INVESTIGATING THE IMPACT OF HELLO MESSAGES ON AODV PERFORMANCE IN UAANET

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Recently there has been an increasing interest in employing Unmanned Aerial Vehicles (UAVs) in a wide range of applications, mainly in real-time surveillance and reconnaissance operations. UAVs have the ability of creating an ad hoc communication network in the air which is known as Unmanned Aeronautical Ad-hoc Network (UAANET). One of the most aspects that has a significant impact on the performance of these systems is the routing protocol. Ad hoc On-demand Distance Vector (AODV) is a very popular reactive protocol that has been widely used in UAANETs. One distinct aspect of this protocol is its ability to provide connectivity information via the use of Hello messages. However, using Hello messages also affects performance. This hello effect has never been studied before in UAANET conditions, and the existing similar studies on MANETs are not ideal for UAANETs. This paper investigates how changing the hello parameters would affect the performance of UAANET in terms of packet drop ratio (PDR), delay, and overload. Simulations were performed using Optimized Network Engineering Tool (OPNET 14.5) modeler. Then mathematical curve fitting was performed on the resulting PDR to find an empirical model that defines the functional relationship between the ALLOWED_HELLO_LOSS parameter and the achieved PDR. This model could help adjusting the hello parameters according to the desired performance results and the UAANET application requirements.

Keywords: UAV, UAANET, AODV, Hello messages, Allowed-hello loss, Packet drop ratio. Polynomial curve fitting

1. Introduction

An Unmanned Aerial Vehicle (UAV) is an aerial vehicle which can operate without a pilot. Instead of that, the UAV either operates autonomously by its own built-in computer or can be remotely controlled by a ground station controller. UAVs are now widely used in a variety of applications in both the civilian field and in the military field. In general, UAV operations can be divided into three main functions: Intelligence, Surveillance and Reconnaissance (ISR)

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[1]. When UAVs are deployed in operations, they communicate wirelessly to share information among them in order to decrease mission completion time, total/maintenance cost, detectability, and to increase scalability, survivability, and reliability [2]. This cooperation is achieved through self-organizing and multi-hop networking architecture. This kind of network between UAVs is usually called Unmanned Aeronautical Ad-hoc Network (UAANET).

UAANET is considered a special case of the well-known Mobile Ad-hoc Network (MANET) as a dynamically self-organizing and infrastructure-less network of mobile nodes communicating over multi-hop wireless links, and moving freely with different speeds and in different directions, where each node functions as both: a host which receives and transmits its own data packets, and a router which forwards packets belonging to other nodes. On the other side, UAANETs have some special characteristics as follows:

(1) UAANET often deploys a lower number of nodes (UAVs) than that in MANET case. This is because the fact that UAVs can fly at relatively high speeds, up to hundreds of kilometers per hour [1], enabling them to cover mission area.

(2) UAANET topology changes more frequently than MANET topology. This is due to the high mobility of network nodes. Moreover, the distance between UAVs harmfully affects connectivity in the network [3] [4].

(3) As the nodes in UAANET are flying UAVs in the sky, then the free-space path loss model is more suitable to characterize propagation in such networks [3] [4].

(4) In UAANET operation scenario, UAVs are supposed to move intelligently. This implies that movement pattern of UAVs depends on the application of the network [5] [1]. Upon that, Mobility models which are being used in evaluating MANETs such as: random walk, random waypoint, random direction, and Brownian motion are inconsistent -by their standard form- with the previous assumption of intelligent UAVs [1].

(5) UAANETs have stronger delay constraints especially in monitoring applications [3] [4].

As stated before, UAVs in a mission usually communicate with each other for many reasons such as cooperation, control, and path planning. Then, a routing protocol is needed to route data traffic through the multiple UAVs within UAANETs. A routing protocol for UAANETs must take into consideration the specific features of these networks as previously detailed to ensure efficient communication between UAVs. However, most existing UAANET routing protocols are extensions of the well-known MANET routing protocols.

In such dynamic networks where topology changes frequently due to node mobility, obtaining accurate local link connectivity information becomes extremely important for route establishment and maintenance. Most proactive and reactive routing protocols use periodic hello messaging scheme to obtain local link connectivity information. Network performance is influenced by the hello messaging settings adopted by the routing protocol. These settings involve: (1) the HELLO_INTERVAL parameter which determines how often a node should broadcast helloes to its neighbors, and (2) the ALLOWED_HELLO_LOSS parameter which determines when a node should timeout its neighbors. Many previous researches have noticed the effect of hello messaging settings on networking performance, and a lot of modified hello messaging schemes have been introduced in literature on MANET to enhance its performance.

Some works like [6] [7] [8] [9] focused on the purpose of making adaptive hello messaging schemes for MANETs. Other works focused on analyzing the impact of hello parameters on network performance either empirically by simulations or mathematically. Authors of [10] worked on optimizing AODV performance via a flexible and parameterized approach for dealing with link breaks and route repairing strategies. In this article, two functions were utilized, the first is link break detection time(L_{lb}), using the HELLO message to detect link failure, and the second is link break position parameter (L_{bp}) for AODV's local route repair. The authors showed that the default setting of the AODV for the HELLO message does not produce optimal results for all cases, especially in case of highly mobile networks. They also showed that using a fixed local route repairing threshold did not yield an optimal PDR value, and that the optimal technique depends greatly on the network load.

In [11], the authors examined the effectiveness of hello messages for monitoring link status by performing experiments in in the lab and in the field. They implemented the Ad hoc On-demand Distance Vector (AODV) routing protocol, and examined two values for ALLOWED_HELLO_LOSS: the recommended value of two, as well as an experimental value of three. They determined that many factors influence the utility of hello messages, including allowed hello message loss settings, discrepancy between data and hello message size and 802.11b packet handling.

In [12], the authors introduced an analytical study of the performance of hello-based link failure detection. They derived an analytical model for hello-based failure detection that provides a lower bound on the packet delivery ratio (PDR). This model was validated by experiments. They showed that packet delivery ratio can be maximized through selecting appropriate values for hello interval and allowed-hello-loss depending on network conditions such as traffic load, link failure rate, and hello delivery rate. In [13], the authors used Ad-hoc On-demand Distance Vector (AODV) routing protocol in real MANET scenarios. They introduced a theoretical and empirical analysis for the impact of HELLO_INTERVAL configuration on network performance. They concluded that changing the default parameter configuration according to network conditions may lead to significant improvement in reactivity to topology changes. On the other hand, this change may have a small impact in power consumption and end-to-end bandwidth.

However, these studies were not ideal for UAANETs because they had their own constrains and assumptions. To the best of our knowledge, no work has been carried out to understand the effect of hello parameters on routing performance within UAANETs, as these networks use the same routing mechanisms of MANETs.

This paper aims to look at the effect of hello messaging settings, precisely the ALLOWED_HELLO_LOSS parameter, on performance metrics such as (Delay, Overhead, and Packet Drop Ratio PDR) within UAANETs. The Optimized Network Engineering Tool (OPNET 14.5) simulation software tool was used for this analysis. The analysis and simulations focus on the Ad Hoc On-Demand Vector Protocol (AODV). Then, the simulation results were used to develop an empirical model that defines the functional relationship between the ALLOWED_HELLO_LOSS and the achieved PDR.

The rest of this paper is organized as follows: the next section provides a theoretical background of MANET routing protocols, AODV working principle, and hello messaging. Section 3 describes the practical study in detail. Simulation Results and discussion are presented in section 4. Section 5 concludes the results together with the directions for future work.

2. Theoretical Background

In the literature on Mobile Ad-hoc Networks (MANETs), there are different categorizations for routing protocols [1] [14] [15]. The approach adopted in this paper, is to classify the protocols based on their routing strategy. Hence, we categorize routing techniques in three major groups: proactive routing (e.g., OLSR, DSDV and B.A.T.M.A.N), reactive routing (e.g., DSR and AODV), and hybrid routing protocols (e.g., ZRP). More detailed descriptions of routing protocols for Ad-Hoc wireless networks and MANET are presented in [16], [17], [18], and [19].

AODV Overview:

Ad hoc On-Demand Distance Vector (AODV) [19] is a routing protocol for mobile ad hoc networks. As we mentioned before, AODV is categorized under reactive routing (on demand routing) as it determines a route only when needed. AODV algorithm consists of three main phases: route discovery, data forwarding and route maintaining [20]. AODV relies on hello messaging mechanism to observe local connectivity of a node on an active route, and to detect link break when it occurs then AODV reports this break to the source node.

Hello Messages:

In dynamic networks where topology changes frequently due to node mobility, maintaining local connectivity information becomes a key factor on network performance. AODV protocol provides connectivity information mainly via the use of Hello messages. Though other link failure detection mechanisms such as link layer feedback are defined [19], hello-based method is preferred because of complexity and link layer dependency of the former method [11] [13] [21] [22] [23].

A node should only use hello messages if it is part of an active route. The process of maintaining network connectivity runs as follows: every HELLO_INTERVAL milliseconds, the node checks whether it has sent a broadcast within the last HELLO_INTERVAL. If it has not, it may broadcast a hello packet. When a node receives a hello message from its neighbor, it creates or refreshes the routing table entry to the neighbor. A node assumes that a neighbor is no longer within transmission range, and connectivity has been lost in case where it has not receive any packets (Hello messages or otherwise) from this neighbor for more than ALLOWED_HELLO_LOSS * HELLO_INTERVAL milliseconds.

Clearly, the determination of local connectivity performance using hello messages is controlled by the two variables: HELLO_INTERVAL and ALLOWED_HELLO_LOSS.

HELLO_INTERVAL specifies the maximum time interval between the transmissions of hello messages. The default value for HELLO-INTERVAL in AODV protocol is one second [19]. Setting this variable to lower values, new neighbors and link breaks are detected faster and then neighbor-tables will be accurate. However, too short hello intervals cause unnecessary protocol overhead. This increases congestion in the network and reduces the network throughput and increases the energy consumption of the nodes. On the other hand, setting this variable to higher values, then congestion due to control overhead will be alleviated. However, long hello interval may cause slow reflection of the network changes and may lead to inaccurate neighbor-tables.

ALLOWED_HELLO_LOSS is a countable number which specifies the maximum number of HELLO_INTERVAL periods to wait without receiving any hello message before detecting a loss of neighbor connectivity. The default value for ALLOWED_HELLO_LOSS in AODV protocol is two [19]. Setting this variable to the only available lower value which is one may decrease performance because neighbors whose helloes have been lost due to temporary bad radio conditions will be considered as disconnected. On the other hand, setting this variable to the next higher value which is three decreases performance since reactivity to topology changes is degraded [11] [13].

3. Practical Study

Searching Mission Configurations:

For the simulation, the authors consider a search mission of an UAANET within a square area of size (2 km * 2 km) where UAVs move according to a certain mobility scenario. In general, proposing accurate mobility scenarios for UAANETs is an open research problem [1] [5] [24] [25]. The mobility scenarios adopted in this simulation depend on using one of the available OPNET mobility models, which can be adapted to fit search missions by changing several OPNET settings, then the authors consider the Random Waypoint (RWP) mobility model. A detailed description of the RWP mobility model can be found in [26] [27]. The authors defined three different UAVs scenarios according to speed range as presented in Table 1. These ranges of speed are typical values for a UAANET including medium size UAVs [1]. The mobility characteristics for search applications are summarized in Table 1 [1].

Table 1

Mobility parameters of a search scenario [1].

Parameter	Value
Mobility Model	Random Waypoint
Low Speed Scenario	Uniform (10,20) m/s
Medium Speed Scenario	Uniform (30,40) m/s
High Speed Scenario	Uniform (50,60) m/s
Size	4 km2
Number of UAVs	10, 20
Pause Time	0
Start Time	0
Stop Time	End of Simulation
Simulation Time	10 hours

The propagation model considered in the simulations is a free space path loss, which models the propagation as a disc around the transmitter [1]. The transmission range of the UAVs will be 1000 m. Transmit power for acquiring such a range is 0.00322798735385 W [1].

MAC layer specifications are also listed in Table 2. The values for such a setting are assumed to be typical values for medium size UAVs based on [1].

Table 2

MAC layer specifications [1].

Parameter	Value
Protocol	IEEE 802.11
Data Rate	1 Mbps
Transmission Range	1000 m

Routing Protocol Settings:

In order to study the impact of hello messaging settings on network performance, the authors considered incrementing the ALLOWED_HELLO_LOSS parameter from the value 1 to 11 for each scenario (OPNET provides this parameter as a countable number of the hello messages allowed to be lost), while keeping the HELLO_INTERVAL parameter as its default.

AODV parameters for hello messages that were adopted in our simulations are available in Table 3. Please note that the rest of AODV configurations were kept as their default values in OPNET simulator [1] [19].

Table 3

AODV configurations.

Parameter	**Value**
Hello Interval	Uniform (1, 1.1)
Allowed Hello Loss	1,2,3,4,….11 (hello messages lost)

To summarize, the practical study covers two different UAANETs in a fixed size region of 4 km^2: one with 10 UAVs and the other with 20 UAVs. For each UAANET, the authors consider three ranges of node velocity (low, medium, high). Then for each pair of (UAANET, Speed), the authors consider 11 distinct values for the ALLOWED_HELLO_LOSS parameter. In consequence, there is a total number of 66 simulations to be carried out. Each of the 66 simulations was run six runs. Each of those runs was generated using a different seed of the pseudo-noise sequence generator available in the OPNET core, after which the average of the six runs was computed for each performance metric. The performance metrics that were considered are: end-to-end delay, packet drop ratio PDR, and overhead.

$$PDR = \left(1 - \frac{Total\ MANET\ Received\ Traffic\ (pkts/sec)}{Total\ MANET\ Transsmitted\ Traffic\ (pkts/sec)}\right) * 100$$

$$Overhead = \frac{AODV\ Routing\ Traffic\ Sent\ (pkts/sec)}{AODV\ Routing\ Traffic\ Sent\ (pkts/sec)\ +MANET\ Traffic\ Sent\ (pkts/sec)} * 100$$

4. Results and Discussion

In this section, simulation results for a search mission with 10 and 20 UAVs are reviewed (remember that all discussed scenarios are within small area of size 2 * 2 km^2). This paper considers the UAANET with 10 UAVs in detail. Our analysis focuses on PDR metric by applying polynomial curve fitting (using MATLAB 2016) to find polynomial p(x) of degree n that is a best fit (in a least-squares sense) for the PDR curve in each scenario, while just mentioning delay and overload results.

First Case: 10 UAVs in low speed scenario

Fig 1 shows PDR changes in the low speed scenario for the different distinct values of ALLOWED_HELLO_LOSS (AHL) parameter from 1 to 11. Results show that the ALLOWED_HELLO_LOSS parameter has noticeable impact on PDR in this UAANET scenario, where the PDR increases from 2.8% to 13.9%. Another noticeable result is that the overload was at a high value (56%) when AHL = 1, then decreased to (20%) when AHL = 2 which is the default value in AODV protocol and kept constant at (18%) for the remaining values of allowed loss.

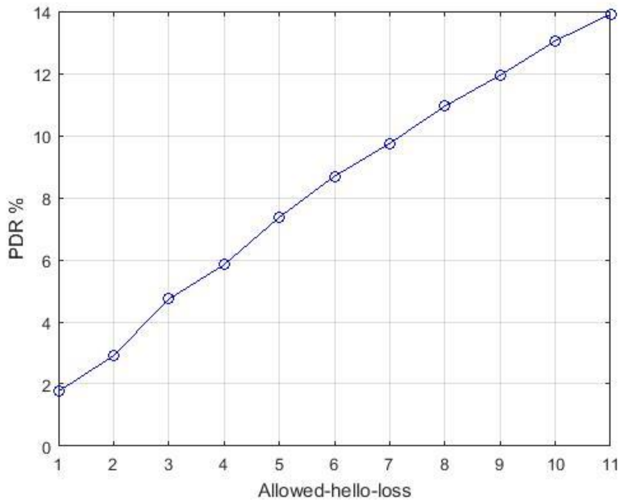

Fig 1. PDR changes in UAANET with 10 UAVs in the low speed scenario

Fig 2 shows the fitting curve of the second degree (n = 2) for the PDR in the low speed scenario. For this degree (n=2), the polynomial $p(x) = ax^2 + bx + c$ has the following coefficients:

$$a = -0.3531599588, b = 4.084348604, c = 8.583664282$$

The maximum and the minimum proportional error were 0.0793, 0.0025 at AHL = 2 and AHL = 11 respectively. The average proportional error was 0.0226. In order to verify fitting by this polynomial, two other simulations were carried out with AHL = 12 and 13, and the proportional errors were 0.005 and 0.007, respectively. Notice (the term AHL = n means that n hello messages are allowed to be lost in succession before detecting a loss of neighbor connectivity).

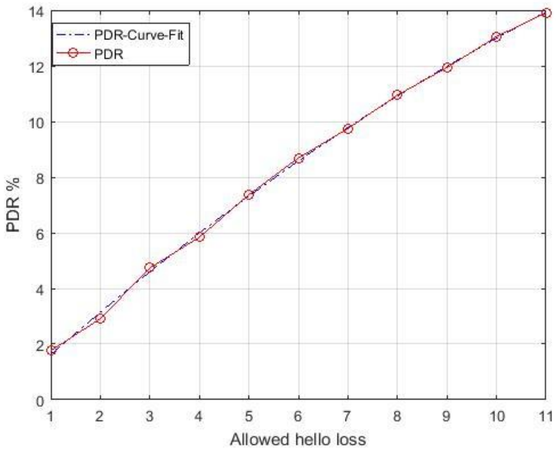

Fig 2. The fitting curve of degree n=2 for the PDR in UAANET with 10 UAVs in the low speed scenario.

Second Case: 10 UAVs in medium speed scenario

Simulation results for the medium speed scenario showed similar behavior in the general sense. Fig 3 shows PDR changes in the medium speed scenario against AHL changes.

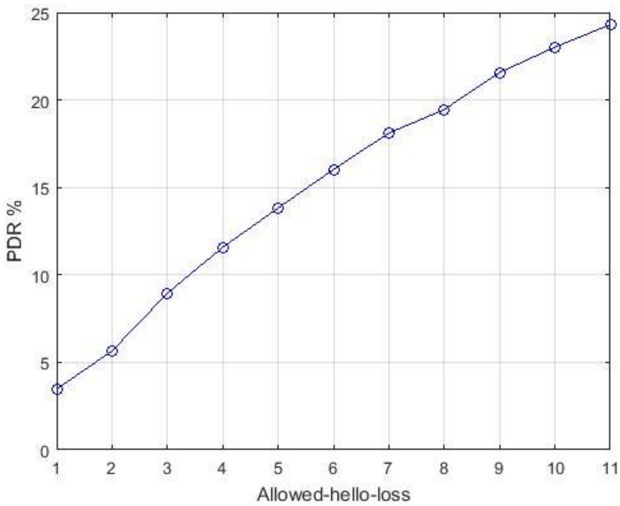

Fig 3. PDR changes in UAANET with 10 UAVs in the medium speed scenario

In this case, PDR scored higher values than the previous case for each individual AHL value by almost twice. Overload results were almost the same as those at the low speed scenario with a negligible shift. Fig 4 shows the fitting curve of the second degree (n = 2) for the PDR in the medium speed scenario. In this scenario the coefficients were:

$$a = -0.9693779437, b = 6.980776773, c = 15.96931587$$

The maximum and the minimum proportional error were 0.086, 7.5807e-04 at AHL = 2 and AHL = 11 respectively. The average proportional error was 0.0197. Simulations with AHL = 12 and 13 were also performed, and the proportional errors were 0.0163 and 0.0034, respectively.

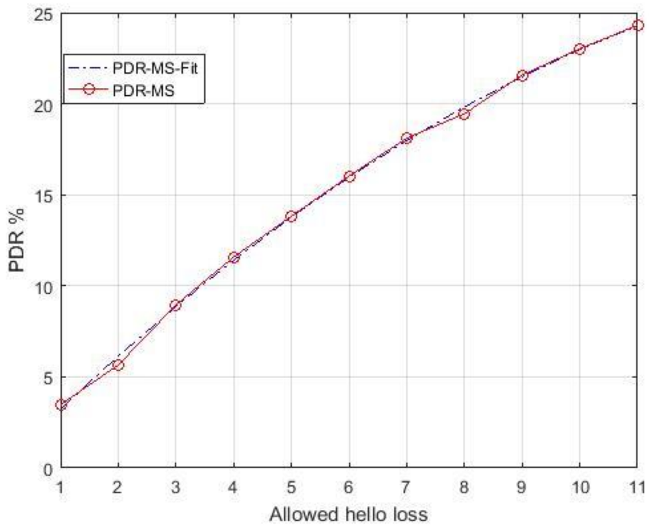

Fig 4. The fitting curve of degree n=2 for the PDR in UAANET with 10 UAVs in the medium speed scenario.

Third Case: 10 UAVs in high speed scenario

Fig 5 shows PDR changes in the High-speed scenario against AHL changes. PDR also scored higher values than the previous two cases for each individual AHL. Overload results are kept without any remarkable change compared to the values mentioned at the low speed scenario. Fig 6 shows the fitting curve of the second degree (n = 2) for the PDR in the high-speed scenario. The polynomial's coefficients in this case were:

$$a = -1.863139366, b = 8.639544199, c = 21.44099342$$

The maximum and the minimum proportional error were 0.0426, 7.8460e-04 at AHL = 2 and AHL = 1 respectively. The average proportional error was 0.0101. Simulations with AHL = 12 and 13 were also performed for fitting verification, and the proportional errors were 0.0293 and 0.0652, respectively.

The resulting delay showed an unsystematic behavior for all previous scenarios, where its values changed within the range of [200, 400] ms. This isn't surprising because the delay is more relevant to the size of the area and the number of nodes in the network.

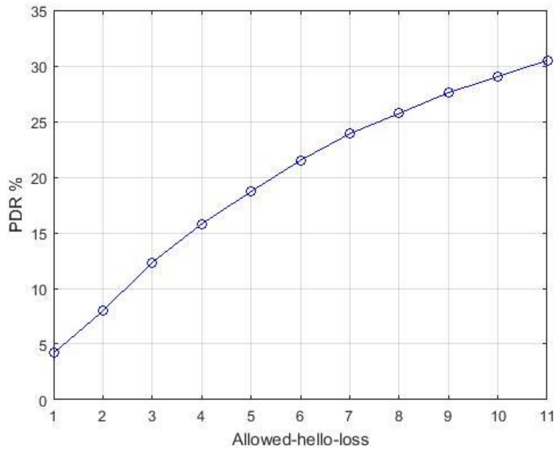

Fig 5. PDR changes in UAANET with 10 UAVs in the high-speed scenario

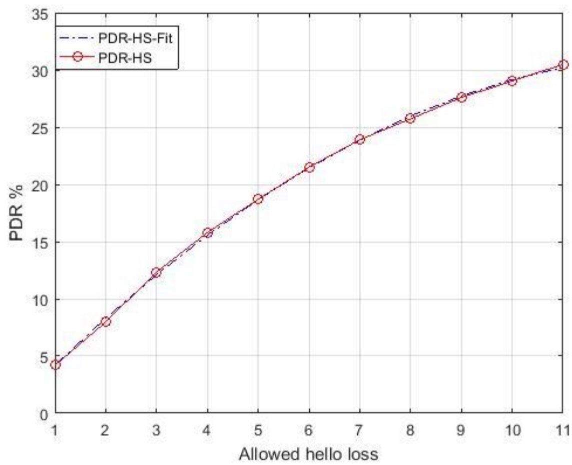

Fig 6. The fitting curve of degree n=2 for the PDR in UAANET with 10 UAVs in the high-speed scenario.

UAANET of 20 nodes:

Simulation results for the PDR in UAANET consisting of 20 UAVs within small area are viewed next. Table 4 shows the results for the polynomial fitting of the second degree (n = 2) for the PDR curve in low, medium, and high-speed scenario. Notice that the first point where AHL = 1 was excluded from the fitting curve. The resulting fitting curves in low, medium, and high-speed scenarios are shown in Fig 7.

Table 4

Fitting results for the PDR curves in UAANET with 20 UAVs.

	Low Speed	**Medium Speed**	**High Speed**
a	-0.3779844618	-1.068768209	-1.591831592
b	3.899572261	6.545175621	7.861692279
c	8.993937965	17.14337837	22.77898703
max proportional error	0.0141 @ AHL = 2	0.038 @ AHL = 1	0.0491 @ AHL = 1
min proportional error	0.0026 @ AHL = 5	0.0015 @ AHL= 7	0.0034 @ AHL = 6
avg proportional error	0.0095	0.01097	0.0133
proportional error @ AHL= 12	0.0165	0.0242	0.0224
proportional error @ AHL = 13	0.0291	0.0421	0.0506

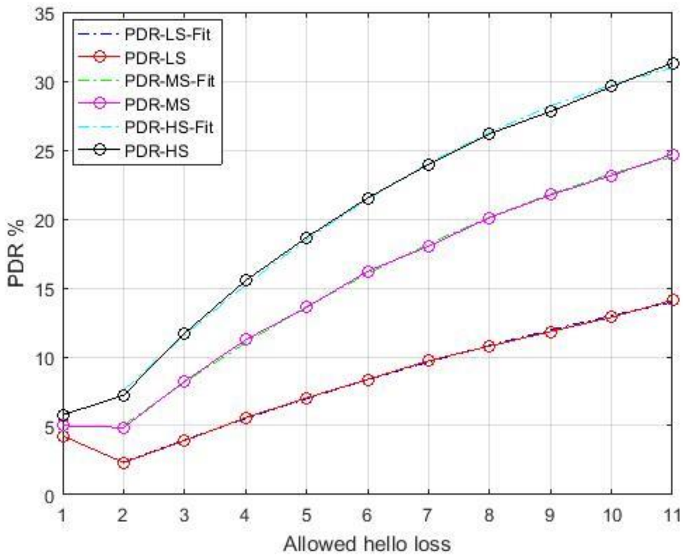

Fig 7. The fitting curves of degree n=2 for the PDR in UAANET with 20 UAVs in low speed (LS), medium speed (MS) and high speed (HS) scenarios.

5. Conclusions

Hello messages configurations including (hello interval and allowed hello loss) have direct impact on the performance of a UAANET. This paper considered precisely the effect of the allowed number of lost helloes on the PDR, overload, and delay when using AODV for routing in UAANETs. Results showed that setting the AHL to 1 provided the best performance in terms of PDR, while it raised the overload to a high value of 56% for all speed ranges in the 10-nodes UAANET. Increasing the AHL degraded the PDR performance by different percentages according to the speed range. For values higher than AHL = 3, changing the AHL had no effect on the overload in all scenarios. The authors used polynomial curve fitting to build empirical models that characterize and predict the PDR over different scenarios of UAANET. The resulting models were polynomials of the second degree (n = 2) and achieved an average proportional error lower than 0.02 in all cases. Such models can then be used in the development of an autonomic control unit inside the UAV. This unit will adjust system parameters and protocols selections based on current and predicted performance results. Future work will include developing a mathematical model for hello messaging approach in the UAANETs environment.

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