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Evaluating the Impact of Beacon Interval and Neighbor Timeout Timer on the Performance of Geographical Routing in FANETs

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ABSTRACT

Geographical routing provides a robust and scalable routing solution for Flying Ad Hoc Networks (FANETs). In this, the reliability of forwarding decisions depends on the accuracy of the position information of neighboring nodes stored in the neighbor table. Each node broadcasts beacon packets to exchange its position with neighboring nodes after a fixed time interval known as beacon interval (BI) to construct the neighbor table. The node that receives the beacon packet adds an entry in its neighbor table for the originator of a beacon. That entry is valid only for a specific time called neighbor timeout timer (N_{TOT}). The fixed value setting of beacon interval and neighbor timeout timer may deteriorate the routing performance in a dynamic scenario like FANETs, where network characteristics change frequently. Therefore, in this paper, we investigate the impact of fixed beacon interval and fixed neighbor timeout timer on the performance of geographical routing. To do so, extensive simulations are conducted by varying the value of beacon interval and neighbor timeout timer for different network settings in ns-3. The simulation results demonstrate that the beacon interval and neighbour timeout timer significantly affects the performance of geographical routing. Also, geographical routing exhibits the best performance at BI = 0.5s and N_{TOT} = 1.5s in most network conditions.

Keywords: *Beacon interval, FANETs, Geographical routing, Neighbor timeout timer, Unmanned Aerial Vehicle (UAV).*

1. INTRODUCTION

The recent technological advancements have paved the way for the development of small-sized unmanned aerial vehicles (UAVs), which are helpful in a wide range of military and civil applications. Equipped with various sensors and communication capabilities, UAVs can perform tasks in a cooperative fashion, giving rise to a new networking paradigm known as flying ad hoc networks (FANETs) [1], [2]. However, due to unique features of small-sized UAVs (like high mobility, sparse deployment and energy constraints) the design of efficient routing protocol is a challenging task. Various topology-based routing schemes have been proposed to overcome these challenges [3]–[5]. The issue related to topology-based routing is that nodes need to construct an entire route before sending data packets, resulting in high control overhead due to the dynamic topology of FANETs. In such scenarios, geographical routing is considered a promising approach that provides simple and scalable routing solutions [6], [7]. In this, nodes only need to maintain one-hop neighbor information for routing decisions and incur low control overhead, making it suitable for dynamic networks. The accuracy of neighborhood information affects the reliability of routing decisions to a large extent and maintaining an accurate view of local topology is a challenging task when nodes are moving at high speed. In this regard, one of the widely used solutions is periodic beaconing, in which each UAV transmits beacons or hello packets at fixed intervals to announce its position. All neighboring UAVs make an entry in their neighbor table for the beacon's transmitter. This entry is valid for a fixed time called neighbor timeout timer (N_{ToT}) and is removed after its expiration.

The first issue with periodic beaconing is that UAVs need to transmit beacons at a high rate to maintain the exact view of network topology, resulting in higher control overhead and energy consumption. On the other hand, the increase in beacon interval (BI) (means beacons transmitted at a lower rate) leads to outdated or stale entries in the neighbor table. Thus there is a trade-off between the accuracy of neighborhood information in the neighbor table and control overhead. Another issue is assigning the same neighbor timeout timer for all neighboring nodes irrespective of their position, speed and direction of motion. There is a high probability of link breakage much before the N_{ToT} with neighboring nodes present at the border of transmission range and moving in the opposite direction.

This paper aims to analyze the impact of beaconing and neighbor timeout timer on the performance of geographic routing in FANETs. To accomplish this, extensive simulations are performed for different BI and N_{ToT} by varying the node density, traffic flows and node speed.

2. BACKGROUND AND RELATED WORK

Generally, in geographical routing, greedy forwarding is used to forward the data packets from source to destination. In this, the forwarding node selects the next-hop closest to the destination from its neighbor list. To do this, each node requires location information of the destination and neighboring nodes. The location of destination is assumed to be known in advance (in case of fixed destination) or can be obtained by using the location services [8]. The position information of neighboring nodes is achieved by exchanging beacons at regular intervals. In greedy perimeter stateless routing (GPSR) [9], the BI is fixed at 1s and N_{ToT} is calculated as:

$$N_{ToT} = \alpha * BI \quad (1)$$

where the value of α is 4.5s.

Several works have been done by researchers for mobile ad hoc networks (MANETs) and vehicular ad hoc networks (VANETs) to control the beacon overhead and to maintain the updated list of neighboring nodes. The impact of location errors caused by mobility and beacon interval on the performance of geographical routing in MANET is analyzed in [10], [11]. In [12], the limitations of periodic beaconing are explored, and authors suggested various dynamic beaconing schemes to mitigate them. In [13], dynamic adjustment of beacon interval is proposed by using the link change rate. In [14], each node utilizes a fuzzy logic controller to reduce the beacon overhead by considering node speed and the number of neighboring nodes. The authors in [15] evaluated the effect of neighbourhood discovery time on the performance of geographic routing in mobile sensor network and calculated the suitable time interval for neighbourhood discovery after considering the communication range, speed and number of neighboring nodes. In [16], a beaconing scheme is proposed to maintain the trade-off between the accuracy of the neighbor table and beacon overhead. The authors in [17] and [18] exploited vehicles' mobility characteristics to design adaptive beaconing schemes for VANETs. In [19], the authors proposed the adaptation scheme to adjust the beacon frequency and beacon transmission power to control the congestion due to beacon messages. However, for FANETs, few proposals are available to overcome the adverse effects of periodic beaconing. For instance, in [20], the adaptive hello-interval scheme is proposed for FANETs to reduce energy consumption while improving network performance. Additionally, in [21], an adaptive beacon scheme is presented in which the fuzzy control system is used to adjust the frequency of beacons dynamically. In [22], a predictive mathematical model is used to adapt the beacon interval of ad hoc on-demand distance vector (AODV) protocol. In this, beacon rate is controlled by considering the dimensions of mission area, velocity and transmission range of UAVs. In [23], mobility information of UAV is exploited to adjust the beacon transmission rate to improve the accuracy of position information stored in neighbour table.

To the best of author's knowledge, no such study has been found that analyzed the impact of beacon intervals for geographical routing in FANETs. As the characteristics of FANET is different from MANETs and VANETs (in terms of mobility, topology change, speed and propagation loss), the studies done for these networks may not be used directly and need to be analyzed for FANETs [24]. Therefore, in this work, the impact of beacon interval on the performance of geographical routing in FANET is analyzed by varying the node speed, node density and number of traffic flows. Moreover, the effect of assigning fixed N_{ToT} to all neighbor table entries is also explored.

3. IMPACT OF BEACON INTERVAL AND NEIGHBOR TIMEOUT TIMER

In this section, the impact of beacon interval and neighbour timeout timer on the performance of geographic routing is discussed.

3.1. Impact of beacon interval

In geographical routing, beacons are broadcasted by nodes at regular interval to exchange their position information with neighboring nodes. In highly mobile scenario, where position of nodes changes frequently, nodes need to broadcast beacons at higher rate to maintain updated topological information in neighbor table. However, the transmission of beacons at higher rate not only consumes extra bandwidth and energy but also interferes with the transmission of data packets which increases the chances of collision and congestion. On the contrary, larger beacon interval leads to outdated and inaccurate position information in the neighbor table, resulting in non-optimal routing decisions. As shown in Figure 1, three UAVs U_i, U_j and U_k are flying with velocity V_i, V_j and V_k respectively and exchange their position information at BI interval. At time t_1, UAVs exchange beacons among themselves and position information of neighboring nodes are stored in their respective neighbor tables. At time $t+\Delta t$, U_i gets a packet for destination (*d)* and searches its neighbor table for optimal next hop closest to the destination according to greedy forwarding. U_i selects U_j as next hop since it is closest to *d* as per neighbor table but in reality, the position of nodes has changed since the last transmission of beacons and currently, U_k is the closest next hop to *d*. U_i takes sub-optimal routing decision for some time, and after BI time neighbor tables of all nodes get updated with the current status of one-hop nodes only if we assume beacons are not lost during transmission. So in best case, U_i makes routing decision sub-optimally for the following time (T).

$$T = BI - \Delta t \qquad (2)$$

Here, the time for which sub-optimal decisions are taken is dependent on BI and Δt. The estimation of Δt is not possible in real-time scenario, but it is evident that as the BI increases, the time for non-optimal routing decisions increases due to stale position information in the neighbor table.

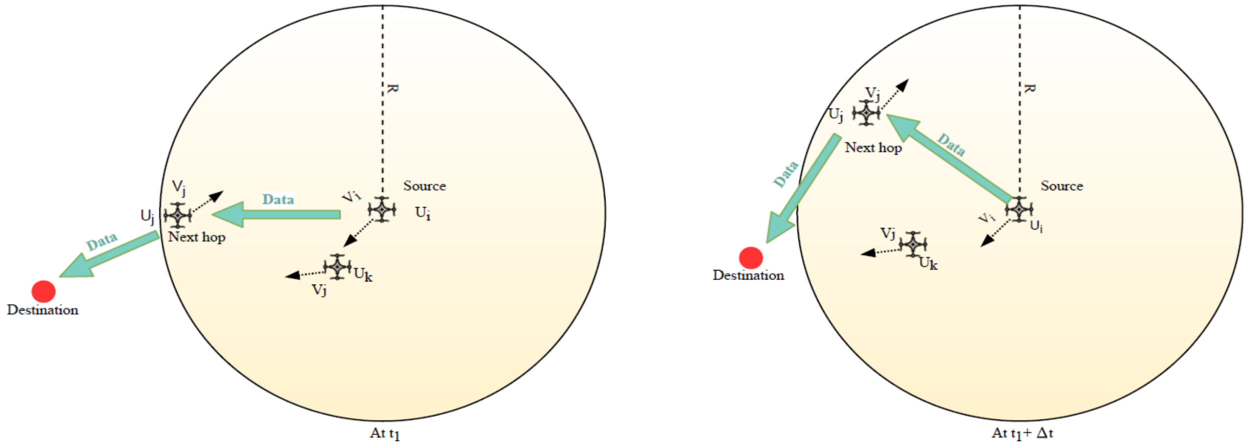

Figure 1 Non-optimal routing decision

Therefore, we try to figure out experimentally that how the transmission rate of beacons influences the performance of geographical routing in different network settings. For that, simulations are conducted for different values of BI (ranging from 0.25s to 3s) by varying the node density, speed and traffic flows.

3.2. Impact of neighbor timeout timer

When node receives a beacon from its neighboring nodes then it extracts the position information and store in its neighbor table. This information is valid for particular time interval known as neighbor timeout timer. If node's neighbor table already contains the entry of its neighboring node, then beacon information is used for updating the position information and timeout timer. When a node needs to forward a packet, it takes routing decisions based on the information present in the neighbor table. In this way, the accuracy of information present in neighbor table affects the effectiveness of routing decisions to a great extent. The accuracy of the neighbor table can be improved by exchanging the beacons at a high rate. However, there are several drawbacks related to the frequent transmission of beacon packets. Moreover, the accuracy of neighbor table not only depends upon the beacon interval but also on the time for which the entry of neighboring node is stored in neighbor table. The information present in neighbor table becomes stale after some time due to the mobility of nodes. Such neighbor table entries are also termed as false neighbors [25], and their presence gives rise to a problem known as the lost link problem [10]. For instance, as shown in Figure 2, UAVs U_i and U_j exchange beacons at time t_1 and stored position information for $\alpha * BI$ time in their neighbor table. At $t_1+\Delta t$, U_j leaves the communication range of U_i, but its entry is already present in neighbor table of U_j. Now, U_i selects U_j as the next hop for each packet which is for destination (*d)*. This situation remains there for a time (T).

$$T = N_{ToT} - \Delta t \qquad (3)$$

$$T = \alpha * BI - \Delta t \qquad (4)$$

Here, α is constant whose value is 2 in most cases. There is a trade-off, as a very large value of α leads to stale entries, and a short value leads to early removal of neighbor table entries. Therefore, to evaluate the impact of N_{TOT}, we conduct simulations for different values of α.

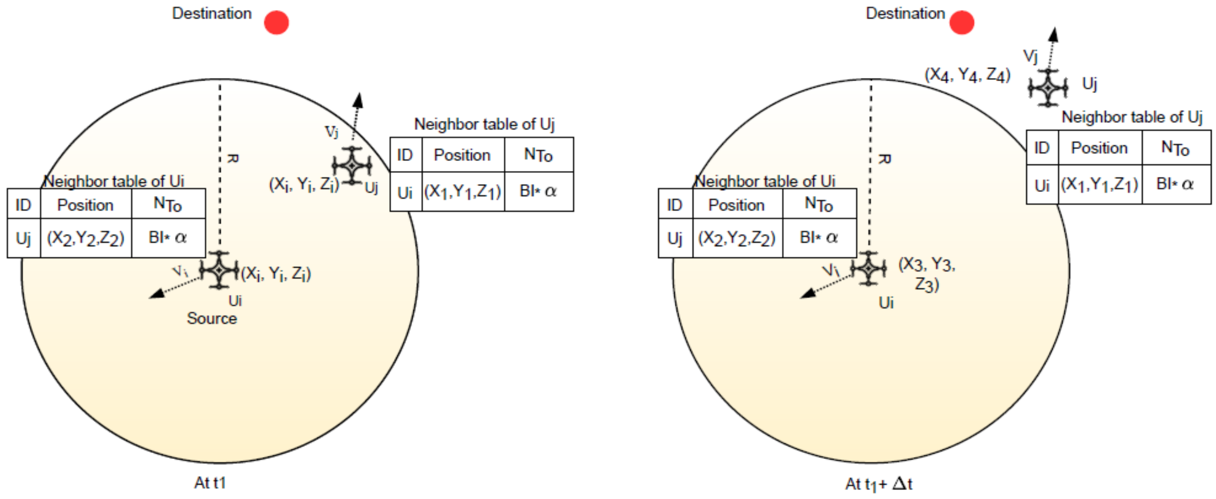

Figure 2 Lost link problem

4. PERFORMANCE EVALUATION

In this section, the impact of beacon interval and neighbor timeout timer on the performance of geographical routing in FANETs is analysed experimentally by conducting a set of simulations. For that, GPSR (one of the widely used algorithm for geographical routing) is implemented in ns-3 and simulations are performed by varying BI and N_{ToT}. In each simulation, multiple UAVs ranging from 20 to 50 are randomly deployed in a field of size 2000 m * 2000 m * 150 m. As a media-access-control (MAC) layer protocol, IEEE 802.11b is used, and each UAV flies according to the 3D version of the Gauss Markov mobility model. The performance metrics considered in this analysis are described as follows:

The performance metrics considered in this analysis are described as follows:

Packet delivery ratio- It is defined as the total number of packets received divided by the total number of packets transmitted.

Mac transmission failures- It represents the total number of transmissions of data packets failed at Mac layer.

4.1. Effect of beacon interval

This subsection analyses the performance of geographical routing for different values of BI in terms of packet delivery ratio and mac transmission failures. The value of BI ranges from 0.25s to 3s, and the value of N_{TOT} is fixed at 2*BI.

4.1.1. Packet delivery ratio

Figure 3 shows the influence of beacon interval on packet delivery ratio for varying numbers of nodes in the network. It is seen that BI at 1s exhibits a superior delivery ratio for low node density and at 0.5s performs better as the number of nodes in the network increases. In addition, the performance of GPSR improves with the decrease in BI and this trend continues only up to 0.5s and after that performance start deceasing.

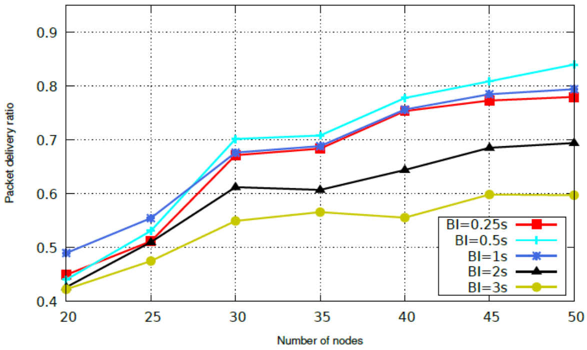

Figure 3 Effect of BI on delivery ratio for varying node density

The accuracy of neighbor table improves as there is decrease in BI since there is frequent exchange of neighborhood information. However, the decrease in BI also increases beacon overhead that leads to congestion and interference with data transmission. Therefore, when BI is set at 0.25s the delivery ratio starts decreasing which is due to the overhead caused by beacons. It is worth mentioning that at BI=3s, GPSR shows underperformance as nodes are unable to maintain the updated neighbour list due to long beacon interval.

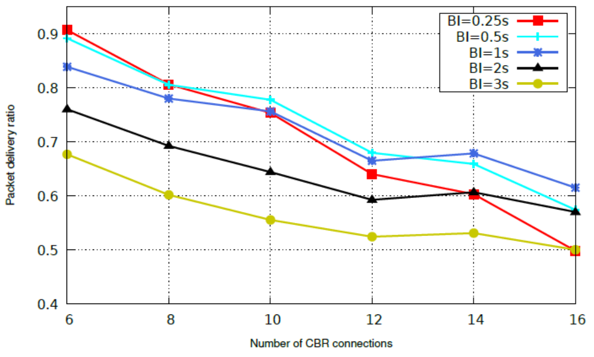

Figure 4 Effect of BI on delivery ratio for different CBR connections

Figure 4 shows the packet delivery ratio versus number of constant bit rate (CBR) flows for different BI. It is interesting to note that GPSR with BI=0.25s outperforms all other beaconing settings when the traffic flow in network is low. Then its performance starts decreasing as the traffic load in the network increases. This is because at a high beacon rate, the possibility of collisions and network congestion increases when there is an increase in the number of data packets. On the other hand, GPSR with BI=3s shows the least packet delivery ratio. The reason behind this is that the exchange of location information after every 3s in dynamic scenario failed to maintain the updated and accurate neighborhood information. As a result, outdated information in the neighbor table leads to inaccurate and sub-optimal routing decisions.

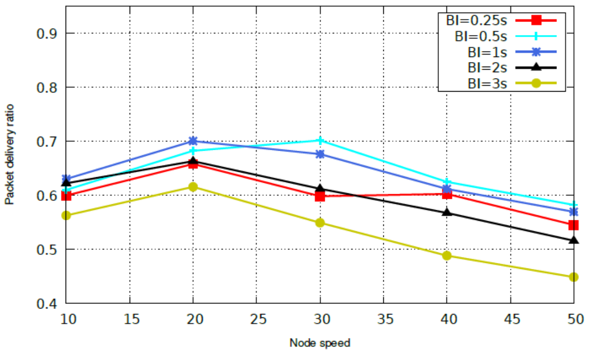

Figure 5 Effect of BI on delivery ratio for varying node speed

Figure 5 shows the packet delivery ratio for different node speeds. The beacon interval at 1s outperforms for low mobile scenarios, and 0.5s performs better when there is an increase in node speed. At low beacon intervals, nodes can capture accurate topological information, which improves the routing performance. However, when BI=0.25s, the network shows a low packet delivery ratio due to increased beacon overhead. Thus, lowering the beacon interval is favourable up to a certain extent, and after that it starts degrading the network performance.

4.1.2. Mac transmission failures

Figure 6 shows the number of mac layer transmission failures of data packets versus the speed of nodes in the network. The reasons behind the transmission failure at Mac layer can be collisions, interference or link failure due to mobility. It is seen that with the increase in node speed and BI, the number of failures increases.

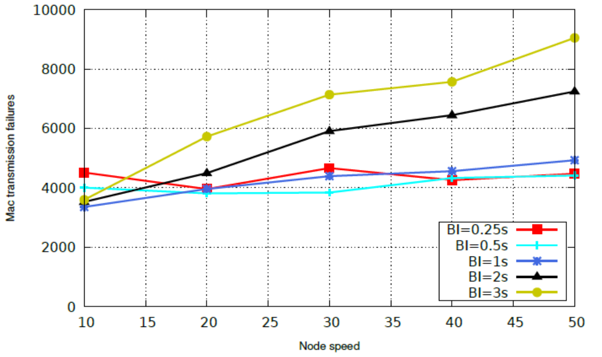

Figure 6 Effect of BI on transmission failures for varying node speed

In GPSR, when a node gets a packet to forward, it selects the most appropriate node (as per rules) from its neighbor table as a next hop. There is a possibility that the selected next-hop may leave the communication range of the forwarding node due to mobility. In that case, transmission failures happen at Mac layer and after multiple re-transmissions packets are dropped by node if acknowledgement is not received. Thus, at higher BI, there is a surge in the proportion of stale entries, leading to erroneous routing decisions and consequently resulting in higher transmission failures at Mac layer.

4.2. Effect of neighbour timeout timer

In this subsection, the impact of neighbour timeout timer on routing performance is analyzed. To do so, the value of BI is fixed at 0.5s, and the value of N_{ToT} is calculated according to α*BI, where α ranges from 1 to 5.

4.2.1. Packet delivery ratio-

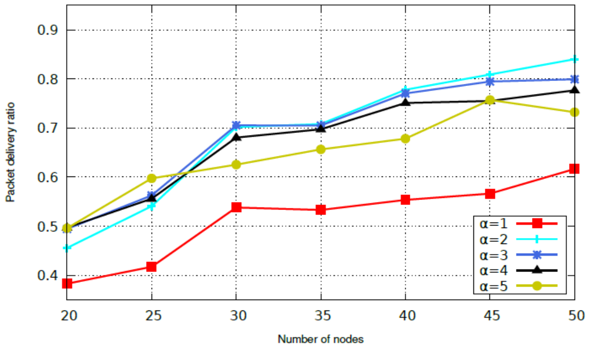

Figure 7 Packet delivery ratio for varying node density

Figure 7 illustrates the packet delivery ratio for different neighbor timeout timer. In sparse network, GPSR with large N_{ToT} performs better, and as the density increases, α=2 outperforms other settings. Moreover, the network performance degrades for very low N_{ToT}. This is because entries related to neighboring nodes are removed too early, and the neighbor table failed to reflect the exact view of topology, which subsequently affects the routing decisions [26-28].

Figure 8 and Figure 9 shows packet delivery ratio versus the node speed and number of CBR connections, respectively. At α=2 and α=3 demonstrates the best performance as compared to other settings. The assignment of very low and very high value to N_{ToT} negatively affect the routing performance. The low N_{ToT} does not reflect exact topology, and large N_{ToT} leads to an increase in the number of false neighbors [29].

Figure 10 shows the transmission failures at Mac layer versus the speed of nodes in the network. Here, α=2 and α=3 outperforms other settings of N_{ToT}. The α=3 shows superior performance for the low mobility, and as the node speed increases, α=2 starts outperforming. This is due to the rise in the number of false entries in neighbor table due to increased node speed. In highly mobile scenario, setting a large neighbor timeout increases the number of false neighbors whose entries are present in the neighbor table of nodes even though they have left their communication range [30-32].

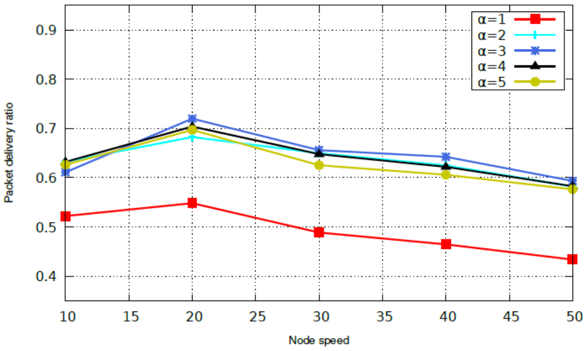

Figure 8 Packet delivery ratio for varying node speed

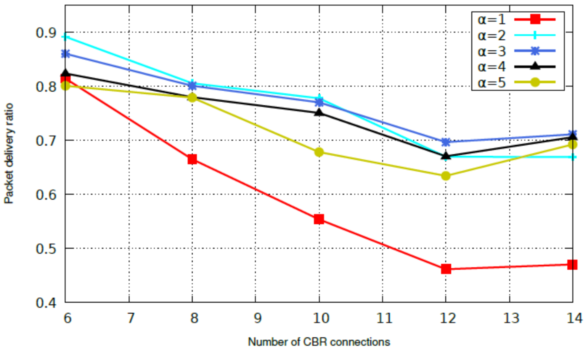

Figure 9 Packet delivery ratio for different CBR connections

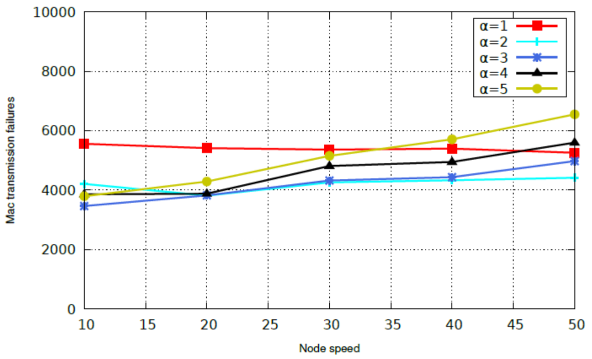

Figure 10 MAC transmission failures for varying node speed

As a result, selecting a false neighbor as a next hop leads to transmission failures at Mac layer [33-39].

5. CONCLUSION AND FUTURE SCOPE

In this work, the impact of beacon interval and neighbor timeout timer on the performance of geographical routing is evaluated. For that, multiple sets of simulations are conducted for different beacon intervals and neighbor timeout timers. The simulation results demonstrate that none of the beacon interval and neighbor timeout timer settings can achieve the best performance in all network conditions. BI=1s exhibit best performance for sparse connectivity and lower mobility. On the other hand, for highly mobile and dense scenarios, BI=0.5s shows outperformance. The neighbor timeout timer at α=2 performs better for lower traffic loads and highly mobile and dense scenarios. On the other hand, in high network traffic and low mobility, α=3 perform better than other settings. As future work, we plan to design an intelligent beaconing scheme that can adapt itself according to the mobility characteristics of UAVs.

LIST OF ABBREVIATIONS

The abbreviations used throughout the manuscript are listed below:

AODV	Ad hoc on-demand distance vector
BI	Beacon interval
CBR	Constant bit rate
FANETS	Flying ad hoc networks
GPSR	Greedy perimeter stateless routing
MAC	Media-access-control
MANETs	Mobile ad hoc networks
N_{TOT}	Neighbor timeout timer
UAVs	Unmanned aerial vehicles
VANETs	Vehicular ad hoc networks

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