Indonesian Journal of Electrical Engineering and Computer Science
Vol. 21, No. 3, March 2021, pp. 1771~1783
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v21.i3.pp1771-1783

Reliability-based routing metric for UAVs networks

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Article Info

Article history:

Received Jun 21, 2020
Revised Nov 1, 2020
Accepted Nov 25, 2020

Keywords:

Ad-hoc networks
FANETs
Routing algorithm
Routing metrics
UAVs networks

ABSTRACT

As a result of technological advances in robotic systems, electronic sensors, and communication techniques, the production of unmanned aerial vehicle (UAV) systems has become possible. Their easy installation and flexibility led these UAV systems to be used widely in both military and civilian applications. Note that the capability of one UAV is however limited. Nowadays, a multi-UAV system is of special interest due to the ability of its associate UAV members either to coordinate simultaneous coverage of large areas or to cooperate to achieve common goals/targets. This kind of cooperation/coordination requires a reliable communication network with a proper network model to ensure the exchange of both control and data packets among UAVs. Such network models should provide all-time connectivity to avoid dangerous failures or unintended consequences. Thus, the multi-UAV system relies on communication to operate. Flying ad hoc network (FANET) is moreover considered as a sophisticated type of wireless ad hoc network among UAVs which solved the communication problems into other network models. Along with the FANET's unique features, challenges and open issues are also discussed especially in the routing protocols approach. We will try to present the expected transmission account metric with a new algorithm for reliability. In addition to this new algorithm mechanism, the metric takes into account the relative speed between UAVs, and thus the increase of the fluctuations in links between UAVs has been detected. Accordingly, the results show that the function of the AODV routing protocol with this metric becomes effective in high mobility environments.

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1. INTRODUCTION

The progresses on miniaturization technologies in addition to the development in both communications and embedded systems have paved the way for producing various types of low-cost UAVs [1, 2]. Unmanned aerial vehicles (UAVs) is an aircraft that flies either fully autonomous (without any human intervention) or remotely (controlled by a ground base station) to operate in a wide range of missions and emergencies. The operational experiences with UAVs have shown that their technologies open new ways not only for military applications but also for civilian applications. This includes, but is not limited to, radio source localization [3], surveillance [4, 5], transportation of suspended loads [6, 7], persuading pollution-free area [8], disaster scenarios [9], relaying for ad hoc networks [10], search and destroy missions [11], reconnaissance and surveillance, maintaining of the weapon systems network, combat support [12], the exploration of oil and gas [13]. Recently, the surge in the number of mobile data traffic because of IoT will impose the utilization of UAVs as key components of upcoming 5G and beyond 5G (B5G) networks [14]. The distinct features of UAVs can potentially facilitate wireless broadcast or point-to-multipoint transmissions within these cellular architectures [15].

In the last decade, single-UAV systems had been utilized in different applications. While the number of UAV increases, the design of efficient network architecture becomes a vital issue in single-UAV systems to solve. By means of the technological advancement in avionics and micro-electromechanical systems, the utilization of the multi-UAV system to perform missions has been emerged [16]. The size, type, and configuration of UAV are altered based on the applications nature [17]. Due to the flexibility, easy installation, and also relatively small operating expenses of UAVs [18], the large scale of UAV applications has proliferated vastly within the last few years. It's worth noting that using multiple UAVs instead of a single one yields a wide range of advantages, which we will try to summarize them as follows [19-23]:

- Multiple simultaneous interventions
- Low detectability
- Increasing accuracy
- High scalability
- Greater efficiency
- Low cost
- Complementarities of team members

Accordingly, groups of UAVs are of special interest due to their ability to coordinate simultaneous coverage of large areas or cooperate to achieve common goals [24]. In any system involving multiple autonomous vehicles, the concept of coordination and cooperation plays an important role. In general, there are two types of coordination, i.e., temporal and spatial coordination. In temporal coordination, UAVs are synchronized with each other, and it is required in a wide range of applications such as object monitoring. However, in spatial coordination, the coordination deals with the idea of sharing the space among multiple UAVs to ensure safe performance for each UAV and coherent with respect to each of the potential obstacles in addition to the plans of other UAVs. Sharing resources is therefore the main issue. To have an accomplished coordination, there exists the other concept known as cooperation. Cooperation means provision common collaborative behaviors by using centralized or decentralized (distributed) architectures [25-27] to produce a coordinated mission. Therefore, a group of homogeneous or heterogeneous UAVs can interact with each other and execute the missions as a single entity. In order to ensure global coherence within the whole system, one main requirement is to have successful coordination and cooperation by sharing information as mentioned in [28]. Typically, two types of information are shared by a multi-UAV system, one of which involves command and control messages. Despite these types of messages, have low bandwidth requirements, command and control messages must be exchanged with minimal delay and error for effective team coordination. The second type is the mission data which is remotely sensed and gathered by the airborne sensors on UAVs and then transmitted to fusion centers [29]. It is worth noting that the fusion center process, exploits, and disseminates the mission data. Thus guaranteeing that UAVs are in communication most of the time during the mission and sharing the information is critical for a multi-UAV system to function properly.

Accordingly, the network and communication systems are the fundamental components of the multi-UAV system. As a result of the fact that this system is rapidly developing and the scope of its usage grows greatly, networked communication will become the most crucial issue that needs vast interest from researchers. Moreover, the communication environment deviates significantly from traditional wireless networks regarding mobility degree, networking models, and communication requirements. The main objective of this paper is to explain FANET as a distinct ad hoc network family. Moreover, to present a new algorithm for calculating the routing metric, which provides more reliability in high mobility environments. The rest of the paper is organized as follows. In Section 2, we present the networking in a multi-UAV system. In Section 3, we explain our algorithm for calculating the routing metric in FANET. In Section 4, we provide the experiment of using this algorithm and the acquired results from the simulation. The last sections are devoted to the conclusions and references.

2. NETWORKING IN A MULTI-UAV SYSTEM

UAVs have become promising mobile platforms due to its capabilities to navigate simultaneously or autonomously in uncertain environments. On the side as depicted in Figure1. A network with flying nodes requires synergistic interactivity between the four design-principle dimensions: control system, network &

communication, information sharing, and situational awareness [30]. Thus, bringing a group of UAVs into a team requires significant coordination efforts to perform a given objective. For that reason, each UAV readily guarantees to be placed appropriately with respect not only to its neighbors but also to its tasks within the mission plan, which imposes the existence of a precise decision-maker (controller) for both path planning and task allocation in addition to the availability of efficient network system. Two important concepts in the multi-UAV system should be mentioned; one of which is coupling, and the other is networking.

Indeed, networking readily characterizes the communication status among UAVs as well as the ways in which the data are transmitted within the whole system, while coupling takes into account how relationship exists among UAVs. Figure 2 shows that there are two types of coupling in a multi-UAV system. The first type is a physical coupling while the other is not physical, and therefore we can call it a logical coupling. Describing the characteristics of the data transmission over the entire multi-UAV system plays an important role in selecting a networking architecture for the best performance. Therefore, there exist different networking architectures proposed and emerged [31].

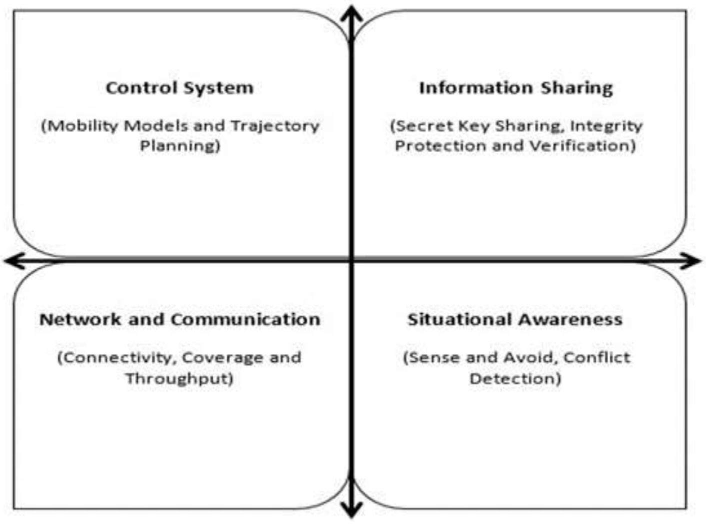


Figure 1. Design principles of network with flying nodes

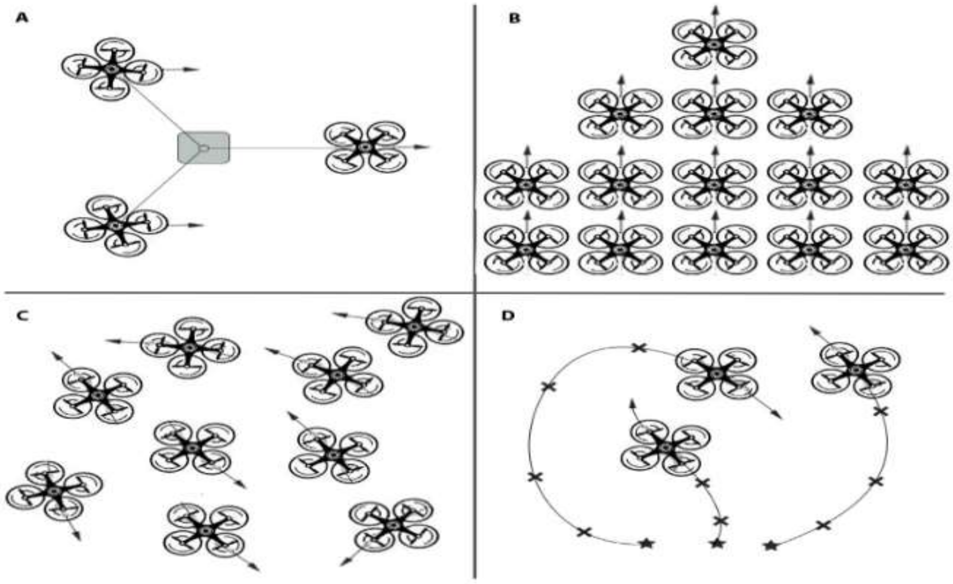


Figure 2. Coupling types in multi-UAV system a) Physical coupling, b) Formations, c) Swarms, d) Intentional cooperation

The simplest one is to have direct communication links between UAVs and a single ground station in a star topology, where a ground station is simply responsible for creating the communication between these UAVs as well as coordinate their motions. It is however worth noting that communication ranges of UAVs, which certainly depend on movement, terrain structure, and dynamic environmental conditions, certainly restrict the operation area. Moreover, the usage of a ground control station (GCS) might result in traffic congestion that accordingly influences system functionality. Figure 3 depicts a multi-UAV system simply employing direct communication architecture.

There exist the other three possible network architectures proposed for the multi-UAV system as depicted in Figure 4. These types are satellite, cellular, and ad hoc each of which solves or alleviates the problems in the direct link approach. Recently, one of the most prestigious technologies in communication and networking is FANET. It is a kind of self-organized wireless network carried by a group of UAVs each of which is a small flying robot [32]. FANET can be considered as a special form of mobile ad hoc network (MANET). Moreover, it can also be considered as a subgroup of vehicular ad hoc network (VANET). It is worth mentioning that setting up an ad hoc network among UAVs imposes challenging issues and needs some additional requirements different from those a traditional network needs.

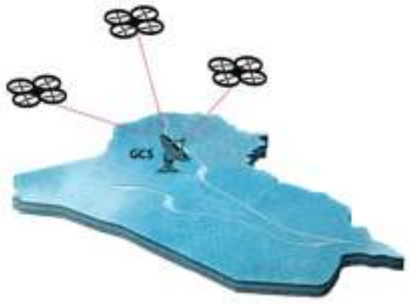
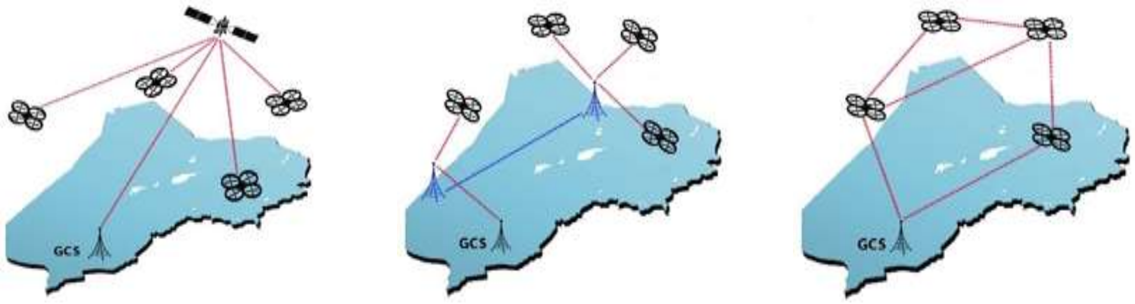


Figure 3. Direct communication architecture



(a) (b) (c)

Figure 4. Basic communication architecture (a) Satellite, (b) Cellular, (c) FANET

3. ROUTING METRIC IN FANET

Over the years, there exists a huge body of works on routing protocols for wireless multi-hop networks such as FANET. These protocols implement discovering the route path and then routing the messages despite that the nodes are mobile and the link quality varies. To improve the performance of routing protocols, there have been proposed many link-quality routing metrics. Each metric can be readily considered as a set of measurements that are contributed into the route computation algorithms to estimate new weights for each hop/link in the routes. The weights, once aggregated, discourage selecting a route going through heavily loaded regions of the network topology.

3.1. Current metric in FANET

One of the main effects on the routing protocol functions is the pace of network topology changes. The routing protocols must be able to update routing tables or cashes dynamically based on these changes on topology [33]. The dynamic nature of FANET results in frequent changes in the network topology and thus makes the routing process among UAVs in FANET a daunting task that needs to be addressed by researchers. Therefore, the data routing between UAVs undergoes a serious challenge or issue. In spite of FANET is a subcategory of MANET or VANET, Most of their protocols are not directly applicable for FANET [34]. In fact, some specific ad-hoc networking protocols have been implemented and some of the previous ones have been modified in order to be feasible in FANET.

The minimum hop count is the metric that is most commonly used by the ad hoc routing protocols. It enables the routing protocols to choose the minimum length path among different paths. Thus, the performance of these protocols is increased by reducing the effects of the successive hop transmission interference on multi-hop paths. These effects actually come from the fact that the middle nodes in a path cannot receive the packets from the previous node and sending it to the next one at the same time. However, due to the choice of minimum length paths is done regardless of the differences in quality of paths' links, these paths may be slow. As a result of that, we can say that the minimum hop count performs well whenever the shortest route is also the fast route with a low loss ratio.

In [35], Douglas S. J. De Couto et al. proposed using the expected transmission count (ETX) metric to overcome the minimum hop count problem. Routing protocols with ETX metric choose the routes with high end-to-end throughput by minimizing the expected total number of transmissions (including retransmissions) required to deliver a packet to the ultimate destination. ETX metric incorporates not only the effects of both interference the successive links of a path and link loss ratios, but also the loss ratios between the two directions of each link. The ETX of a link is calculated by using the forward (r^f) and reverse (r^r) delivery ratios of the link:

$$ETX = \frac{1}{r^f\, r^r} \tag{1}$$

The measured probability that a data packet successfully arrives at the recipient is r^f while r^r is the probability that the ACK packet is successfully received. Thus, the best routes are the ones that have the smallest ETX and not necessarily to be with the least number of hops. If all links forming route “R” are errorless, ETX(R) will be equal to the number of hops in “R”. Although of these ETX features, Using ETX is not reactive enough to cope with very dynamic wireless ad hoc networks, such as multi-UAV networks (FANET). For solving this problem, the (ETX) metric must be weighted by using a factor that takes into account the relative speed & direction between nodes. In [36], Rosati et al. presented the Predictive-OLSR protocol. The Predictive-OLSR is a proactive link-state routing protocol with the capability to enable efficient routing in very dynamic conditions. It is an extension of the Optimized Link-State Routing (OLSR) protocol [37]. As in OLSR protocol, this protocol uses receiving ratios (r^f and r^r) to measure the quality of wireless links. By using a Hello packet as a link probe in addition of using exponential moving average (EMA), r^f is computed as shown below:

$$\begin{cases} r_l^f = \alpha h_l + (1-\alpha) r_{l-1}^f \\ \qquad r_0^f = 0 \end{cases} \tag{2}$$

where α denotes a link-quality aging ($0 \le \alpha \le 1$) and where the coefficient h_l is defined as

$$h_l = \begin{cases} 1 \quad if\, l th\ Hello\ packet\ received \\ \qquad 0\ otherwise \end{cases} \tag{3}$$

Due to the EMA, a node takes an amount of time before noticing the degradation of a wireless link quality. During this time, it will continue route packets and thus yielding an interruption of the service. To overcome this problem, predictive-OLSR redefines the ETX metric to be a Speed-Weighted ETX metric by using the relative speed between two nodes and also using a fresh GPS information to improve the routing. Thus, the ETX had shown as below:

$$ETX^{i,j} = \frac{e^{v_l^{i,j} \beta}}{r^f\, r^r} \tag{4}$$

$$\begin{cases} v_l^{i,j} = \gamma\, w_l^{i,j} + (1-\gamma) v_{l-1}^{i,j} \\ \qquad v_0^{i,j} = 0 \end{cases} \tag{5}$$

where γ and β denote a predictive-OLSR (P-OLSR) parameter ($0 \leq \gamma \leq 1$) and a non-negative parameter, respectively. Moreover, $v_l^{i,j}$ and $w_l^{i,j}$ denote the relative speed and the instantaneous relative velocity, respectively, between UAVs i and j.

Whenever the two UAVs i and j are closer to each other, the relative speed will be negative, thus the ETX is weighted by a factor smaller than 1. Conversely, the relative speed will be positive and the ETX is weighted by a factor larger than 1 when UAV i and j move away from each other. As stated in [38], the P-OLSR is currently used as a FANET-specific routing protocol. Within the P-OLSR, the routing follows the topology changes without interruptions. By comparing with OLSR, P-OLSR succeeds in providing a reliable multi-hop communication in very dynamic wireless ad hoc networks where OLSR mostly fails. Another extension to the (OLSR) protocol is a directional optimization link state routing protocol (DOLSR) [39]. It is a novel routing protocol that is used in UAVs with a directional antenna. DOPLR capable of decreasing the end-to-end delay by reducing the number of the multipoint relays in the network, and thus the number of overhead packets will be reduced. As a result, the overall throughput of FANET is increased. Moreover, the simulation shows that the performance of DOLSR is better than both OLSR and AODV in terms of end-to-end delay. The other approach in FANET routing protocol is the use of reactive routing protocols (RRPs) such as ad hoc on-demand distance vector (AODV). As mentioned in [40], [41], ad hoc on-demand distance vector (aodv) is a reactive protocol that forms the path only whenever there is data to send. This protocol is adaptive to severe link conditions, low network utilization, and memory overhead. AODV is capable of preserving the bandwidth consumed in the proactive routing protocol (PRP) as a result of periodically updating the routing table. Indeed, the problem of efficiently routing messages (commands and data) between UAVs is a significant challenge in itself for FANET. Moreover, it is further exacerbated as the number of UAVs grows, as wireless link qualities continuously fluctuate under fading, and as the network topology rapidly changes. It is paramount to route the messages to its destination with adequate data rate capacity, minimal delay and with minimal number of dropped packets. Thus, the problem of the delay in addition to other issues such as cost overhead to establish the multi-hop route, reliability in case of high mobility, etc., are remained to be studied and analyzed by the researchers to find better solutions satisfying all FANET requirements.

3.2. Reliability-based expected transmission count (ReLX)

The channel quality from one UAV to another UAV is defined as how much volume of information could be transmitted, namely, with a small bit error rate (BER). As it is understood from the definition of the quality, the channel quality has an averaging meaning about the volume size of information that could be transmitted. In literature, most of the existing routing protocols rely on the link quality, i.e. the forward and reverse channel qualities at the same time. The protocols are about the route selection from all available routes between any pair of two nodes. Routing protocols are optimized to take into account the quality of route selection. However, during the transmission, the information is subjected to the effects that certainly change. Within this context, the link reliability comes into the light. Almost all routing protocols are not optimized out of the reliability scope. The channel reliability from one UAV to another one is defined as how much a volume of information could be successfully transmitted. Let us consider two channels whose qualities are the same (i.e. their BER are the same). Note that the bit errors have occurred during transmission over a channel could be sequential; the group of successive errors is called burst-error. In the second channel, the bit errors are separated from each other by successful transmission, i.e. the bit errors are distributed along the transmitted bit sequence. In consequence, the reliability of the second channel is better than the first channel even if their qualities are the same. In order to characterize the reliability of the link based on the burst error-length (i.e., burst loss situation) in addition to the speed and direction of UAVs, we will try to define our routing metric to be a speed and reliability-based metric. Our metric will be consisted of two parts SpD and $MoBX$ as follows:

$$ReLX = SpD * MoBX \tag{6}$$

where SpD denotes the relative speed between two nodes, which is the numerator in (4), $MoBX$ denotes the predicted number of transmissions/retransmissions required to send a packet over the link. In this routing metric, we provide a new method for calculating the probability of delivery ratio (P). Also, we suggest a new algorithm to detect the most reliable links among the links with equal quality. For calculating the delivery ratio for forward or reverse channel, each node will probe the channels with its neighbors by sending probe packets to them within a time window (T). Then, the nodes count the successful probe packets (pck_s) that received from its neighbors in each slot time (τ), and divide it by the total probe packets (pck_t).

$$P = \frac{pck_s}{pck_t}, \tag{7}$$

$$pck_t = \frac{T}{\tau} \tag{8}$$

Accordingly, each attempt to transmit a probe packet can be considered as a Bernoulli trial. The probability of successful transmission in forward and reverse channels P_s is considered as the probability density function (PDF) of the transmission attempts, while the probability of failed transmission P_f can be considered as the complementary probability of P_s:

$$P_s = P_{fr}\, P_{rv} \tag{9}$$

$$P_f = 1 - P_s \tag{10}$$

where P_{fr} denotes the delivery ratio of the forward channel, P_{rv} denotes the delivery ratio of the reverse channel. Based on the Information theory, we will try to define our metric ($MoBX$) in a mathematical method instead of the intuitional method. Depending on the average amount of information contents obtained from P_s and P_f, we define the $MoBX$ as follows:

$$MoBX = 1 + \varphi \times \phi \times log_2(P_s) \tag{11}$$

$$\varphi = \frac{P_s}{P_f} \tag{12}$$

$$\phi = \frac{log_{10}(2)}{log_{10}(P_f)} \tag{13}$$

It is worth noting that the value of ϕ is always negative and the value of φ is always positive. When the value of φ increases on a positive side, the value of ϕ decreases on a negative side. With this context, the product of them is roughly equal to -1. Consequently, the equation of $MoBX$ can be mathematically expressed as:

$$MoBX = 1 - log_2(P_s) \tag{14}$$

By observing Figure 5, we can note that the behavior of $MoBX$ metric is mostly equal to the behavior of the expected transmission count (ETX) metric over the values of the probability of delivery ration (P_s). Also, we can note that $MoBX$ metric curve is slowly changed when the link variability at a high level, while the basic ETX is dramatically changed. Accordingly, the bits that are needed for representing the $MoBX$ values will be less than these bits for basic ETX metric values, and thus it reduces the size of the control messages that convey these values. $MoBX$ will decrease the consumption amount of network resources such as bandwidth, energy, memory, and overhead. This will have a significant positive impact, especially in networks that suffer from a lack of resources such as wireless sensor networks [42, 43]. In wireless sensor networks, the sensor nodes are much more resource-constrained. As a result, the heavy-weight routing protocols as those used in other networks may not suitable for using them in WSNs. The limited communication and computational resources of the sensor nodes need to utilize the routing protocols with minimum probe packet size, energy consumption, memory, and overheads. UAV calculates the probability of delivery ratio within fixed slots without consideration of the fluctuation of the channel quality caused by the high mobility of UAVs.

In terms of the reliability concept, $MoBX$ has not have the capability of detecting the reliable links aptly, i.e., burst-loss situation yet. A reliable link within the wireless multihop networks will be a link with ordered forward and reverse channels as much as possible. For example, let us check the value of $MoBX$ and ETX of two links within a network. The main time window belonging to two links consists of 20 slots. Where each of these two links includes a forward and reverse channel. The patterns that these channels look like are as shown in Figures 6 and 7.

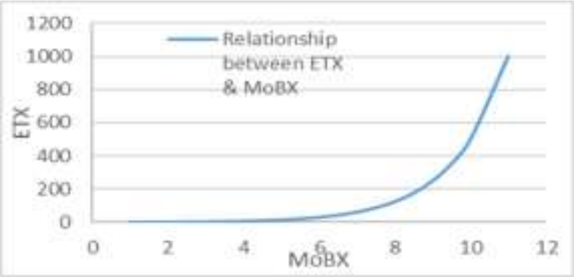
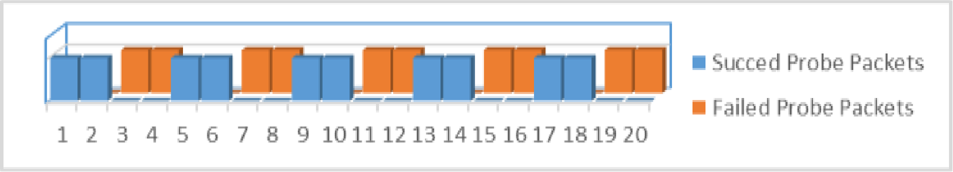
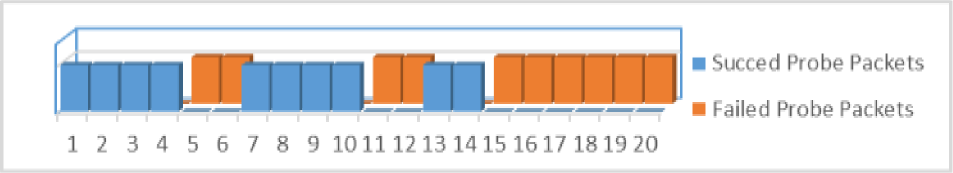


Figure 5. Relationship between ETX and MoBX

Although of the differences in channel patterns and their fluctuation in the connectivity on these two links, the values of ETX and $MoBX$ for both links are 4 and 3 respectively. Accordingly, we need to combine an algorithm to the available routing protocols of FANETs in order to enable them to detect the link's fluctuations. This algorithm will increase the value of $MoBX$ for the links with high disordered, and thus enables $ReLX$ metric to select the links with high reliability.

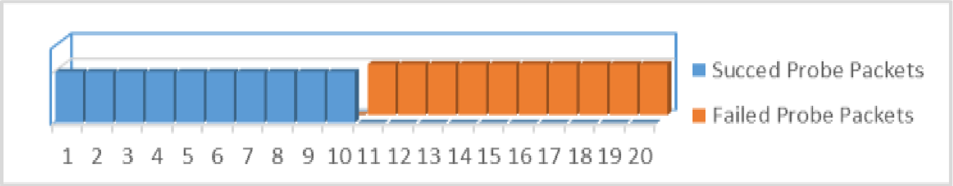


(a)

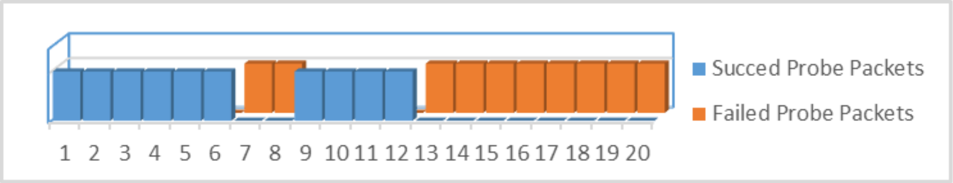


(b)

Figure 6. Forward and reverse channels for the first link (a) Forward channel, (b) Reverse channel



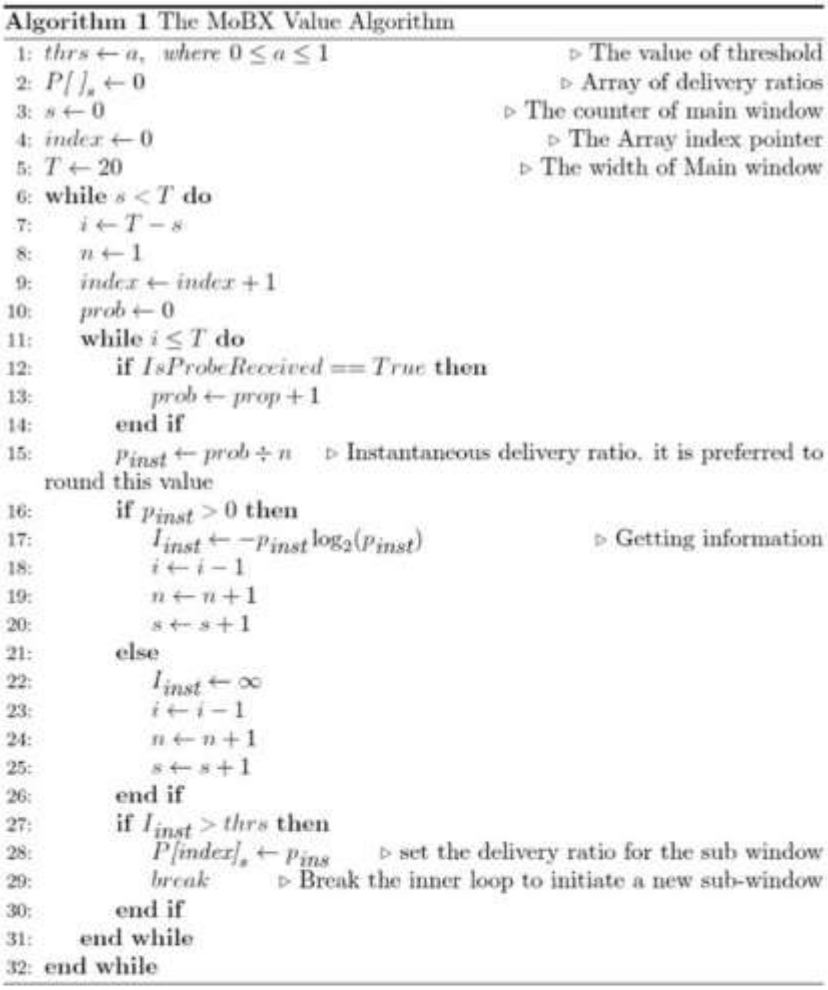
(a)



(b)

Figure 7. Forward and reverse channels for the second link (a) Forward channel, (b) Reverse channel

By using our algorithm in Figure 8, the main window time will be divided into sub-windows with a changeable width. The width of this sub-windows depends on the quantity of information getting from delivery ratios of successful probe packets. Whenever this information value exceeds a predefined threshold, the new sub-window is created and new information is calculated. The threshold represents the acceptable disorder within the sub-window. At the end of the main window time, the average of these probabilities (ratios) is computed. Depending on the average probabilities for both forward and reverse channels that UAVs have calculated, the value of $MoBX$ for the network links will be defined as mentioned in (14). By using threshold equals to 0.2, the values of $MoBX$ of the two links from the previous example will be about 4 and 6 respectively. Thus, increasing the fluctuations in links between UAVs, increasing the value of $MoBX$.



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Algorithm 1 The MoBX Value Algorithm
$thrs \leftarrow a, \ where\ 0 \leq a \leq 1$                ▷ The value of threshold
$P[\,]_s \leftarrow 0$                                      ▷ Array of delivery ratios
$s \leftarrow 0$                                            ▷ The counter of main window
$index \leftarrow 0$                                        ▷ The Array index pointer
$T \leftarrow 20$                                           ▷ The width of Main window
while $s < T$ do
    $i \leftarrow T - s$
    $n \leftarrow 1$
    $index \leftarrow index + 1$
    $prob \leftarrow 0$
    while $i \leq T$ do
        if $IsProbeReceived == True$ then
            $prob \leftarrow prop + 1$
        end if
        $p_{inst} \leftarrow prob \div n$    ▷ Instantaneous delivery ratio. it is preferred to
round this value
        if $p_{inst} > 0$ then
            $I_{inst} \leftarrow -p_{inst} \log_2(p_{inst})$          ▷ Getting information
            $i \leftarrow i - 1$
            $n \leftarrow n + 1$
            $s \leftarrow s + 1$
        else
            $I_{inst} \leftarrow \infty$
            $i \leftarrow i - 1$
            $n \leftarrow n + 1$
            $s \leftarrow s + 1$
        end if
        if $I_{inst} > thrs$ then
            $P[index]_s \leftarrow p_{ins}$     ▷ set the delivery ratio for the sub window
            $break$        ▷ Break the inner loop to initiate a new sub-window
        end if
    end while
end while
```

Figure 8. Algorithm for MoBX

4. EXPERIMENTS AND RESULTS

To evaluate the performance of $ReLX$ metric, we used NS2 simulator. We compared our metric $ReLX$ with ETX metric in two mobility values in terms of throughput and average packet delay over a simulation time equals to 100 sec. The simulation was performed on a 1000 * 500 m field of 25 UAVs. Each UAV is provided with an omnidirectional antenna (OmniAntenna), which conforms to IEEE 802.11. Thus, each UAV has a range of 250 m in the absence of obstacles and a nominal bandwidth of 20 Mbps. The two-ray ground model is the radio propagation model that is used in our simulation. UAVs exchange probe packets after being initiated and uses CBR traffic as source traffic. In addition to the delivery ratios that are carried by the probe, each probe will contain the position information too. Each source sends out packets with a size of 512 bytes. In our simulation, each UAV has a priority queue with a maximum capacity of 50 packets, which gives priority to routing protocol packets.

In our simulation, the mobility model used is a Random Waypoint model with two maximum speed values: $mob1$ equals to 25 m/sec, and $mob2$ equals to 50 m\sec. The UAVs are initially placed at random positions except for the senders and receivers, which initial with fixed positions at the edge of the simulation area and in the opposite direction. The aim of the residence the senders and receivers at the edge is to make the control message and data packet circulate over the largest possible number of intermediate nodes. It's worth noting that all results of our simulation are the cumulative results of these two senders and receivers. Established links should be as reliable as possible to avoid data packet loss and thus decreasing in throughput and increasing delay. This means that maintaining and sensing the link should be robust against burst loss or the transient connectivity between UAVs in a network.

A link-state routing protocol such as OLSR tries to detect the transient connectivity among the nodes by using the link hysteresis techniques. However, the hysteresis technique provides a more robust link sensing at the cost of more delay before establishing links. For the distance vector routing protocols such as AODV, there is no technology is used to provide robust links. Even if the AODV concerns the link quality by using the ETX metric instead of the hop count metric, it will remain unable to capture the transient connectivity. The $ReLX$ metric enables AODV routing protocol from detecting the distribution pattern of receiving probe packets over a time window and increases the quality metric value for these links that has irregular distribution even if these links have the same ETX. By increasing the mobility value, the disorder of the pattern is grown and thus the quality of routing metrics decreased and its effectiveness. However, $ReLX$ provides an observed high performance over the ETX metric when with the second mobility $mob2$ is applied.

Offer guarantees to application concerning the time taken to transfer data packets from source to destination is one of the main purposes of all routing protocols. It is very important to consider the capacity of the routing protocol to transmit data packets from the source to the desired destination node when we want to evaluate the performance of this protocol. We can define the throughput as the number of successfully received packets in a unit of time. $ReLX$ for many reasons we mentioned before will provide a higher throughput than the ETX in both mobility values as shown in Figure 9.

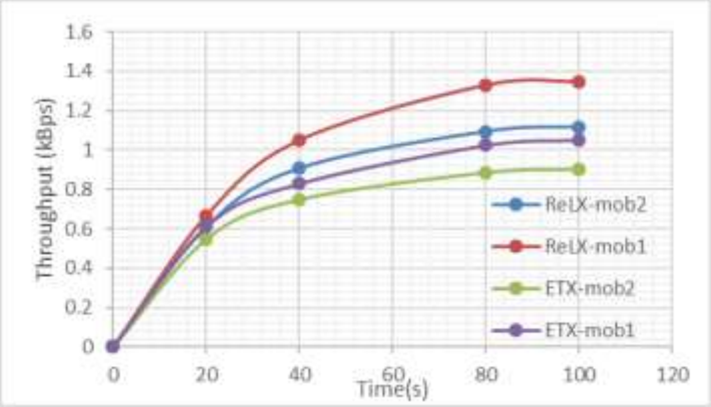

Figure 9. Throughput comparison

Indeed, one of the main purposes of all routing protocols is to offer guarantees to application concerning the time taken to transfer data packets from source to destination. Thus, we try to evaluate the delay parameter for the AODV protocol with: $ReLX$ and ETX metrics and compare the results when we utilize the two mobility values ($mob1$ and $mob2$). Indeed, the delay parameter gives the average time necessary to transfer a packet from source node to destination. It is worth noting that the more spread out the UAVs are, the lower the possibility of finding a route. We can note from Figure 10 that the average delays in these two metrics are close to each other until the second 20. When the UAVs begin to move a far from each other and the possibility of establishing a robust route is decreased, the average delay will increase in ETX metrics more than the $ReLX$ metric. The main reason behind the results that have been got, is the $ETX's$ selection of the links with the lowest reliability, which therefore result to need for additional time for launching a new route discovery and retransmission loss packets.

Most of the UAVs are Li-ion powered that has inadequate battery lifetime and very little payload potential. Accordingly, power is one of the other key issues in the unmanned aerial vehicle communication networks. The network lifetime decreases or increases depending on the energy consumption of wireless nodes, and thus the energy-efficient mechanism is needed in these types of networks [44]. By using the AODV protocol with ReLX and ETX metrics, we try to evaluate and compare the power consumption of our UAVs network in two mobility values mob1 and mob2. We can note from Figure 11 that the power consumption in these two metrics are close to each other although the ReLX needs more computational time for each sub-window. The main reason behind this fact that the AODV routing protocol with the ETX metric needs additional time to re-establish the route within the network and then retransmitting loss packets. However, when the mobility value is increased, we can note that the power consumption of the ReLX is slightly less than with the ETX metric.

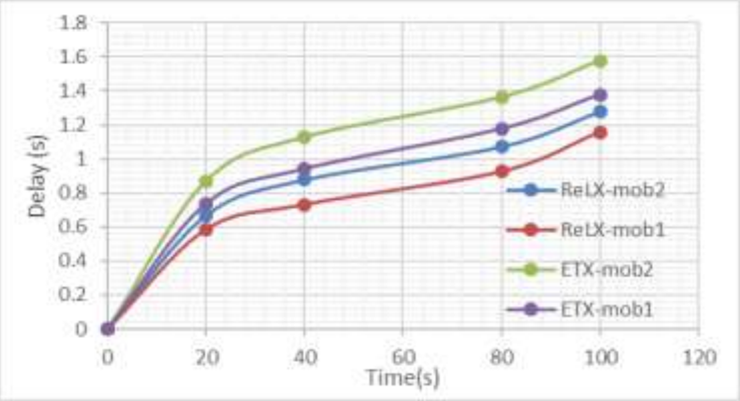

Figure 10. Delay comparison

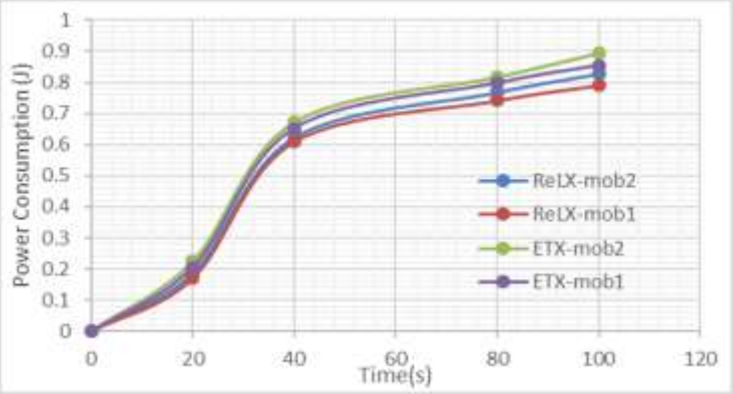

Figure 11. Power consumption comparison

5. CONCLUSION

UAVs have seen unprecedented levels of growth over the past 20 years with military applications dominating the field. However, UAVs have recently played a major role in a broader range of civilian applications and have gained popularity over traditional full-size piloted aircraft. Progressively, UAVs need to cooperate with each other in order to perform complex tasks especially in areas that are relatively inaccessible from the ground. Thus, a multi-UAV system has emerged that has many advantages beyond a single UAV system. Information sharing, which means communication, is one of the most challenging design issues in the multi-UAV system. There are therefore lots of communication architectures, such as cellular and satellite, each of which has been proposed to create links among UAVs in the system. Despite all the advantages offered by these cellular and satellite-based communication architectures, they are suffering a lot of the main issues/problems such as a limited communication range and scalability. In order to overcome these problems, FANET architecture, which is an ad hoc network among nodes in a multi-UAV system, has been proposed as the best solution possessing many merits and also challenges each of which must be taken into account by any researcher working in this area. The dynamic nature of FANET results in frequent changes in the network topology and thus makes the routing process among UAVs in FANET a daunting task that needs to be addressed by researchers. Within that context, we developed the idea behind the ETX metric in a mathematically way and applied a new metric called $ReLX$. Indeed, the $ReLX$ is a speed and reliability-based metric that takes into account the quality and the reliability of the forward and reverse channels of any links within a network. It has the capability to detect the channel variability by considering the burst errors length until a predefined threshold. As shown in our comparison using different mobility values, $ReLX$ helps a routing protocol to select the high reliability and qualitative routes among the available routes, and hence improve the overall network performance. Accordingly, FANET represents a new era of ad hoc networks, which will offer a wide range of future applications to the community. It is worth saying that, lots of researchers and practitioners should study this type of ad hoc network to find solutions for the most challenging problems such as routing protocols in FANET.

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