Effects of Communication Channel on AODV performance within UAANETs

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Abstract: Many Modern researches are interested in UAVs because of their importance in a wide range of applications. The most important aspect of these researches is routing protocols due to their significant effect in their performance. One of the most popular protocols used in this type of network is AODV, which belongs to reactive protocols family. The major problem with this routing protocol and others is that they do not take into account the state of the channel and they assume it is always AWGN. This paper demonstrates the channel model as an important factor which affects the overall network performance. The paper also shows the great difference in performance between the case of AWGN channel and a shadowed fading channel which exists in real channel. The simulation was done in Optimized Network Engineering Tool (OPNET) 14.5 modeler.

Key-words: fading, path loss, shadowing, UAV network, geographic routing protocol, channel models, reactive routing.

Abbreviations: *AODV*, Ad-Hoc On Demand Distance Vector; *LOS*, Line of Sight; *PDF*, Probability Density Function; *SER*, Symbol Error Rate; *SNR*, Signal to Noise Ratio; *UAV*, Unmanned Aerial Vehicle; *PDR*, Packet Drop Ratio.

1. Introduction:

Unmanned Aerial Vehicle (UAV) is defined as an aircraft with no human operator. In recent years, there has been a trend towards using UAVs in many applications especially surveillance and tracking systems because UAVs are light and consume less fuel and energy. These UAVs share information wirelessly by sending it to a remote control center. When UAVs are put together, they form UAANETs. There are many applications of UAVs and UAANETs as in transportation, scientific research, rescue operations, agricultural crop control and, transport observation of natural phenomena and also in civil applications, where UAVs are used as sensors. UAVs are also used in many military tasks, such as in monitoring and destroying targets, and in detecting secret research laboratories. The most important feature of UAANETs is the rapid change in network topology [1]. Here we are talking about UAVs traveling at speeds up to hundreds of kilometers, so they are quick to navigate which changes the topology of network, besides the nature of the mission also changes this topology. This change will affect the behavior of the UAV in tracking missions. Some of the proposed UAANETs structures rely on MANETs and IEEE 802.11 protocols [3, 4]. UAANETs are types of MANET networks, which are infrastructure-less and self-organized.

The design of routing protocol is essential for good communication [2], but it is very difficult for UAANETs because of the rapid changes in network topology resulting from high-traffic UAVs, the low number of UAVs, and their high mobility. Thus, ensuring constant changes in network topology is major challenge to the performance of UAANETs. UAANETs should have effective network architecture to address these issues which make using traditional routing protocols impossible.

Several protocols for UAANETs have been proposed, but the main problem with all these protocols is that they consider the channel as AWGN without taking into account the effect of communication channel models such as large scale fading model and small scale fading model on protocol performance. [5]

This article presents the impact of communication channel on one of reactive routing protocols which is AODV, and demonstrates by means of results derived from simulation on OPNET 14.5 that the state of the channel should be considered because of the performance of AODV in AWGN channel is significantly different from that in shadowed fading channel.

The remainder of the article is arranged as follows: after the introduction, we present a review of routing protocol and then AODV. After that, we introduce the channel models and the shadowing model statistics which we depend on, and then we talk about scenarios, OPNET, and the parameters of our simulation. Finally, the results and conclusion are shown.

2. Routing Protocol in UAANETs Networks:

The UAANETs protocols were designed based on MANET protocols, taking into account the difficult challenges because of the node's high speed, thus the topology changes rapidly. So we will introduce a brief description of MANET protocols. Increasing the number of nodes in the environment degrades the performance causing the routing protocols face many challenges. Therefore, large ad-hoc network is difficult to be managed. The routing protocols in MANETs are classified into reactive, proactive and hybrid protocols. See figure 1 [6].

2.1 Reactive Routing Protocol:

It is also called on demand routing. Here, the path is established only upon request. Reactive routing protocol involves two processes: route discovery and route maintenance and it is bandwidth efficient because it reduces the control overhead, but it suffers from high latency compared with proactive protocols due to route discovery mechanism. Examples of these types of protocols are: Ad-hoc On-demand Distance Vector (AODV) and Dynamic Source routing (DSR). [6, 7]

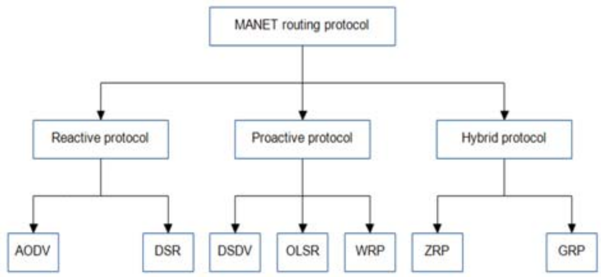

Fig.1 MANET routing protocol.

2.2 Proactive Routing Protocol

Proactive routing protocol stores the information of routes in tables. These tables are updated by exchanging messages periodically between nodes. If there is no path towards the destination node, the packet is placed in the buffer until information about the path to the destination is obtained. In such protocols, route information is available immediately, when the route to a destination is required. Examples of these types of protocols are: Destination Sequence Distance Vector (DSDV), Optimized Link State Routing (OLSR), and Wireless Routing Protocol (WRP).

2.3 Hybrid Routing Protocol

Hybrid routing protocol is a combination of proactive and reactive protocols. It works well for any network. The performance of this protocol is good in networks where the number of nodes is small. Examples of hybrid protocols are: ZRP, GRP. [6]

3. AODV (Ad-Hoc on Demand Distance Vector):

AODV offers high and quick adaptation to dynamic link conditions, low processing and memory overhead, and network utilization. It determines unicast routes to destinations within the ad hic network [8]. The Ad hoc On-Demand Distance Vector (AODV) algorithm enables dynamic, self-starting, multi hop routing between participating mobile nodes wishing to establish and maintain ad-hoc network. The operation of AODV is loop-free by avoiding Bellman-Ford "counting to infinity" problem, it offers quick convergence when the ad-hoc network topology changes (typically, when a node moves in the network). When links break, AODV causes the affected set of nodes to be notified so that they are able to invalidate the routes using the lost link. The types of messages in AODV are: Route Requests (RREQs), Route Replies (RREPs), and Route Errors (RERRs). AODV is a routing protocol that deals with routing table management. Routing table information must be kept even for short-lived routes, like those created to temporarily store reverse paths towards nodes originating RREQs. You can find other details about AODV protocol and it's mechanism in [8].

Many modifications and additions were introduced to the AODV protocol in order to improve its performance. For example, in Ref [9], the authors introduced new modification to the AODV protocol to improve QoS parameters. In QAODV, message field adds extra information like data rate; delay etc, to improve the performance of AODV. To select a route, this protocol considers only those routes which have minimum hop count and total path delay less than or equal to the predefined in the route request. For calculating path delay, it estimates current delay at each node. The algorithm do best route during route discovery and informs all the intermediate nodes about that.

In [10], the author introduced an enhancement to security in AODV by presenting an algorithm against the black hole attacks. The author suggested a new algorithm that enhances the security of AODV routing protocol to encounter the black hole attacks, where protocol IDSAODV has been used with some changes. This algorithm tries to identify malicious nodes according to nodes behaviors in an Ad Hoc network and delete them from routing.

In [11], the author evaluated and improved the performance of AODV by taking two performance metrics; throughput and end-to-end delay with varying number of mobile nodes or vehicle node density. In [12], the author introduced power-hop protocol based on AODV, which is PH-AODV, that uses node power and hop count parameters to select the best routing path. In [13], the author proposed a modification on AODV to make it adaptive for Vehicular Ad-hoc Network (VANET). VANET is generation of ad-hoc networks that implements between vehicles on a road. When a node is mobile, it has three mobility parameters: position, direction and speed. In this method, direction as most important parameter has been used to select next hop during a route discovery phase. With respect to mobility model, if nodes have same direction with source and/or destination nodes, they might be selected as the next hop. Position is another parameter that can be used for next hop selection.

4. Communication Channel Model in UAANETs:

In [14], the author proposed a statistical signal reception model for the shadowed communication channel between two neighbors in a UAV network. In this model, he considered both the shadowing effect and the small-scale fading effect assuming that shadowing is line of sight (LOS) lognormal one [15]. He related the power spectral density of the received signal to noise ratio (SNR) per symbol with the physical path parameters, which could be measured in real time. The precise channel model gave accurate information about the routes. In addition, it was mandatory to find the type of fading within the channels (slow/fast, flat/frequency selective) which had a main role in determining the best techniques for the communication system of the nodes [14]. A lot of work has been proposed in order to find the optimal channel model between network nodes. [16, 17]

The communication channel in UAV networks is dynamic, so the transmitted signals in this channel are affected by random shadowing effects. Shadowing appears because of the differences in obstacles that exist in the Signal path. To describe the received signal envelope, it is mandatory to formulate the statistical model by taking into account the shadowing effects. In the proposed model in [14], the author took the same case of Rician fading, in which there are scattered waves together with the LOS signal component. The author in [14] succeeded in finding a channel model that could be used to calculate the channel quality depending on the channel parameters estimated in real time.

4.1 Large scale fading:

Large scale fading exists when the average received power of UAV is attenuated because of the movement for large distance. This type characterizes the strength changes of the long distance field between the UAV and the ground receiver which are caused by the signal path loss due to distance changes and the shadows of buildings, terrains and other large obstacles. In UAV networks we have both LOS (Line Of Sight) and a group of reflected paths which are Non LOS. LOS component exists between the ground receiving station and the UAV. This component can be seen as large-scale fading in free space of the direct path. The combined reflected paths, receive power changes with the change of the distance between the UAV and the receiving station. [5]

In [14], According to the free space path loss model, the received power signal formula can be written according to the Friis power transmission formula as follows:

$$P_r = P_t G_t G_r (\frac{\lambda}{4\pi d})^2 \ldots. (1)$$

Where d is the distance between the two nodes, G_r and G_t are the antenna gains of receiving node and the transmitting node, respectively, P_t , P_r are the transmitted and received power, respectively, λ is the wavelength of the carrier frequency. This means that the received signal power decays as d^{-2}.

It is better to use the generalized path loss model which could be written in decibel units as below, because the network will work mostly in nonfree space environment:

$$PL(dB) = PL_{ref}(dB) + \alpha 10 \log\left(\frac{d_{ref}}{d}\right) \ldots (2)$$

Where PL is the path loss for a given distance d, and P_{ref} refers to the path loss at a reference distance d_{ref} which is also determined according to the used antennas at the two communicating nodes.

4.2 Small Scale fading:

The presence of long interference and destructive interference of signal path between the UAV and ground receiver, causes Small scale fading to emerge. Small scale fading or simply fading is an expression used to describe the rapid fluctuations of the amplitude, phases or multipath delays of a radio signal over a short period of time or distance travelled, so that large scale path loss effects may be ignored.

According to [14], assuming narrowband stationary model, and according to the definition of the LOS component (random variable with lognormal distribution) and the scatter component, the low pass equivalent complex envelope of the received signal could be written as follows:

$$R(t) = W(t). e^{j\phi(t)} + A(t). e^{j\phi_0} \ldots. (3)$$

Where W(t) is the amplitude of the scatter component. It is a stationary random process that follows a Rayleigh distribution, (it was demonstrated in [14]), A(t) is the amplitude of the LOS component and it is assumed to be lognormal distributed. In this model, ϕ_0 is the deterministic phase of the LOS component and $\phi(t)$ is the stationary random phase process with uniform distribution over the range [-π,π]. A(t) and W(t) are independent random processes, and they are also independent of $\phi(t)$.

4.3 Rician Effect:

The conditional PDF of the received signal envelope R(t)=|R(t)|is a PDF of Rician distribution if A(t) is initially held constant:[14]

$$f_{R\backslash A}(r\backslash a) = \frac{r}{b_0}\exp(-\frac{r^2+a^2}{2b_0})I_0(\frac{ar}{b_0}).....(4)$$

Where $2b_0 = E[W^2]$ represents the average scattered power due to the multipath components, and $I_0(.)$ is the modified Bessel function of the first kind and zeroth order.

4.4 Shadowing Effect

We can use the conditional mathematical expectation "*theorem of total probability*" in order to determine the distribution of the received signal envelope at the time where the LOS component is a lognormal distributed random variable:[14]

$$f_R(r) = E_A\left[f_{R/A}\left(\frac{r}{a}\right)\right] ....(5)$$

$$f_R(r) = \int_0^\infty f_{\frac{R}{A}}\left(\frac{r}{a}\right) f_A(a).da \quad ...(6)$$

Where $E_A[.]$ is the expectation with respect to the previous equation given:

$$f_R(r) = \frac{r}{b_0}\int_0^\infty \exp\left(-\frac{r^2+a^2}{2b_0}\right) I_0\left(\frac{ar}{b_0}\right) f_A(a).da \,..... (7)$$

Where

$$f_A(a) = \frac{1}{a\sqrt{2\pi d_0}} exp\left[-\frac{(\ln(a)-\mu)^2}{2d_0}\right]....(8)$$

Here, $\mu = E[\ln(A)]$ and $d_0 = Var[\ln(A)]$, $Var[.]$ is the variance, are the mean and the variance of the lognormal distribution, respectively.

4.5 Combined model:

According to [14], we can find the definition of PDF (Probability Density Function) as below:

$$f_Y(\gamma) = \frac{\bar{S}}{2\bar{\gamma}\sqrt{2\pi d_0}b_0}\int_0^\infty \frac{1}{a} exp\left[-\frac{(\ln(a)-\mu)^2}{2d_0}\right]$$

$$exp\left(-\frac{\frac{\bar{S}}{\bar{\gamma}}\gamma + a^2}{2b_0}\right) \times I_0\left(\frac{a}{b_0}\sqrt{\frac{\bar{S}}{\bar{\gamma}}\gamma}\right) \quad ...(9)$$

Where $f_Y(\gamma)$ is the probability density function of the SNR per symbol when the average SNR per symbol is $\bar{\gamma}$, the shadowing variance is $\sigma^2_{X_{dB}}$, and the average Rician factor is $K_r = \frac{\Omega}{2b_0}$, and $\bar{S} = \Omega + 2b_o$ where Ω is the average power of the LOS component.

5. Change the Channel Model in OPNET:

OPNET Modeler is designed to accelerate the R&D process for analyzing and designing communication networks, devices, protocols, and applications [1]. To show and prove that we must take the state of channel into consideration during design protocols, we compare the performance of GRP in two cases, the first is in AWGN channel, and the second in shadowed fading channel where we imposed that Rician factor Kr=13.2 dB and the standard deviation $\sigma = 2.7$. [22]

Then By using Mathematica 9 and according to [14], we calculate the real SNR for Channel with Kr=13.2 dB and $\sigma = 2.7$. And then, we edit dra_ber file in OPNET and insert the results which we extract from Mathematica as an array to OPNET.

6. The Scenarios in OPNET:

In order to evaluate AODV performance, different instances of the channel model were taken.

The scenarios which we took were divided according to three parameters: speed of UAVs, area, and number of UAVs [1]. In this simulation, the attempt was to use one of the available OPNET mobility models, which can be adapted to fit searching missions by changing several OPNET settings.

6.1 Mobility Parameters For Searching Mission:

The mobility scenarios are derived from the RWP model. In the RWP mobility model [18,19], a node selects location and speed randomly, and moves from its current position towards the location chosen by a straight line, where it remains in that place for a certain period of time "*pause time*", then the process is repeated. For modeling a searching mission of an UAANET, a square area is selected. Since we have assumed two different sizes for the mission ($4km^2$,$25km^2$), a node chooses a destination and speed, and then moves from its current location at that speed towards the destination. A node then remains at that location for *pause time* seconds and the process repeats. We consider a continuous flight mission in which the UAVs never come to a rest. This is why *pause time* is set to 0. Also, the mission starts at time 0 and ends at *t*=10 hours, which is the end of the simulation. The mobility characteristics for search applications are summarized in Table 1. [1].

Table 1. Mobility parameters of a searching scenario.[1]

Parameters	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	$4km^2$, $25km^2$
Number of UAVs	10,20,30
Pause Time	0 seconds
Start Time	0 seconds
Stop Time	End of Simulation
Simulation Time	10 hours

We defined three different UAV scenarios. The first scenario was low speed search for UAVs and speed was changed based on a uniform distribution in the [10, 20] m/s interval. The second scenario was medium speed search, so the UAVs uniformly selected a velocity in the [30, 40] m/s interval. Finally, our high speed scenario had UAV speeds uniformly distributed in [50, 60] m/s. Note that these ranges of speeds are typical values for a UAANET including medium size UAVs [1, 20].

The propagation model adopted in our simulations was a free space path loss, which modeled the propagation as a disc around the transmitter. [1]

Based on packet reception power threshold, which is -95 dBm, the transmission range of the UAVs will be 1000 m. Transmit power to acquire such 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, 21].

Table 2. MAC layer specifications.[1]

Parameters	Value
Protocol	IEEE 802.11
Data Rate	1 Mbps
Transmission Range	1000 m
Packet Reception Power Threshold	-95 dBm
Buffer Size	256000 bits

For AODV, we set these parameters in OPNET as Table 3 shows:

Table 3. AODV parameters:[1]

Parameters	Value
Active Route Timeout	5 sec
Hello Interval	Uniform (1,1.1)
Allowed Hello Loss	3
Net Diameter	35
Node Traversal Time	0.04
Route Error Rate Limit	10 pkts/sec
TTL Start	1
TTL Increment	2
TTL Threshold	7
Timeout Buffer	2

7. Practical Results:

In this section, simulation results for a searching mission with 10, 20 and 30 UAVs are displayed. We considered two size search region. The first size was a 2000×2000m square (which was tested for number of UAVs equal to 10 and 20) and the other was a 5000× 5000 m square (which was tested for 10, 20 and 30 UAVs).

We choose the following parameters: packet drop ratio (PDR), end-to-end delay, and overhead to compare the performance in these 2 situations (AWGN, shadowed fading channel). In order to measure these 3 parameters, 10 independent scenarios were generated in OPNET. Each of those scenarios was generated using a different seed of the pseudo-noise sequence generator available in the OPNET core. We considered the same 10 seeds for each situation.

$$\mathbf{PDR} = 1 - \frac{\textbf{Total Traffic Recieved MANET(packet/sec)}}{\textbf{Total Traffic Sent MANET(packet/sec)}} \times 100$$

$$\textbf{Overhead} = \frac{\textbf{Routing Traffic Sent AODV (packet/sec)}}{\textbf{Total Traffic Sent MANET(packet/sec)}}$$

We applied the scenarios mentioned before, and concluded by showing the difference in AODV performance. We proved that we should take the channel state in consideration instead of always imposing AWGN (the case for all UAANETs protocol). We will present our results for AWGN and for shadowed fading channel in different scenarios, and then we will compare them.

7.1 The Effect of Speed in AWGN Channel:

We will show figures for some scenarios and only give the conclusion for others. For scenario 10 UAVs, area $4km^2$ and AWGN channel, figures [2], [3], [4] illustrate the effect of speed on delay, overhead, PDR, respectively.

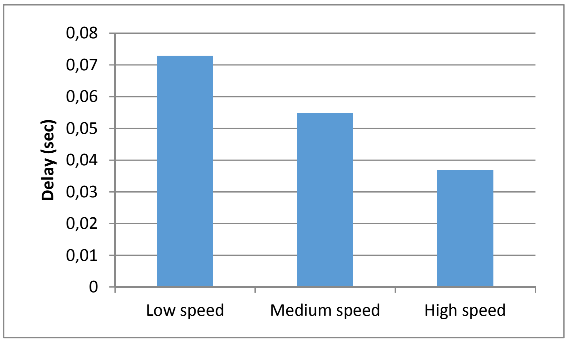

Fig. 1 Impact of AWGN channel on delay of AODV in a searching scenario of area 4km^2 including 10 UAVs.

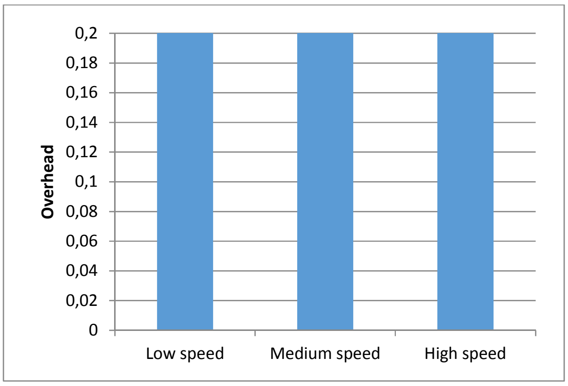

Fig. 2 Impact of AWGN channel on overhead of AODV in a searching scenario of area 4km^2 including 10 UAVs.

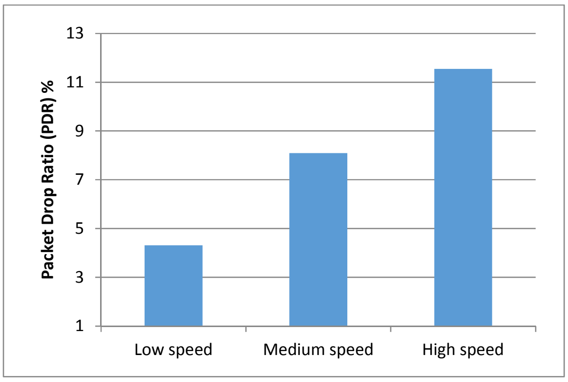

Fig. 3 Impact of AWGN channel on PDR of AODV in a searching scenario of area $\mathbf{4km^2}$ including 10 UAVs.

From Figures [2], [3], [4], it can be shown when the speed increases: the delay decreases, as the amount of decreasing is approximately 20 milliseconds, whereas PDR increases between 3 to 4 % , and overhead increases slightly, this for an area of $4km^2$ (10 UAVs). For 10 UAVs and area of $25km^2$, the delay increases significantly when speed increases, ranging from 400 to 800 milliseconds, but overhead and PDR increase slightly when speed increases.

For scenario 20 UAVs, area $4km^2$ and AWGN channel ,figures [5], [6], [7], illustrate the effect of speed on delay, overhead, and PDR, respectively.

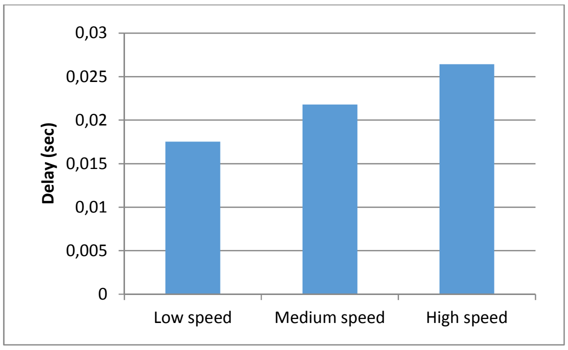

Fig. 4 Impact of AWGN channel on delay of AODV in a searching scenario of area 4km^2 *including 20 UAVs.*

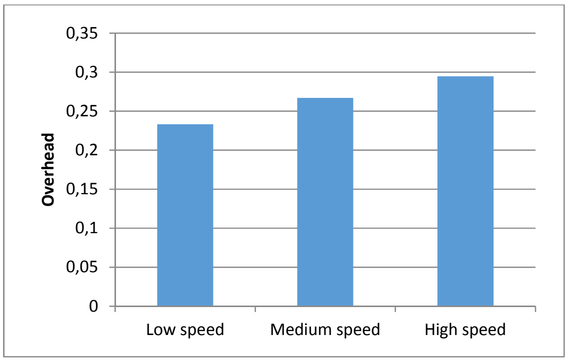

Fig. 5 Impact of AWGN channel on Overhead in a searching scenario of area size $\mathbf{4km^2}$ *including 20 UAVs.*

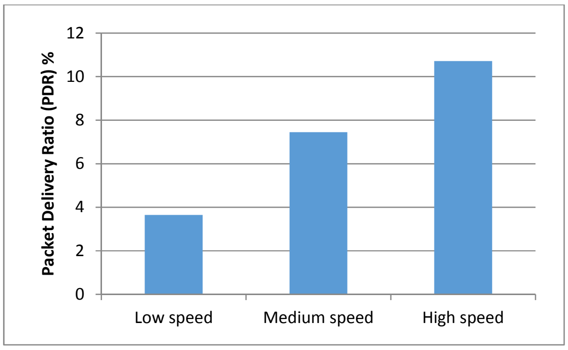

Fig. 6 Impact of AWGN channel on PDR of AODV in a searching scenario of area size $\mathbf{4km^2}$ *including 20 UAVs.*

Figures [5], [6], [7], show that delay and overhead increase slightly when speed increases, PDR increases between 3 to 4% when speed increases, this for scenario 20 UAVs, and area $4km^2$. For 20 UAVs and area of $25km^2$ we notice that: the delay increases significantly when speed increases, ranging from 500 ms to 1.8 second, while PDR and overhead increase slightly when speed increases.

For scenario 30 UAVs, area $25km^2$ and AWGN channel, figures [8], [9], [10], illustrate the effect of speed on delay, overhead, and PDR, respectively.

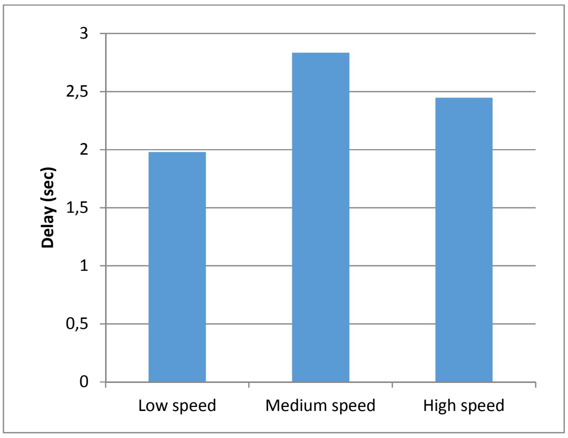

Fig. 7 Impact of AWGN channel on delay of AODV in a searching scenario of area $25\ \text{km}^2$ *including 30 UAVs.*

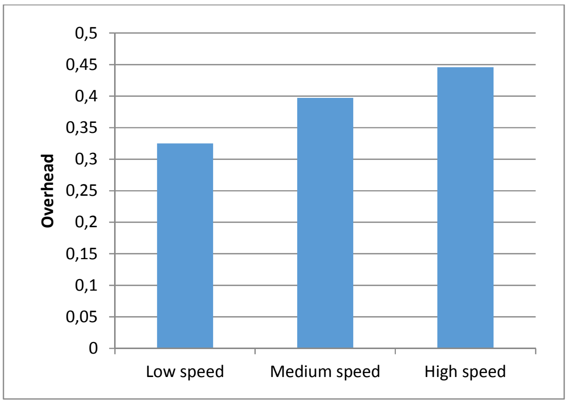

Fig. 8 Impact of AWGN channel on overhead of AODV in a searching scenario of area $25\ \text{km}^2$ *including 30 UAVs.*

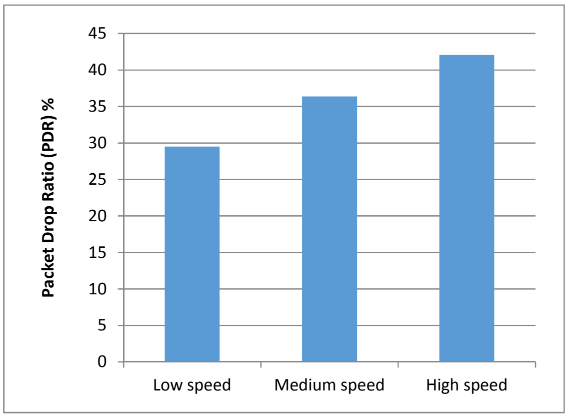

Fig. 9 Impact of AWGN channel on PDR of AODV in a searching scenario of area $\mathbf{25km^2}$ including 30 UAVs.

Figures [8], [9], [10], show an increase in delay of 900 ms when moving from low to medium speed. While overhead increases slightly with increased speed. PDR increases between 6 to 7% when speed increases.

7.2 The Effect of Area Size in AWGN Channel:

In Table 4, we present the values obtained for AWGN channel, 10 UAVs and two different regions:

Table 4. Impact of area on AODV performance.

Area size	Speed	Delay(sec)	Overhead	PDR %
$4km^2$	Low	0.072887	0.204555	4.311399
	Medium	0.054841	0.220098	8.092399
	high	0.036894	0.232201	11.54312
$25km^2$	**Low**	1.000739	0.132859	70.13906
	Medium	1.824383	0.143504	71.94213
	high	2.272426	0.151051	72.79462

Table 4, shows the following: The time delay in area of $25km^2$ is much greater than the time delay in area of $4km^2$, where the increase ranges from about 900 ms to 2.2 second , overhead in $4km^2$ is larger by 0.1 of area of $25km^2$. PDR in area $25km^2$ is much greater than PDR in area of $4km^2$, where the increase ranges from 61 to 64%.

In Table 5, we present the values obtained for AWGN channel, 20 UAVs and two different regions:

Table 5. Impact of area on AODV performance.

Area size	Speed	Delay(sec)	Overhead	PDR %
$\mathbf{4km^2}$	**Low**	0.01754	0.233278	3.651605
	Medium	0.021795	0.267073	7.455315
	High	0.026426	0.294564	10.71468
$\mathbf{25km^2}$	**Low**	2.943877	0.225344	47.9115
	Medium	4.714532	0.26172	50.03636
	High	5.209854	0.287862	51.29342

Table 5 shows: The time delay in area of $25km^2$ is much greater than the time delay in area $4km^2$, where the increase ranges from about 2.8 to 5.1 second. Overhead does not change dramatically. PDR in area of $25km^2$ is much greater than PDR in area of $4km^2$, where the increase ranges from 41 to 44%.

7.3 The Effect of Node's Number in AWGN Channel:

In Table 6, we present the values obtained from the simulation for AWGN channel, different number of nodes, different areas, different speeds, and conclude by showing the effect of changing the node's number on delay, PDR, and overhead. When the area is $4km^2$ we get the following values:

Table 6. Impact of node's number on AODV performance.

Speed	Num of Nodes	Delay(sec)	Overhead	PDR %
Low	10	0.072887	0.204555	4.311399
	20	0.01754	0.233278	3.651605
Medium	10	0.054841	0.220098	8.092399
	20	0.021795	0.267073	7.455315
High	10	0.036894	0.232201	11.54312
	20	0.026426	0.294564	10.71468

Table 6, shows that when the number of nodes increases, the delay decreases between 10 to 60 ms according to speed, while overhead increases slightly. But the PDR is still almost the same. When area is $25\,km^2$ we get the following results:

Table 7. Impact of node's number on AODV performance.

Speed	Num	Delay(sec)	Overhead	PDR %

	of Nodes			
low	10	1.000739	0.132859	70.13906
	20	2.943877	0.225344	47.9115
	30	1.979325	0.324994	29.51298
medium	10	2.272426	0.151051	72.79462
	20	4.714532	0.26172	50.03636
	30	2.834521	0.397286	36.38951
high	10	2.272426	0.151051	72.79462
	20	5.209854	0.287862	51.29342
	30	2.447201	0.445965	42.06993

Table 7, shows that when node's number and the speed increase, delay increases clearly and overhead increases slightly, while PDR decreases between 21 to 23%. When the node's number increases from 20 to 30, and the speed increases, delay decreases very sharply, overhead increases slightly, while PDR decreases between 10 to 17%.

7.4 The Effect of Speed in Shadowed Fading channel:

As mentioned before, the channel has been edited in OPNET by calculating the SNR according to [14] and assuming Kr=13.2 dB and $\sigma = 2.7$.

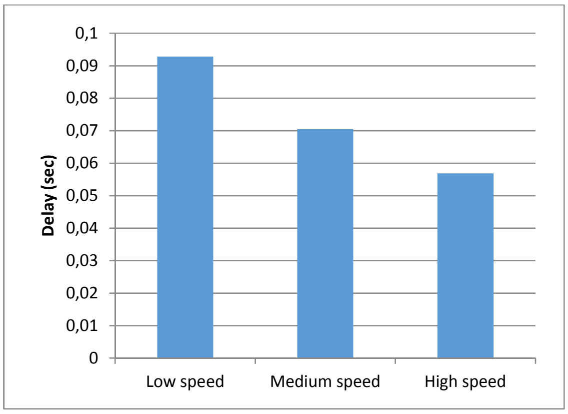

Fig. 10 Impact of shadowed fading channel on delay of AODV in a searching scenario of area $4km^2$ including 10 UAVs.

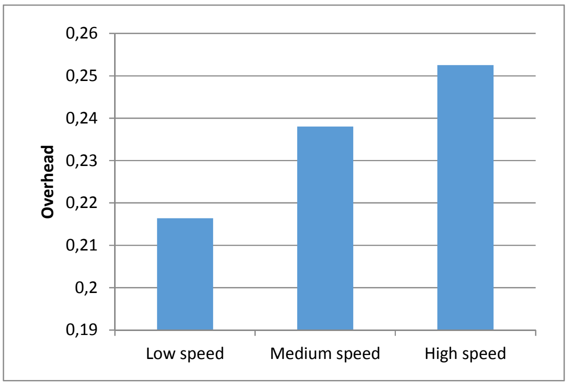

Fig. 11 Impact of shadowed fading channel on overhead of AODV in a searching scenario of area $4km^2$ including 10 UAVs.

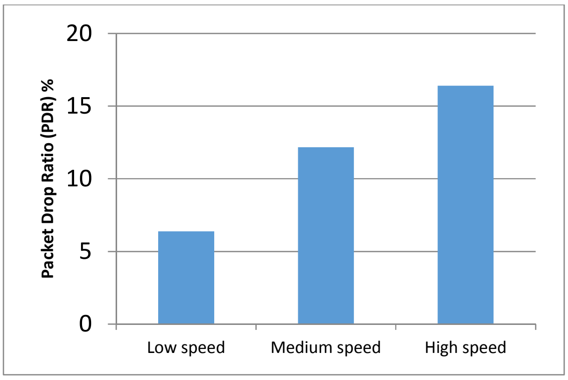

Fig. 12 Impact of shadowed fading channel on PDR of AODV in a searching scenario of area $4km^2$ including 10 UAVs.

For scenario 10 UAVs, and area $4km^2$ and shadowed fading channel, figures [11], [12], [13] illustrate the effect of speed on delay, overhead, and PDR. We concluded that delay decreases when speed increases, where the amount of decrease is almost 20 ms, but the overhead increases slightly when speed increases. PDR increases in range between 4 to 6% when speed increases. For 10 UAVs and area $25km^2$, we noticed that delay increases significantly when speed increases, with an increase between 500 to 700ms. Overhead and PDR increase slightly when speed increases.

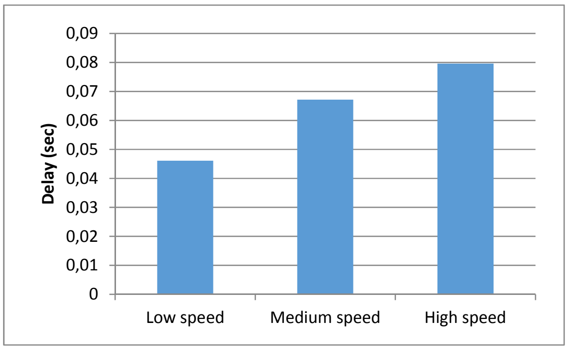

Fig. 13 Impact of shadowed fading channel on delay of AODV in a searching scenario of area $\mathbf{4km^2}$ *including 20 UAVs.*

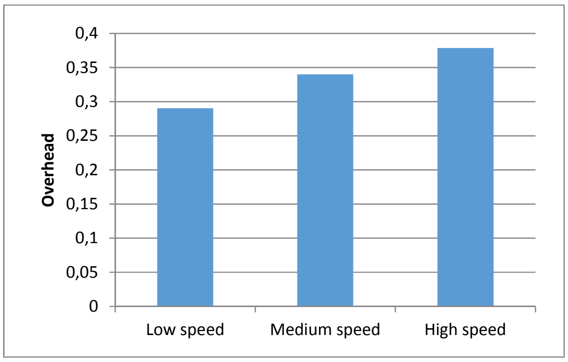

Fig. 14 Impact of shadowed fading channel on overhead of AODV in a searching scenario of area $\mathbf{4km^2}$ *including 20 UAVs*

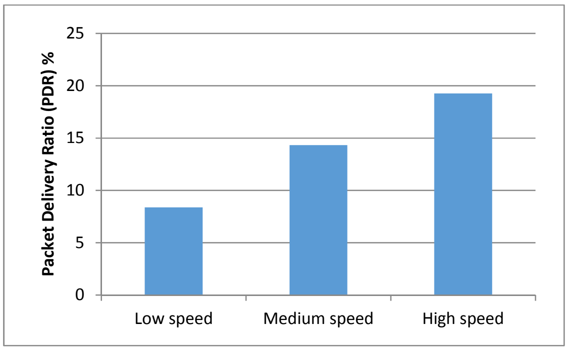

Fig. 15 Impact of shadowed fading channel on PDR of AODV in a searching scenario of area $\mathbf{4km^2}$ *including 20 UAVs.*

For scenario 20 UAVs, area $4km^2$ and shadowed fading channel, figures [14], [15], [16] illustrate the effect of speed on delay, overhead, and PDR, respectively. We concluded that all of delay, PDR, and overhead increase slightly for an area of $4km^2$, when speed increases. For 20 UAVs and area of $25km^2$,we noticed that delay increases significantly when speed increases, with an increase between 800 to 1.5 second, but overhead and PDR are increasing significantly when speed increases.

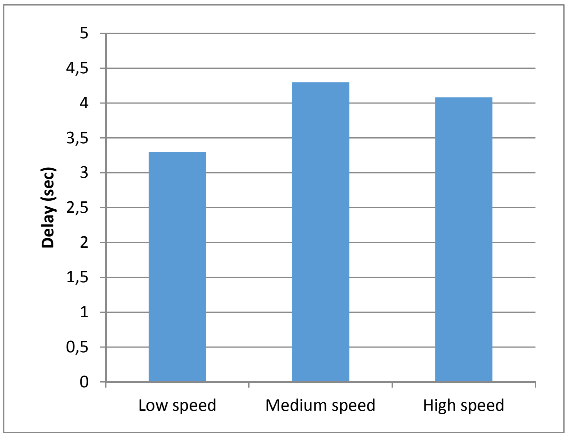

Fig. 16 Impact of shadowed fading channel on delay of AODV in a searching scenario of area $\mathbf{25\ km^2}$ *including 30 UAVs.*

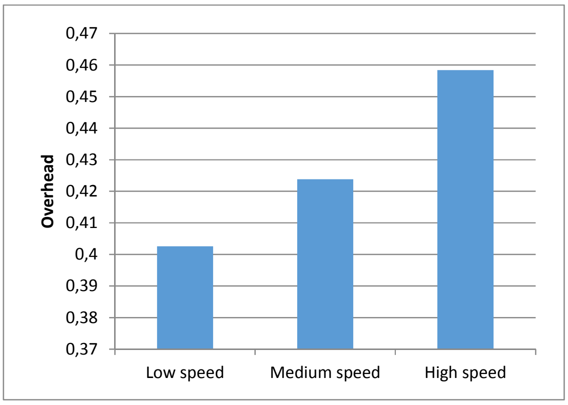

Fig. 17 Impact of shadowed fading channel on overhead of AODV in a searching scenario of area size $\mathbf{25km^2}$ *including 30 UAVs.*

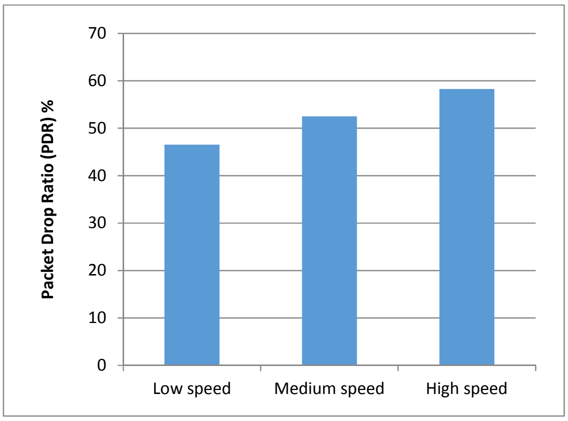

Fig. 18 Impact of shadowed fading channel on PDR of AODV in a searching scenario of area $\mathbf{25\ km^2}$ *including 30 UAVs.*

For scenario 30 UAVs, area $25km^2$ and shadowed fading channel, figures [17], [18], [19] illustrate the effect of speed on delay, overhead, and PDR, respectively. We concluded that speed does not affect almost both time delay and PDR, but overhead sharply increases when speed increases.

7.5 The Effect of Area Size in Shadowed Fading Channel:

For scenario 10 UAVs, two different regions, and shadowed fading channel, Table 8 presents the values obtained from the simulation:

Table 8. Impact of size area on AODV performance.

Area size	Speed	Delay(sec)	Overhead	PDR %
$4km^2$	Low	0.09281	0.216387	6.375849
	Medium	0.070488	0.238042	12.16537
	high	0.056888	0.252532	16.40759
$25km^2$	Low	1.118598	0.130344	71.29629
	Medium	1.840038	0.13894	74.22492
	high	2.329676	0.146711	75.43061

Table8 shows the following: The delay in area of $25km^2$ is much larger than delay in the area of $4km^2$ where increase varies between 1 to 2.2 second (according to increased speed). Overhead in area $4km^2$ is larger by 0.1 of area $25km^2$. PDR in area of $25km^2$ is much greater than PDR in area of $4km^2$, where the increase ranges from 59 to 65%.

For scenario 20 UAVs, two different regions, and shadowed fading channel, Table 9 presents the values obtained from the simulation:

Table 9. Impact of area size on AODV performance.

Area size	Speed	Delay(sec)	Overhead	PDR %
$4km^2$	Low	0.046147	0.290477	8.374345
	Medium	0.067156	0.340112	14.3305
	high	0.079615	0.378621	19.26815
$25km^2$	Low	3.59065	0.22984	53.45132
	Medium	5.153532	0.258337	55.76129
	high	5.962843	0.280368	58.66759

Table 9 shows the following: The delay in time increases when the area increases, where the increase ranges between 3.8 to 5.8 seconds. Overhead does not change noticeably. PDR increases significantly when area increases; it increases between 39 to 45%

7.6 The Effect of Node's Number in Shadowed Fading Channel:

Simulation results for shadowed fading channel, different numbers of nodes, and different speeds are shown in Table 10. It also concludes the effect of changing the number of node on delay, PDR, and overhead. In area size $4km^2$ we get the following results:

Table 10. Impact of node's number on AODV performance.

Speed	Num of Nodes	Delay(sec)	Overhead	PDR %
Low	10	0.09281	0.216387	6.375849
	20	0.046147	0.290477	8.374345
Medium	10	0.070488	0.238042	12.16537
	20	0.067156	0.340112	14.3305
High	10	0.056888	0.252532	16.40759
	20	0.079615	0.378621	19.26815

Table10 shows that delay decreases while increasing node's number according to low and medium speed. When the speed is high, delay increases. Overhead and PDR increase when node's number increases. Simulation results when area is $25km^2$ are shown in Table 11:

Table 11. Impact of node's number on AODV performance.

Speed	Num of Nodes	Delay(sec)	Overhead	PDR %
low	10	1.118598	0.130344	71.29629
	20	3.59065	0.22984	53.45132
	30	3.300555	0.402569	46.52356
medium	10	1.840038	0.13894	74.22492
	20	5.153532	0.258337	55.76129
	30	4.296427	0.423835	52.51347
high	10	2.329676	0.146711	75.43061
	20	5.962843	0.280368	58.66759
	30	4.083053	0.458388	58.27868

Table11 shows that delay increases by amount of 900 ms when node's number increases from 10 to 20 and speed from low to medium, and it decreases in by amount of 200 ms when node's number increases from 20 to 30 and move from medium to high speed. Overhead increases slightly when speed and number of nodes increase. PDR decreases when number of nodes and speed increase; the amount of decreasing ranges between 3 to 20%.

8. Comparison Between AWGN and Shadowed Fading Channel:

8.1 Scenario 10 UAVs and Area Size $4km^2$:

- Time delay in the case of a shadowed fading channel is larger than time delay in AWGN channel by 20ms and increases when speed increases.

- Overhead is not affected in either case.
- PDR in the case of shadowed fading channel is approximately 6% higher than that of the AWGN channel and increases when speed increases. The same results obtained for 10 UAVs and area of $25km^2$.

8.2 Scenario 10 UAVs and Area Size $25km^2$:

- Time delay in the case of a shadowed fading channel is larger than time delay in AWGN channel by 20ms, overhead and PDR aren't affected in either case.

8.3 Scenario 20 UAVs and Area Size $4km^2$:

- Time delay in the case of a shadowed fading channel is larger than delay in AWGN channel by 30 to 50 ms and increases when speed increases.

- Overhead is increasing by about 0.08 in shadowed fading channel.

- PDR in the case of a shadowed fading channel increases approximately 5% to 9% over the state of AWGN channel and increases when speed increases.

8.4 Scenario 20 UAVs and Area Size $25km^2$:

- Time delay in the case of a shadowed fading channel is between 400 to 700ms higher than that of the AWGN channel and increases when speed increases.

- Overhead is not affected in either case.
- PDR in the case of a shadowed fading channel is approximately 5 to 7% higher than that of the AWGN channel. (It increases when speed increases).

8.5 Scenario 30 UAVs and Area Size $25km^2$:

- Time delay in the case of a shadowed fading channel is approximately higher than that of the AWGN channel by 1.4 to 1.7 seconds. (It increases when speed increases).

- Overhead increases by 0.1 in shadowed fading channel.

- PDR in the case of a shadowed fading channel is larger than PDR in the AWGN channel by 17%. (It increases when speed increases).

9. Conclusion:

Channel has significant impact on performance of reactive routing protocol especially AODV, where the channel affects delay, PDR, and overhead. Delay in shadowed fading channel increases between 20 \ms to 1.6 seconds times according to scenario and speed. PDR in shadowed fading channel increases by about 2 to 17% according to scenario and speed. So it is mandatory to take the channel model in consideration during design the AODV protocol.

Medium shadowing and intermediate multipath of channel are considered, where Kr=13.2 dB, $\sigma = 2.7$. So for future work, we can take other cases of channel and other protocols such as DSR for future researches.

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