (T)
Output: Movement of node
Begin
    For each node do
        Assign i= movement duration, j= identification of node
        Set vector $P_i^{(j)}$ = random waypoint
        $\{P_i^{(j)}\}_{i\epsilon N_0} = P_0^{(j)}, P_1^{(j)}, P_2^{(j)}, P_3^{(j)}, \ldots\ldots$ [28]    (3.1)    //represent movement traces of a node in the model
        Select $V_i$ from $\{P_{i-1} - P_i\}$
        Set $T_{p,i}$ at $P_i$
        $\{(P_i, V_i, T_{p,i})\}_{i\epsilon N} = (P_1, V_1, T_{p,1}), (P_2, V_2, T_{p,2}), (P_3, V_3, T_{p,3}), ..$ [28]    (3.2)  // complete movement of a node
    end for each
End
```

waypoint and Gauss–Markov to improve various QoS parameters i.e. packet delivery ratio, throughput, jitter and delay of AODV, DSR and DSDV protocols.

3.2. QoS parameters

In FANETs, the main objective is to minimize the delay and jitter and maximize PDR and throughput. The proposed chain mobility model will help in improving these QoS parameters such as PDR, delay, jitter and throughput. PDR is the ratio between the received packets at the destination and the sent packets from the source as found in the trace file. For the calculation of PDR, the formula is given as Equation (1). *End to End Delay* is the average time taken to reach the destination by a sent data packet and is represented in milliseconds (ms). For the calculation of end-to-end delay, the formula is as given in Equation (2). *Jitter* is the time variation in received packets at destination because of topology change and network congestion. *Throughput* is the rate of successfully received packets and is represented in kbps. Throughput is calculated by using the following formula in Equation (3).

$$\text{PDR} = \frac{\text{Total number of received packets}}{\text{Total number of sent packets}} \tag{1}$$

$$\text{Delay} = \frac{\text{Packet arrive time} - \text{Packet sent time}}{\text{Number of connections}} \tag{2}$$

$$\text{Throughput} = \frac{\text{Received packets}}{\text{Transmission period}} \tag{3}$$

3.3. RGIM

The proposed model is a combination of two mobility models: random waypoint and Gauss–Markov. In FANET, at starting the movement of UAVs will be modeled according to the random waypoint model, and when the UAVs are near their destination, the movement is modeled by the Gauss–Markov model. Firstly, the mobility scenario of nodes is created using the random waypoint model and Gauss–Markov model separately for the same number of nodes with BonnMotion. In the next step, both the created scenarios are integrated with the help of the chain model.

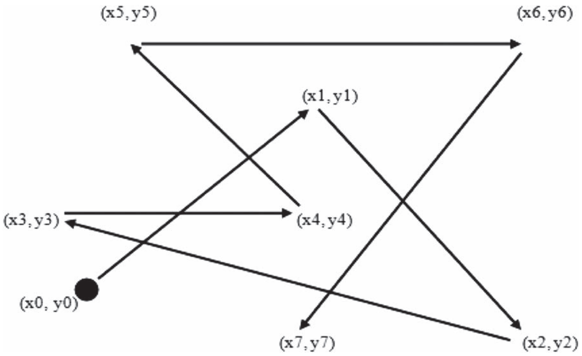

FIGURE 2. Node movement in random waypoint model [29].

3.3.1. *Random waypoint model*

The model uses the pause time before changing the speed or direction of a node. The nodes are free to move randomly with any speed in any direction within the simulation area for this model. Figure 2 shows the node movement in the random waypoint model. In FANET, the UAVs that move randomly in this model decide their action on the basis of fixed probabilities. This mobility model depends on three activities: 'go straight', 'turn left' and 'turn right' [27]. The algorithm of the random waypoint model [28] is explained above.

3.3.2. *Gauss–Markov model*

In this model, each mobile node is initialized with a particular speed and direction, which is updated after a fixed interval of time. To be precise, the node direction and speed value at the *n*th instance of time are computed on the basis of value at the *n*-1st instance of time. This model is used for the simulation of UAV behavior in a swarm. Figure 3 shows the movement of nodes in the Gauss–Markov model as per earlier node position. The algorithm of the Gauss–Markov model [30] is explained to the next page:

```
Algorithm 2:  Gauss-Markov Model (GMM)

Input : $s_n$ = speed of node for n duration, $d_n$ = direction of node for n duration, $\bar{s}$ = mean speed, $\bar{d}$ = mean direction,  random variables in
………Gaussian distribution to give randomness ($s_{x_{n-1}}$ = speed, $d_{x_{n-1}}$= direction), α = constant (0 – 1) where  α = 0 implies maximum speed
………and direction, α = 1  implies minimum speed and direction.
Output : Node speed and direction ($s_n$ , $d_n$ )
Begin
    For each node i = 1 to n do
        Assign initial speed = $s_i$, initial direction = $d_i$, average speed = $\bar{s}$  and average direction = $\bar{d}$
        Calculate
            $s_n = \alpha s_{n-1} + (1-\alpha)\bar{s} + \sqrt{(1-\alpha^2)s_{x_{n-1}}}$        [30]        (3.3)   // node speed

            $d_n = \alpha d_{n-1} + (1-\alpha)\bar{d} + \sqrt{(1-\alpha^2)d_{x_{n-1}}}$        [30]        (3.4)   // node direction
    End for each
End
```

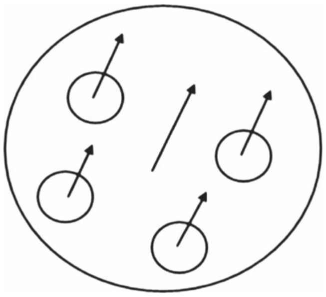

FIGURE 3. Node movement in the Gauss–Markov model [29].

3.3.3. *Chain mobility model*

The chain model is a concatenation of various mobility models (random waypoint, reference point group mobility model, Manhattan Grid, Gauss–Markov). For chaining, the node's last position of *n*-1st scenario is joined with the first position of the *n*th scenario. In this paper, the chain model is formed by connecting the last position of the *n*-1st scenario (random waypoint model) with the first position of the *n*th scenario (Gauss–Markov model). The chain scenario generated is the integration of the random waypoint model and Gauss–Markov model, having a duration value equal to the sum of duration of both models; the number of nodes will be equal to the nodes in any of the model used. The duration of the simulation done is 500 s. For 0 to 250 s, nodes move with the random waypoint model, and for next 250 s the nodes move with the Gauss–Markov model. The proposed chain model, i.e. RGIM, is formed only if the nodes of both scenarios, i.e. random waypoint and Gauss–Markov, are equal, and the simulation area of the first scenario is within the scope of the second scenario. If these conditions are satisfied, the chain model has generated; otherwise, the generation fails. The proposed algorithm of the chain mobility model is represented by an activity diagram as given below in Fig. 4. The proposed RGIM is described in Algorithm 3 as given in the next page.

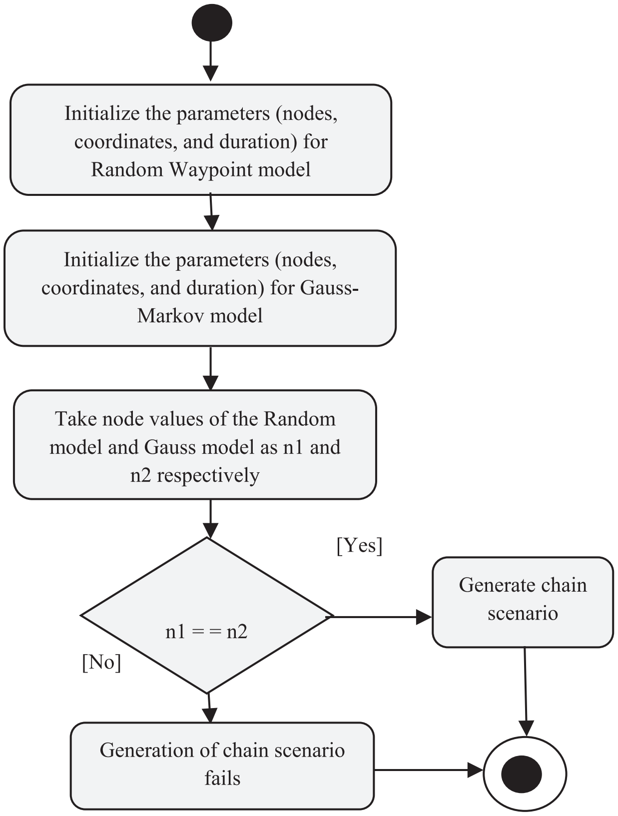

FIGURE 4. Activity diagram showing proposed chain mobility model.

4. IMPLEMENTATION AND EXPERIMENTAL RESULTS

In this section, we implemented our proposed chain model, i.e. RGIM, to know its effectiveness in various QoS performance parameters. Firstly, the simulation parameters are defined and then RGIM is compared with the random waypoint, Gauss–Markov models in terms of PDR, delay, jitter and throughput.

Algorithm 3: Random Gauss Integrated Model (RGIM) generation

```
Input : number of nodes (n1,n2), coordinates (x, y, z), duration ($D_1$,$D_2$)   // n1, $D_1$ => Random Waypoint model ; n2, $D_2$ => Gauss-Markov model
        Random Speed (V), movement trace (P), pause time (T), nodes' movement duration (i), nodes (j), node speed (s), $\alpha$ (constant),
Output : Generation of chain scenario
Begin
    Create mobility scenarios
        Set d1= 0 s to 200 s , coordinates, n1          // Random waypoint scenario
        Set d2 = 250 s to 500 s , coordinates, n2       // Gauss- Markov scenario
    End
    Generate chain model
    If $n_1 == n_2$ && RWPM scenario ($n-1^{th}$ )is in scope of GMM scenario ($n^{th}$)
        for $D_1 \leftarrow$ 0 s to 250 s do
            Select $V_i$ from $P_{i-1}$ to $P_i$
            Set $T_{p,i}$ at $P_i$
            $\{(P_i, V_i, T_{p,i})\}_{i\in N} = (P_1, V_1, T_{p,1}), (P_2, V_2, T_{p,2}), (P_3, V_3, T_{p,3}), ....$   // represents node movement
        end for
        for $D_2 \leftarrow$ 250 s to 500 s do
            $s_n = \alpha s_{n-1} + (1-\alpha)\bar{s} + \sqrt{(1-\alpha^2)s_{x_{n-1}}}$   // node speed calculation
            $d_n = \alpha d_{n-1} + (1-\alpha)\bar{d} + \sqrt{(1-\alpha^2)d_{x_{n-1}}}$   // node direction calculation
        end for
    else
        chain scenario fails
    end if else
End
```

4.1. Implementation details

The proposed model is implemented in the NS2 simulator [14] using various simulation parameters to evaluate the results on different performance parameters.

4.1.1. *Simulation platform*

The NS2 simulator [14] is used to calculate and analyze the performance of AODV, DSR and DSDV with various mobility models. NS2 is an event-driven simulation tool used to simulate the wired and wireless network protocols. NS2 uses C++ language at backend and OTcl at the front-end.

4.1.2. *Simulation parameters*

The various parameters for simulation are described in Table 2. In simulation, a high dynamic scenario having frequent topology changes [31, 33, 34] is generated by using pause time i.e. 10 s.

TABLE 2. Simulation parameters.

Parameter	Value
Simulator	NS2 (Version-2.35)
Channel type	Channel/wireless channel
Protocol	AODV, DSR, DSDV
Mobility models	Random waypoint, Gauss–Markov, chain mobility model
Traffic type	TCP
MAC layer protocol	802.11
Number of nodes per simulation	10, 50
Node speed	50 m/s, 500 m/s
Pause time	10 s

4.1.3. *Performance parameters*

Three performance parameters, i.e. packet delivery ratio, throughput, jitter and average end-to-end delay, are used to analyze AODV, DSR and DSDV performance with different mobility models.

4.2. Experiential results and analysis

In the simulation, AODV, DSR and DSDV routing protocol have been analyzed with different mobility models (RWPM, GMM, RGIM) for varying number of nodes (10, 50) and varying speed of nodes (50 m/s, 500 m/s). The results of the simulation are obtained from the generated trace files using AWK scripts.

4.2.1. *Simulation results of AODV routing protocol with different mobility models*

Test Case 1: PDR Figure 5 represents the variation of packet delivery ratio due to change in the number and speed of nodes for AODV protocol using different mobility models (random waypoint, Gauss–Markov and RGIM). The graph represents that the AODV with RGIM gives an increase in packet delivery ratio values as compared to RWPM and GMM.

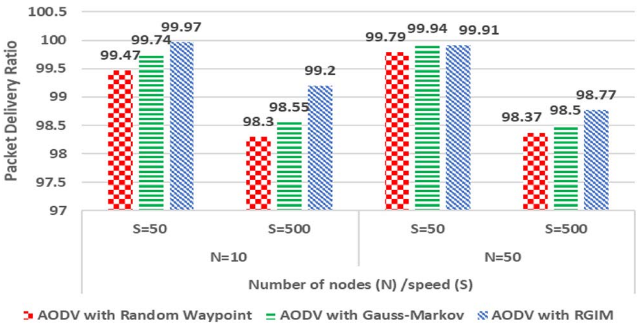

FIGURE 5. Number/speed of nodes vs. PDR for AODV.

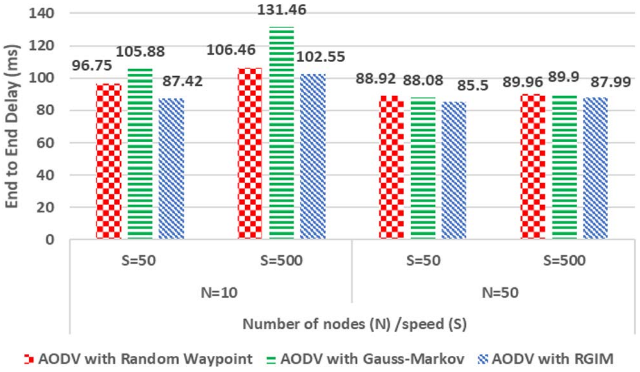

FIGURE 6. Number/speed of nodes vs. end-to-end delay for AODV.

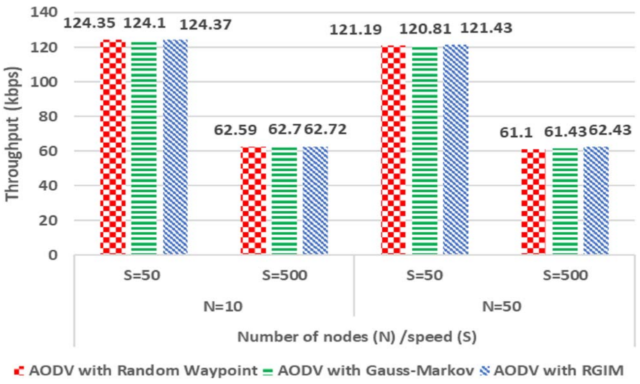

FIGURE 7. Number/speed of nodes vs. throughput for AODV.

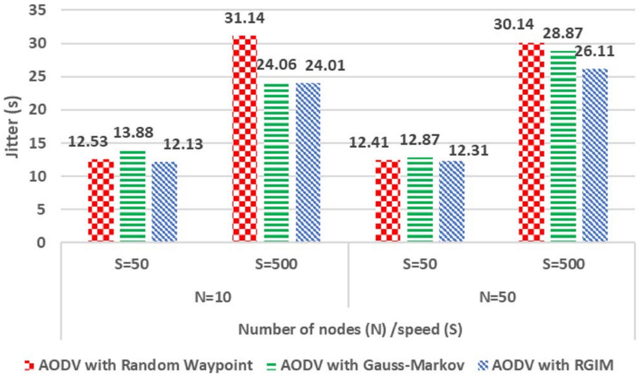

FIGURE 8. Number/speed of nodes vs. jitter for AODV.

Test Case 2: end-to-end delay Figure 6 presents the variation in the end to end delay due to change in the number and speed of nodes for AODV routing protocol using different mobility models (random waypoint, Gauss–Markov and RGIM). From the graph, it is clear that AODV with RGIM gives a decline in delay values in comparison with RWPM and GMM.

Test Case 3: throughput Figure 7 displays the variation of throughput of the AODV routing protocol with the change in the number and speed of nodes using different mobility models (random waypoint, Gauss–Markov and RGIM). The graph shows that the AODV with RGIM gives increase in throughput values as compared to RWPM and GMM.

Test Case 4: jitter Figure 8 displays the variation of jitter of the AODV routing protocol with the change in the number and speed of nodes using different mobility models (random waypoint, Gauss–Markov and RGIM). The graph shows that the AODV with RGIM gives decrease in jitter values as compared to RWPM and GMM.

Simulation analysis of AODV From Fig. 5, it is observed that for 10 and 50 numbers of nodes, with high speed of nodes i.e. 500 m/s, there is a decrease in PDR. In RGIM, there is an increase in PDR compared to RWPM and GMM. The increase in PDR is not much significant, but the minor increase is there because of less link interruption in RGIM. From Fig. 6, it is observed that for 10 and 50 numbers of nodes, with a high node speed of 500 m/s, the delay values increase. In RGIM, there is significant decrease in end-to-end delay compared to RWPM and GMM. The decrease in delay occurs because the proposed model makes more stable links during communication. From Fig. 7, it is observed that for 10 and 50 numbers of nodes, as the speed of node is high i.e. 500 m/s, there is a significant decrease in throughput values. The model RGIM shows a minor increase in throughput compared to RWPM and GMM. There is high throughput for speed 50 m/s, as the models work better for low node speed in the simulation. From Fig. 8, it is observed that for 10 and 50 numbers of nodes, with a high node speed of 500 m/s, the jitter value increases. The model RGIM shows a decrease in jitter compared to RWPM and GMM.

4.2.2. *Simulation results of DSR routing protocol with different mobility models*

Test Case 1: PDR Figure 9 displays the variation of the PDR of DSR routing protocol with the change in the number and speed of nodes using different mobility models (random waypoint, Gauss–Markov and RGIM). The graph shows that

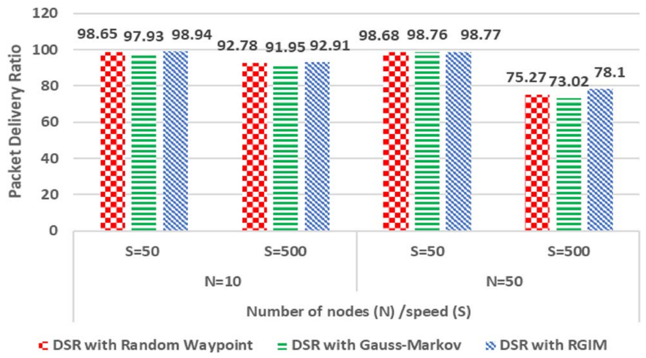

FIGURE 9. Number/speed of nodes vs. PDR for DSR.

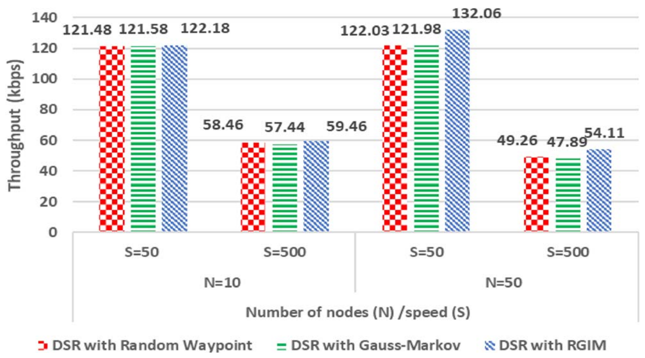

FIGURE 11. Number/speed of nodes vs. throughput for DSR.

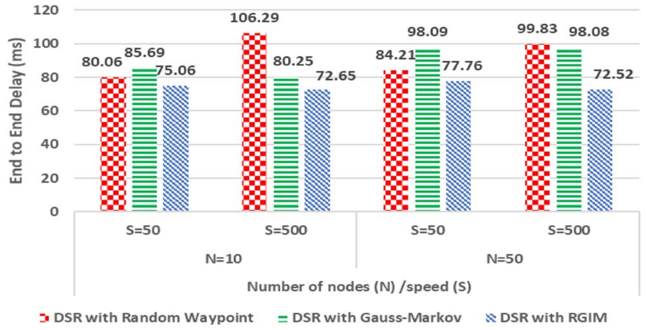

FIGURE 10. Number/speed of nodes vs. end-to-end delay for DSR.

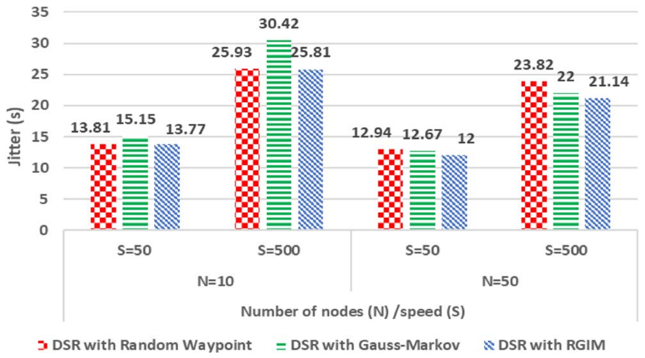

FIGURE 12. Number/speed of nodes vs. jitter for DSR.

the DSR with RGIM gives an increase in packet delivery ratio values as compared to RWPM and GMM.

Test Case 2: end-to-end delay Figure 10 shows the variation in delay for the DSR routing protocol with the change in number and speed of nodes using different mobility models (random waypoint, Gauss–Markov and RGIM). The graph displays that the DSR with RGIM gives a decline in delay values as compared to RWPM and GMM.

Test Case 3: throughput Figure 11 displays the variation of throughput of the DSR routing protocol with the change in the number of nodes and speed of nodes using different mobility models (random waypoint, Gauss–Markov, RGIM). From the graph, it is found that DSR with RGIM gives increase in throughput values as compared to RWPM and GMM.

Test Case 4: jitter Figure 12 displays the variation of jitter of the DSR routing protocol with the change in the number of nodes and speed of nodes using different mobility models (random waypoint, Gauss–Markov, RGIM). From the graph, it is found that DSR with RGIM gives a decrease in jitter values as compared to RWPM and GMM.

Simulation analysis of DSR From Fig. 9, it is observed that for nodes equal to 10 and 50, DSR with RGIM gives an increase in the packet delivery ratio compared to RWPM and GMM. At a high node speed i.e. 500 m/s and high number of nodes i.e. 50, PDR values decrease. The proposed model shows some increase in PDR as packets are delivered with less disruption in RGIM. From Fig. 10, it is observed that for node counts equal to 10 and 50, RGIM gives a significant decline in delay values compared to RWPM and GMM. The proposed model makes a significant decrease in the delay as compared to RWPM and GMM because in RWPM and GMM the communication is difficult to handle but in RGIM communication is maintained easily. From Fig. 11, it is observed that for node counts equal to 10 and 50, RGIM gives a more efficient throughput than RWPM and GMM. For node speed 500 m/s, there is a decrease in throughput compared to low node speed. The throughput increases in RGIM as it integrates both individual models to make the model perform better in the simulation. From Fig. 12, it is observed that for 10 and 50 numbers of nodes, the model RGIM shows a decrease in jitter compared to RWPM and GMM. As the node speed is high i.e. 500 m/s, the jitter value increases.

4.2.3. *Simulation results of DSDV routing protocol with different mobility models*

Test Case 1: PDR Figure 13 displays the variation of the PDR of DSDV routing protocol with the change in the number

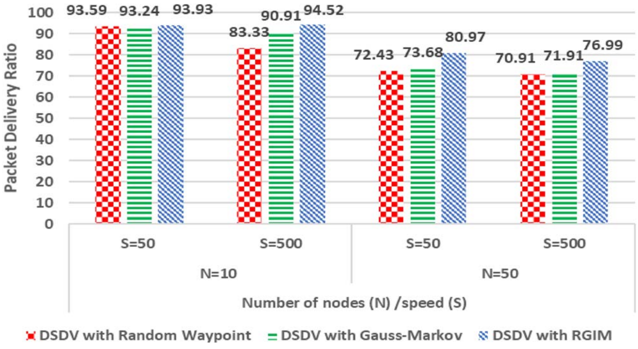

FIGURE 13. Number/speed of nodes vs. PDR for DSDV.

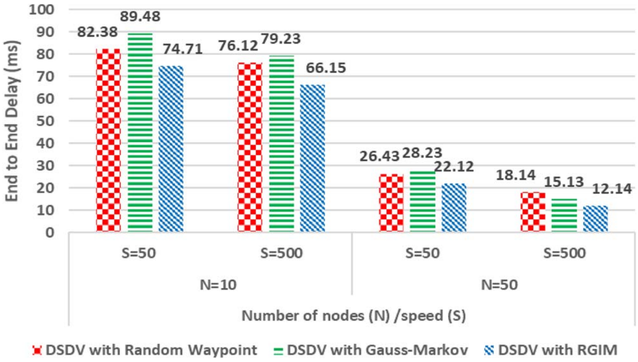

FIGURE 14. Number/speed of nodes vs. end-to-end delay for DSDV.

and speed of nodes using different mobility models (random waypoint, Gauss–Markov and RGIM). The graph shows that the DSDV with RGIM gives an increase in packet delivery ratio values as compared to RWPM and GMM.

Test Case 2: end-to-end delay Figure 14 shows the variation in delay for DSDV routing protocol with the change in number and speed of nodes using different mobility models (random waypoint, Gauss–Markov and RGIM). The graph displays that the DSDV with RGIM gives decline in delay values as compared to RWPM and GMM.

Test Case 3: throughput Figure 15 displays the variation of throughput of the DSDV routing protocol with the change in the number of nodes and speed of nodes using different mobility models (random waypoint, Gauss–Markov, RGIM). From the graph, it is found that DSDV with RGIM gives an increase in throughput values as compared to RWPM and GMM.

Test Case 4: jitter Figure 16 displays the variation of jitter of the DSDV routing protocol with the change in the number of nodes and speed of nodes using different mobility models (random waypoint, Gauss–Markov, RGIM). From the graph, it is found that DSDV with RGIM gives a decrease in jitter values as compared to RWPM and GMM.

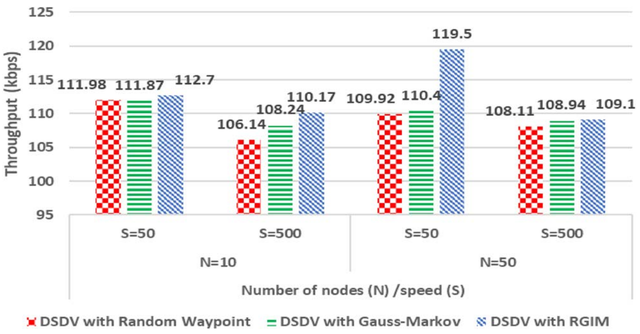

FIGURE 15. Number/speed of nodes vs. throughput for DSDV.

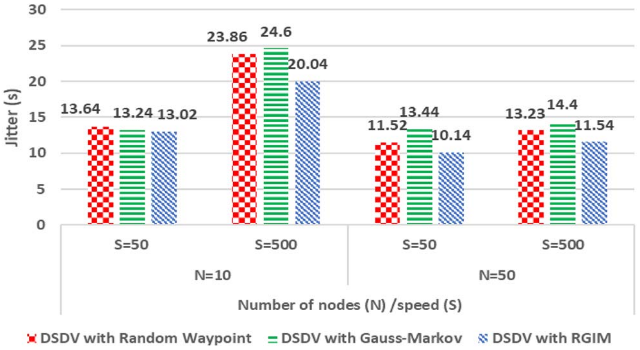

FIGURE 16. Number/speed of nodes vs. jitter for DSDV.

Simulation analysis of DSDV From Fig. 13, it is observed that for nodes equal to 10 and 50, DSDV with RGIM gives an increase in the packet delivery ratio compared to RWPM and GMM. At a node count 50 and node speed 500 m/s, PDR values decreases. From Fig. 14, it is observed that for node count 50, for both low and high speed there is significant decrease in end to end delay. It shows that in DSDV with a high node count, the communication is easy to maintain. RGIM shows a decrease in delay compared to RWPM and GMM. From Fig. 15, it is observed that for node counts 10 and 50, with RGIM there is an increase in throughput compared to RWPM and GMM. For high node speed i.e. 500 m/s, the value of throughput is decreasing. From Fig. 16, it is observed that RGIM shows a decrease in jitter for node counts 10 and 50 compared to RWPM and GMM. For high node speed i.e. 500 m/s, the jitter value increases.

4.2.4. *Statistical analysis*

To validate the results, the coefficient of variation method is used. The coefficient of variation is calculated by dividing the standard deviation of observations with mean of the observations in a sample as given in Equation (4). By applying the coefficient of variation on PDR, throughput, delay and jitter test case for validation the variation is shown in Table 3.

$$\text{Coefficient of variation} = \frac{\text{Standard deviation}}{\text{Mean}} \tag{4}$$

TABLE 3. Coefficient of variation with respect to node speed variation.

Performance parameters		Coefficient of variation					
		$S = 50$			$S = 500$		
Test case		Random waypoint	Gauss–Markov	RGIM	Random waypoint	Gauss–Markov	RGIM
1	PDR	0.11	0.10	0.08	0.14	0.14	0.11
2	Throughput	0.05	0.04	0.05	0.34	0.36	0.30
3	Delay	0.32	0.33	0.34	0.48	0.46	0.44
4	Jitter	0.07	0.07	0.09	0.25	0.23	0.23

Test Case 1: PDR For random waypoint model, the coefficient of variation range is (0.11–0.14) as speed of node varies from 50 to 500 s. For the Gauss–Markov model, the coefficient of variation range is (0.10–0.14) with respect to speed 50 and 500 s. For RGIM, Coefficient of variation range is (0.08–0.11) with speed variation from 50 to 500 s.

Test Case 2: throughput For the random waypoint model, the coefficient of variation range is 0.05–0.34 as speed of node varies from 50 to 500 s. For the Gauss–Markov model, the coefficient of variation range is 0.04–0.36 with respect to speed 50 and 500 s. For RGIM, the coefficient of variation range is 0.05–0.30 with speed variation from 50 to 500 s.

Test Case 3: delay For the random waypoint model, the coefficient of variation range is 0.32–0.48 as speed of node varies from 50 to 500 s. For the Gauss–Markov model, the coefficient of variation range is 0.33–0.46 with respect to speed 50 and 500 s. For RGIM, the coefficient of variation range is 0.34–0.44 with speed variation from 50 to 500 s.

Test Case 4: Jitter For the random waypoint model, the coefficient of variation range is 0.07–0.25 as the speed of node varies from 50 to 500 s. For the Gauss–Markov model, the coefficient of variation range is 0.07–0.23 with respect to speed 50 and 500 s. For RGIM, the coefficient of variation range is 0.09–0.23 with speed variation from 50 to 500 s.

For RGIM, the small value of the coefficient of variation signifies that the proposed model is more stable and effective as compared to the random waypoint and Gauss–Markov models.

4.3. Discussions and limitations

From the simulation analysis, it is observed that the overall performance of RGIM is increased for AODV, DSR and DSDV protocols. It is because in the chain model, the communication link is steady, and it will work for the long simulation duration as it incorporates both the random waypoint and Gauss–Markov features. Also, in the chain model, the link interruption happens less as it is steadier. However, when the individual mobility model is used, in the random waypoint, with an increase in simulation duration, the speed of nodes diminishes significantly and in Gauss–Markov it is hard to deal with communication. The main finding is that the RGIM model which is the chain of random waypoint and Gauss–Markov performs best for low-node speed of 50 m/s for both 10 and 50 numbers of nodes. When comparing our proposed RGIM with the chain model (random waypoint and Manhattan Grid mobility model) by Shukla [8], for AODV having 10 nodes there is an increase of 69 kbps for throughput and increase of 9.9% for PDR. When comparing RGIM with chain model (RWP+ RPGM+ Pursue) by Hong and Zhang [31], for AODV having 50 nodes and 500 m/s speed, there is an increase of 23.83% for PDR and for 50 nodes and 50 m/s speed there is an increase of 16.9% for PDR. Also, for DSDV, having 50 nodes and 500 m/s speed there is an increase of 21.55% for PDR and for 50 nodes and 50 m/s speed there is an increase of 25.97% for PDR.

When compared, the throughput using RGIM for AODV having 10 nodes is 124 kbps compared to 55 kbps with the chain model (random waypoint and Manhattan Grid mobility model) proposed by Shukla [8]. Also, PDR using the RGIM model is 99.9% compared to 90% by the chain model [8]. As compared to AODV using chain (RWP + RPGM) proposed by Hong and Zhang [32] which gives 74.94% PDR for 50 nodes and 500 speed, the RGIM model gives 98.77% PDR. For AODV having 50 speed and 50 nodes, the chain model [32] gives 83% PDR, and RGIM gives 99.9% PDR. For DSDV, having 50 nodes and 500 speed, the chain model [32] gives 55.44% PDR, and RGIM gives 76.99% PDR. For DSDV, having 50 nodes and 50 speed, the chain model [32] gives 55% PDR, and RGIM gives 80.97% PDR. The limitation is observed for a high node speed of 500 m/s, as it results in low performance. It is because the topology is highly affected by high node speed.

5. CONCLUSIONS AND FUTURE SCOPE

In this paper, the chain mobility model using the existing random waypoint mobility model and Gauss–Markov mobility model is proposed for the flying *ad hoc* network. It integrates random waypoint and Gauss–Markov and gives an effective improvement in various QoS parameters. The proposed model, i.e. RGIM, has been simulated using the NS2 simulator. Using RGIM, different mobility scenarios are developed by varying numbers of nodes and speed of nodes. The routing protocols AODV, DSR and DSDV are experimentally analyzed for various performance parameters, i.e. packet delivery ratio, the end-to-end delay, jitter and throughput by using these generated mobility scenarios. From the simulation results, it is observed that the AODV, DSR and DSDV protocol with RGIM gives less end-to-end delay, more packet delivery ratio, less jitter and better throughput than with the random waypoint mobility model and Gauss–Markov mobility model. So, it is concluded that RGIM gives better performance for routing protocols as compared to the random waypoint and Gauss–Markov model applied individually.

In this research work, RGIM is applied only to evaluate the performance of AODV, DSR and DSDV routing protocols. In future, other reactive or proactive routing protocol's performance can be evaluated using the proposed chain model i.e. RGIM. Also, the chain model can be varied by using a combination of some different existing mobility models to get better results.

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