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Satisfactory Video Dissemination on FANETs Based on An Enhanced UAV Relay Placement Service

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Abstract The user experience on watching videos transmitted by a Flying Ad-Hoc Networks (FANETs) should always be satisfactory even under influence of topology changes in reason of the Unmanned Aerial Vehicles (UAVs) mobility. However, one of the main challenges to route packets in FANETs is how to mitigate the effects of UAV mobility to preclude communication flaws, delays, and void area, which hence increase the packet loss over video transmissions. In this way, routing protocols require an efficient relay placement service to find out the ideal location for UAVs that act as relay nodes, and thus mitigating the effects of UAV movements on the Quality of Experience (QoE) of transmitted videos. In this article, we introduce an extended analysis of our proposed relay placement mechanism, called MobiFANET, in order to diagnose the impact of videos with different characteristics on the QoE and route failure. We also present detailed information about the MobiFANET mechanism, as well as the contributions of each component on the routing performance. Simulation results show how MobiFANET works jointly with a routing protocol for satisfactory multimedia transmission, where it provides better QoE and a reduction of the number of route failures compared to existing routing protocols.

Keywords FANET · Relay Placement · Video Distribution · QoE

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1 Introduction

In disasters, such as earthquake or hurricane, the recovery process demands an efficient and rapid deployment of a communication system, since the standard telecommunication infrastructure might be damaged or unavailable [3]. In this context, Unmanned Aerial Vehicles (UAVs) have the potential to support autonomous actions in such environments by forming a Flying ad-hoc networks (FANETs) [21]. Video dissemination over FANETs enable a large class of multimedia applications, such as disaster recovery, environmental monitoring, safety & security, and others [25]. Hence, multimedia data plays an important role to provide rich visual information to help the ground rescue teams to take appropriate decisions in case of natural disasters [18].

Video must be delivered with Quality of Experience (QoE) [14] support, which became essential on ad-hoc networks with resource constraints or unstable infrastructure as FANETs. This is because users expect to receive satisfactory live videos, *i.e.*, a video without ghosting, blocking, pixelization, freeze frame, and others, no maters the network conditions [12]. Consequently, there is a demand for video transmission with low frame loss rate, tolerable end-to-end delay, and low jitter to provide QoE support [6]. Several beaconless Opportunistic Routing (OR) protocols have been proposed to meet the requirement for delivering videos with satisfactory QoE over FANET scenarios [9], but this is a hard task due to topology changes caused by UAV mobility.

The sorts of UAV mobility impacts on the QoE of videos transmitted via such OR protocols, since UAVs movements breaks plenty of communication links [15]. Existing beaconless OR protocols select relay nodes along the line-of-sight between the source and destination UAVs, which may often not be possible due to void area, *i.e.*, UAV mobility might lead it for an area without any UAV [5]. Hence, mitigating the effects of UAV mobility on communication flaws, delays, and packet loss during the video transmission is one of the main challenges to route packets in FANETs [20]. Controlling the relay position is an essential issue to maintain some network properties (*e.g.*, connectivity, coverage, throughput, and fault-tolerance), and also to reduce the radio interference (*i.e.*, improve the traffic carrying capacity) [24], [10], [22]. Though, in general the current OR protocols have not applied an effective relay placement mechanism to deliver high quality videos in FANET scenarios.

The relay placement service aims to point out an ideal location for UAVs, which mitigate the effects of connection breaks caused by UAV movements, improving the network connectivity, reachability, and throughput. Particularly, this service may be limited to a subset of UAVs acting in the relaying task, by controlling the network topology to relieve the effects of UAV mobility [13]. This service collaborates to enhance the performance of beaconless OR protocols, where a relay placement services should consider geographical location, and also UAV mobility trajectory.

In this article, we introduce an extended analysis of our proposed relay placement mechanism, called MobiFANET [17], in order to diagnose the impact of the videos dissemination with different characteristics on the QoE to end users. We show detailed information about the operation of the MobiFANET mechanism, as well as the role of each component on the MobiFANET performance. Specifically, it enhances the run of beaconless OR protocols over FANETs by considering both geographical location and the UAV mobility model to establish the ideal relay location, seeking mitigate route failures and void areas caused by UAV movements. Simulation results point out the efficiency of MobiFANET in supporting video dissemination with QoE gain, as well as its capability to decrease the number of route failures compared to two beaconless OR protocol.

The remainder of the article is organized as follows. Section 2 outlines existing works for video dissemination over FANET, and their main drawbacks to support user QoE. Section 3 describes the MobiFANET mechanism and its components. Section 4 shows an evaluation by simulation of the MobiFANET performance. Section 5 concludes the article.

2 Related Work

In general beaconless OR protocols and relay placement mechanisms have been not effective to meet the requirement of delivering videos with QoE support in FANET scenarios, due to communication flaws and void areas. One of the reasons of this vulnerability consists in the absence of a better integration between relay placement and UAV mobility models. It is essential to consider an efficient relay placement service to find the ideal relay location by considering UAV geographical location and mobility trajectory to provide video dissemination with QoE support. However, so far not all of these key features have been provided in a unified relay placement mechanism.

Braun et al. [5] introduced the concept of Dynamic Forwarding Delay (DFD) as forwarding decision in the Beaconless Routing protocol (BLR). Instead of continuous information exchange with the neighbour nodes, each node makes the forwarding decision by computing a DFD value based on the packet header information and its current location. All receivers set a timer, and the one that first counts down to zero will be selected as relay node. Rosário et al. [18] proposed the Cross-layer Link quality and Geographical-aware beaconless OR protocol (XLinGO), which combines a set of cross-layer parameters to compute the DFD, namely queue length, link quality, geographical location, and residual energy. However, UAVs mobility worsens the QoE of videos transmitted via those protocols, since UAV movements break plenty of communication links. In addition, such protocols must deal with void area.

Routing path lifetime and neighbour location prediction have sought to mitigate the effects of UAVs mobility. Hu et al. [9] proposed a link Lifetime-aware Beaconless Routing protocol (LBR) that computes the DFD based on link lifetime, node speed, and geographical information. Lin et al. [11] proposed a routing protocol, where all nodes estimate their neighbour location by means of a Gaussian probability distribution function. The routing decision considers distances between nodes and destination, and a time prediction to select the relay node, but it ignores the routing path lifetime. However, ensuring connectivity by monitoring only distance or path lifetime is not effective in case of high node mobility, since UAVs movement is still causing route failures.

Magán-Carrión et al. [13] introduced a relay placement mechanism to estimate the optimal locations for relay nodes by taking into account Leave-one-out (LOO) and particle swarm optimization (PSO) algorithms. Sinha et al. [23] formulated a total cost Markov decision process for placing relays on a random lattice path, optimizing a linear combination of average total hop cost, *i.e.*, transmitter power, and the average number of relays deployed. However, these mechanisms consider only a static network, and thus they do not take into account UAV mobility trajectory to find the ideal relay location. Mozaffari et al. [16] proposed an efficient deployment method, leading to the maximum coverage by determining the optimal 3D locations of the UAVs based on target geographical area, coverage requirements of the ground users, and number of UAVs. Nevertheless, this work focuses on coverage without considering UAV movement to keep the network connectivity.

3 MobiFANET

This section details the MobiFANET mechanism, which works together with any geographic routing protocol for supporting satisfactory video transmissions over FANETs. MobiFANET takes into account the UAV location and mobility trajectory to establish the ideal relay node location, keeping the connectivity between neighbour UAVs of a given path, mitigating the effects of UAV mobility, avoiding communication flaws, delays, and void area.

3.1 System and Network Model

A FANET could monitor and send live video from a given area, as soon as the standard fixed network infrastructure is unavailable due to a natural disaster, as depicted in Figure 1. In this way, humans in the control centre could take action to explore the hazardous area based on visual information. We consider n UAVs (nodes) deployed in the monitored area, and each UAV has an individual identity ($i \in [1, n]$). Those UAVs are represented in a dynamic graph $G(V, E)$, where the vertices $V = \{v_1, \cdots, v_n\}$ mean a finite set of UAVs, and edges $E = \{e_1, \cdots, e_n\}$ build a finite set of asymmetric wireless links between 1-hop UAV (v_i) neighbour. We denote $N(v_i) \subset V$ as a subset of all 1-hop neighbours within the Radio Range (R_{max}) of a given UAV v_i.

Each UAV v_i is equipped with camera, image encoder, radio transceiver, and limited energy supply. As soon as a given UAV v_i detects an event, it becomes the Source Node (SN) $\subset V$ to disseminate high relevant video to the Destination Node (DN) $\subset V$ via multiple relay nodes ($RN_i \in V$). We assume a FANET scenario composed by one static DN equipped with a radio transceiver, an image decoder, and unlimited energy, which is responsible to receive the video for further processing, analysis, and dissemination. Each UAV v_i has a queue (Q) with a maximum queue capacity (Q_{max}), and the queue policy schedules the packet transmission based on First In First Out (FIFO) algorithm, and drops packets based on Drop Tail algorithm. Each UAV v_i is aware of its own location $L(X_i, Y_i)$ by means of any positioning system, such as GPS. Each UAV (v_i) flies with a given speed s_i ranging between a minimum (*e.g.*, s_{min}) and a maximum (*e.g.*, s_{max}) speed limit.

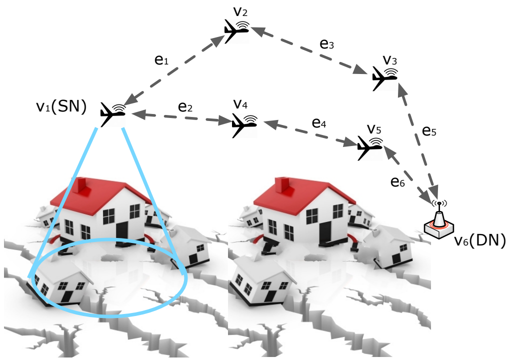


Fig. 1 FANET Deployed in an Emergency Situation to Disseminate Video

Each UAV v_i might fly based on the Random way point, Gaus Markov, Semi random circular, Mission Plan Based, and Paparazzi (PPRZM) mobility model [8]. However, Random way point, Gaus Markokv, and Semi random circular mobility models are not suitable for FANETs, since UAVs do not change their direction and mobility speed rapidly and cannot stay for a while at the same point like random waypoint model. In Mission plan mobility model, UAVs are aware of the entire trajectory planned in advance, *i.e.*, UAVs travel along the predetermined path consistently. PPRZM enables UAVs to adapt to any type of mission, since it groups most possible UAV movements by changing the probability of each movement type as needed [4]. Particularly, the PPRZM considers five possible movements: Stay-At (*i.e.*, UAV flies in a circle), Way-point (*i.e.*, UAV flies following a straight line to a destination position), Eight (*i.e.*, UAV trajectory has the 8 form around two fixed position), Scan (*i.e.*, UAV performs a scan in an area defined by two points along the round trip trajectories); and Oval (UAV trajectory has the oval form).

3.2 The MobiFANET Architecture

The MobiFANET architecture consists of two modules, namely *mobility movement* and *ideal location*, which interact with application protocol, geographic routing protocol, and mobility manager, as depicted in Figure 2. Application protocol detects an event, as well as codes and decodes the video. Routing protocol establishes a path $P_{SN,DN}$ between SN and DN via RN_i for video transmission. MobiFANET finds the ideal relay location and UAV movement by taking into account UAV location and mobility trajectory. It is important to highlight that MobiFANET works together with any geographic routing protocol, since most of them provide location information without any additional overhead. Finally, the mobility manager enables UAVs to fly following any mobility trajectory.

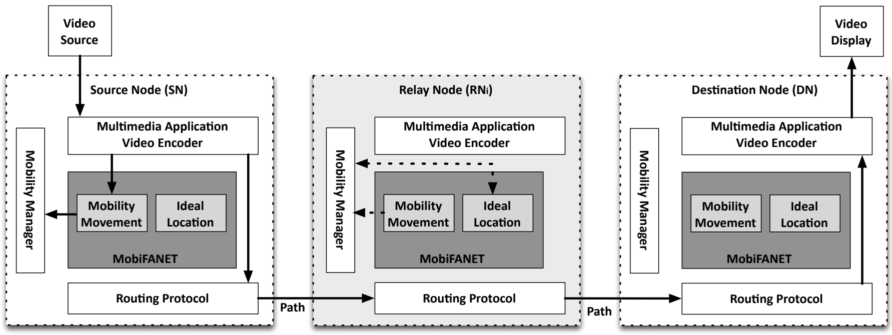


Fig. 2 MobiFANET Components and Its Interaction with a Geographic Routing Protocol and Mobility Manager

Each UAV v_i flies following any type of PPRZM movements to search and to detect an event in the environment, where the SN captures and transmits videos to the DN by detecting an event. Specifically, the SN application starts the MobiFANET mobility movement module to select the ideal SN moving trajectory. The SN must fly following the Stay-At, Eight, or Oval movements, since these trajectories enables the SN to fly around a fixed position to capture high relevant video from the detected event. Afterwards, the mobility movement module informs the mobility manager the selected UAV trajectory, making the UAV flying following such trajectory.

As soon as a given RN_i become part of $P_{SN,DN}$, it starts the MobiFANET ideal location module. This module computes the ideal RN_i location $L_{ideal}(X_i', Y_i')$ to forward the packets without breaking the communication with its last-hop, as well as avoiding to fly for a void area. The ideal location module requires the last-hop location stored in the routing table, and also the RN_i location $L(X_i, Y_i)$, and flying parameters from the mobility manager to compute the $L_{ideal}(X_i', Y_i')$. In addition, the mobility movement changes the RN_i moving trajectory to Stay-At, keeping the connectivity among UAVs that belongs to $P_{SN,DN}$, while reduce the packet loss and increase the video quality level. The mobility manager enables the RN_i to move this ideal location, and then make it flying following the Stay-At trajectory.

3.3 Topology Control Operations

The Ideal location at each RN_i computes the ideal location $L_{ideal}(X_i', Y_i')$ based on: SN location L(X_{SN}, Y_{SN}), DN location L(X_{DN}, Y_{DN}), radio range (R_{max}), Stay-At movement range (MR), and the Euclidian distance ($Dist_{SN,DN}$) between SN and DN, as shown in Eq. (1). The geographic routing protocol provides SN and DN location information in a routing table, and every UAV v_i has the same R_{max} and MR values. The ideal location must seek to reduce the number of hops, while mitigates route failures and void areas caused by UAV movements.

$$L_{ideal}(X_i', Y_i') = \begin{cases} X_i' = X_{SN} - \frac{(R_{max} - 2MR) \times (X_{SN} - X_{DN})}{Dist_{SN,DN}} \\ \\ Y_i' = Y_{SN} - \frac{(R_{max} - 2MR) \times (Y_{SN} - Y_{DN})}{Dist_{SN,DN}} \end{cases} \quad (1)$$

Figure 3 shows $L_{ideal}(X_i', Y_i')$ without considering UAV mobility model information, which should be the point onto the line from the SN to the DN with $Dist_{SN,RN_i}$ equals to the radio range R_{max}. This might keep RN_i inside the SN radio range, and provides a $P_{SN,DN}$ with the shortest distance to DN, reducing the number of hops. Considering the proposed architecture, the RN_i must fly to $L_{ideal}(X_i', Y_i')$ with the maximum speed S_{max} to quickly reach such location, since the main goal of MobiFANET is to place each RN_i at $L_{ideal}(X_i', Y_i')$ to forward the video packets with QoE support. Arriving at $L_{ideal}(X_i', Y_i')$, the RN_i must fly over this point following the Stay-At movement at a given speed S_i to keep the connectivity among UAVs that belongs to $P_{SN,DN}$. Without considering UAV moving trajectory, as soon as RN_i starts to fly following the Stay-At movement, it might move out of the SN radio range, as depicted in Figure 3.

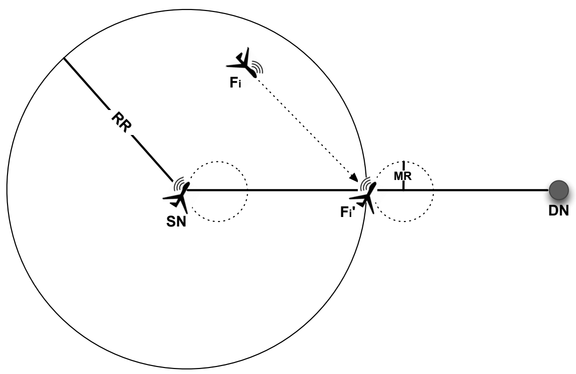


Fig. 3 Ideal Relay Location Without UAV Mobility Model

To handle such issue, the ideal location module of MobiFANET considers the UAV mobility trajectory to compute $L_{ideal}(X_i', Y_i')$. This module handles the Stay-At moving diameter (*i.e.*, 2 × MR) to reduce this value from the ideal point. By doing this, MobiFANET keeps the RN_i inside the SN radio range, while fly following the Stay-At movement, as shown in Figure 4.

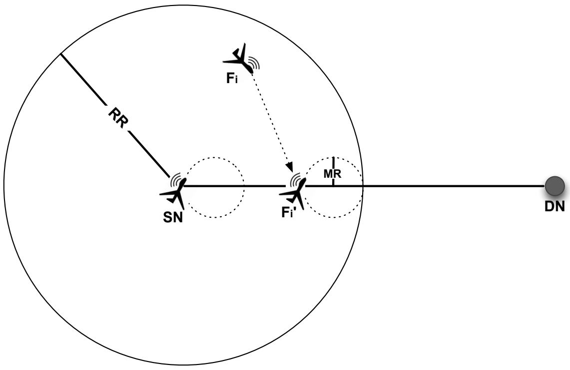
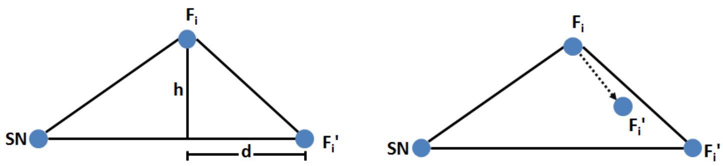


Fig. 4 Ideal Location Considering UAV Mobility Model

A given RN_i takes a time T to move to $L_{ideal}(X_i', Y_i')$. As expected, a long distance from $L(X_i, Y_i)$ to $L_{ideal}(X_i', Y_i')$ increases the time t need to reach such location, reducing the performance of the routing protocol. Hence, the ideal location module must find an alternative $L_{ideal}(X_i', Y_i')$ based on Eq. (2). The alternative $L_{ideal}(X_i', Y_i')$ is a point between $L_{ideal}(X_i', Y_i')$ and $L(X_i, Y_i)$, mitigating the problems related to UAV mobility. Figure 5 depicts the parameters used to compute the alternative $L_{ideal}(X_i', Y_i')$. After a given RN_i reaches the $L_{ideal}(X_i', Y_i')$, it must start the Mobility Movement Module to move following the Stay-At movement at speed S_i. Algorithm 1 describes the main operations for the MobiFANET.

$$L_{ideal}(X_i', Y_i') = \begin{cases} X_i' = X_i \pm \frac{d}{2} \\ \\ Y_i' = Y_{SN} \pm \frac{h}{2} \end{cases} \quad (2)$$



(a) (b)

Fig. 5 Alternative Relay Parameters and Location

Algorithm 1: MobiFANET Operations

begin
  Event: Becoming the forwarding for a path from SN to DN
  $L_{ideal}(X'_i, Y'_i) \leftarrow$ (Eq. 1)
  $T \leftarrow \frac{Dist_{F_i, F'_i}}{S_{max}}$
  if $T > t_{th}$ **then**
    $L_{ideal}(X'_i, Y'_i) \leftarrow$ (Eq. 2)
  MobilityMovement.moveTo($L_{ideal}(X'_i, Y'_i)$, S_{max}, Way-Point)
  while *true* **do**
    if $L(X_i, Y_i) = L_{ideal}(X'_i, Y'_i)$ **then**
      MobilityMovement.moveTo($L_{ideal}(X'_i, Y'_i)$, S_i, Stay-At)
      break

Figure 6 depicts an use case scenario composed of nine UAVs flying following the PPRZM to detect an event following the Stay-At, Way-Point, Eight, Scan, and Oval movements, *i.e.*, v_3, v_2, v_8, v_1, and v_4, respectively. The UAV v_1 detected an event, captures a video and sends it to DN.

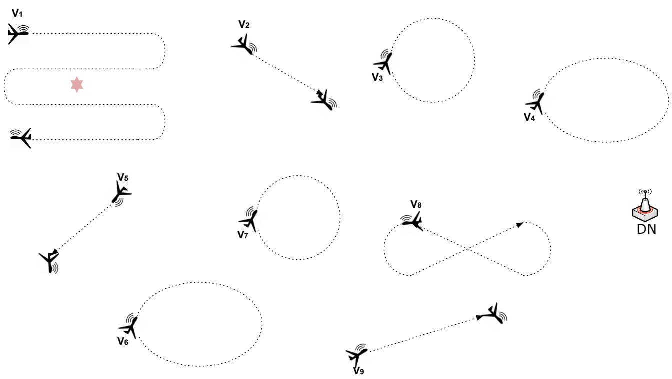


Fig. 6 UAVs Flying Following PPRZM to Find an Event a Given Area

After the event detection, a set of RN_i are placed in the ideal location to forward the video packets as shows Figure 7. Specifically, the Mobility Movement Module of UAV V_1 selected the Stay-At trajectory, enabling such UAV to capture high relevant video from the event. The Ideal Location Modules of a set of RN_i (*i.e.*, V_2, V_7, V_4) computed their ideal location to reduce the effects of UAV mobility. The Mobility Movement Module of these RN_i makes them flying following the Stay-At trajectories, precluding route failures and void areas caused by UAV movements.

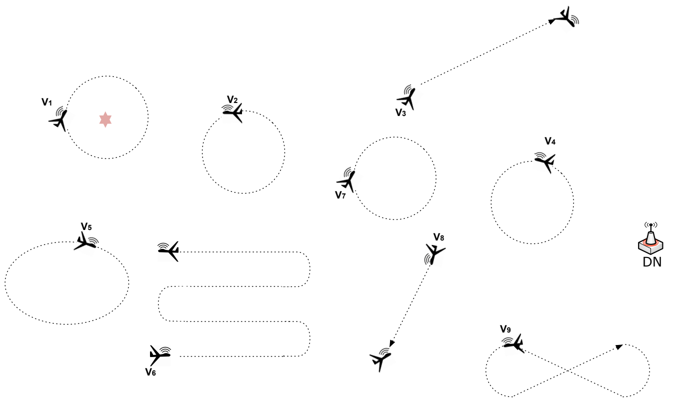


Fig. 7 UAVs Flying and Transmitting Video from the Event Considering the MobiFANET Mechanism

4 Evaluation

This section presents the methodology and metrics applied to evaluate the MobiFANET performance jointly with a routing protocol. We evaluated the impact of different UAV speeds on the maintenance of the route duration, number of route failures, and QoE.

4.1 Simulation Description and Metrics

We implemented the MobiFANET on the OMNeT++ framework [19], and conducted 33 simulation with different randomly generated seeds. Results show the values with a confidence interval of 95%. The simulations last for 200 seconds (s) and run with the lognormal shadowing path loss model. We set the simulation parameters to allow wireless channel temporal variations, link asymmetry, and irregular radio ranges, as expected in a real FANET scenario.

We consider a FANET scenario composed by 30 UAVs moving following the PPRZM [4] over the entire flat terrain of 200 x 200m [18]. Such UAVs are flying with different speed limit intervals: i) 1 to 5 m/s; ii) 5 to 10 m/s; iii) 10 to 15 m/s; iv) 15 to 20 m/s. As expected in FANET multimedia applications, we have one fixed Destination Node (DN) located at $(100, 0, 0)$. Further, all UAV nodes are equipped with IEEE 802.11 radio and the transmission power is set to 12dBm, resulting in a nominal R_{max} of 55 meters. Based on the simulation area and R_{max}, videos are received at the DN via 1 to 4 RN_i depending on the routing protocol.

Figure 8 illustrates the network stack executed on each UAV for the simulations conducted to evaluate mobiFANET for disseminating video content over FANETs. UAVs rely on the CSMA/CA MAC protocol, where it does not consider RTS/CTS messages and retransmissions. In case of buffer overflow, UAVs considers a drop tail mechanism to drop packets. At the application layer, UAVs take into account a QoE-aware redundancy mechanism to add redundant packets only to priority frames [18]. To analyse the relevance of the relay placement mechanism on a routing protocol, we have conducted simulations with three sets up: XLinGO-MobiFANET, XLinGO [18], and BLR [5]. BLR makes routing decision based only on geographical location, while XLinGO considers a set of cross-layer parameters, namely queue length, link quality, geographical location, and residual energy. XLinGO-MobiFANET considers XLinGO as routing protocol coupled with the MobiFANET mechanism.

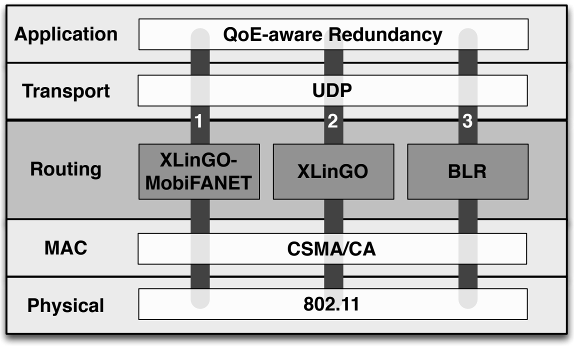


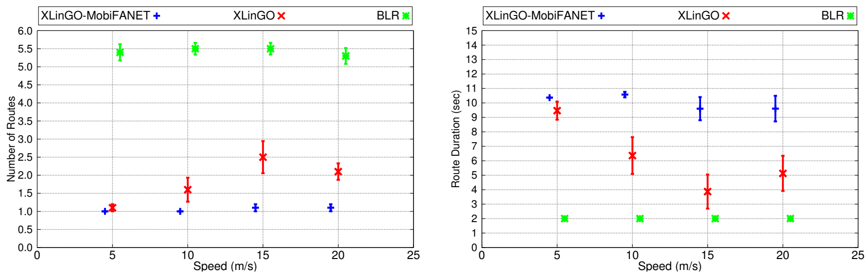
Fig. 8 Simulation Scenario

We scheduled a random event at different location, and when a given UAV detects such event, it starts to capture and disseminate a video about the event, such as explained in the Section 3.2. We considered video sequences with different video features downloaded from the YUV video trace library and YouTube [1], *i.e.*, Container, UAV_1, and UAV_2. The Container video has similar characteristics as a UAV hovering in a given area to capture the video, which means that there is a small moving region of interest on a static background. UAV_1 and UAV_2 videos are captured from a UAV flying in a city and in a rural environment, but UAV_2 has a higher motion level than UAV_1 caused by UAV instability during the flight. We encoded those videos with a H.264 codec at 300 kbps, 30 frames per second, GoP size of 20 frames, and common intermediate format (352 x 288 pixels). The decoder applies a Frame-Copy method for error concealment to replace each lost frame with the last received one, reducing frame loss and maintaining the video quality.

We evaluated the QoE by means of SSIM $\in$ [0,1], which is based on a frame-by-frame assessment of three video components, i.e., luminance, contrast, and structural similarity [14]. We considered the following metrics to evaluate the effects of UAV mobility, namely, number of route failures and route duration. Number of route failures represents the amount of times that the routing protocol established a new route. Route duration means the time that a given route is available to forward packets without route failure.

4.2 Simulation Results

By analysing the results of Figure 9(a), we conclude that XLinGO-MobiFANET outperform XLinGO and BLR in terms number of established routes to disseminate videos. Specifically, XLinGO-MobiFANET established only one route, regardless the moving speed. This is because it considers geographical location and UAV mobility trajectory to compute the ideal relay location, keeping the network connectivity, and avoiding route failure during video transmission. On the other hand, during the video transmission via BLR and XLinGO, UAVs mobility leads to route failures and void area, since RN_i moves faster out of the radio range of its last hop, breaking the connectivity between such nodes. For instance, BLR established about 5 routes, and XLinGO about two routes to disseminate each video. Figure 9(b) shows that route established by XLinGO-MobiFANET lasts for around 11 seconds, which is the time needed to disseminate each video. Routes for BLR and XLinGO last for around 2 and 6 seconds, due to node mobility lead to route failures. Routes established by BLR lasts for less time than routes of XLinGO, since BLR selects the most distant RN_i closest to the DN. However, the most distant node might suffer from a bad connection, since the RN_i is closer to the radio range limit.

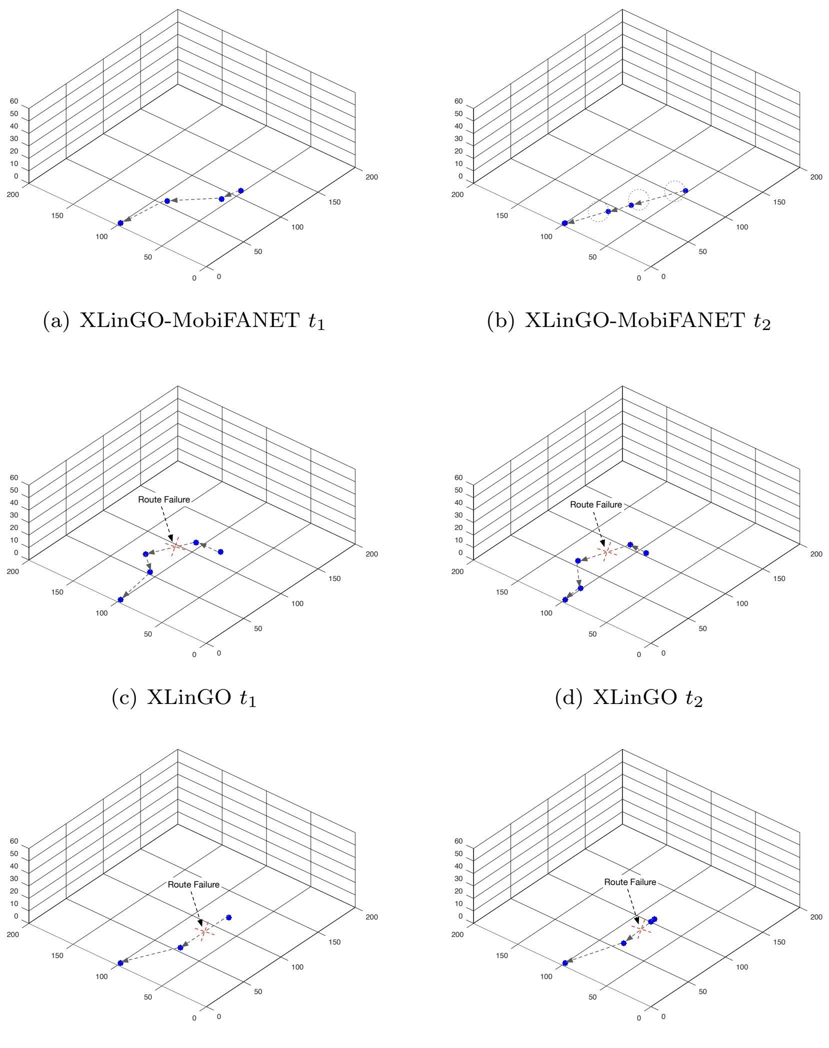


(a) Number of Route Failures (b) Route Duration

Fig. 9 Impact of Node Mobility on the Number of Route Failures and Route Duration

Figure 10 depicts the protocols behaviour in different timestamps, *i.e.*, t_1 and t_2. Figure 10(a) shows the route established by XLinGO-MobiFANET with 3 hops to disseminate the video at t_1, while Figure 10(b) depicts the same route with relay nodes located at their ideal location and moving following the Stay-At trajectory. This route last for the entire video dissemination, such as explained in the Figure 9(b). Figures 10(c) and 10(d) demonstrate the route created by XLinGO at t_1 and t_2, where after 4 seconds there is a route failure in both cases. Figures 10(e) and 10(f) show the routes created by BLR, where there is a route failure after 2 seconds.

Figure 11 shows the SSIM for each video delivered via XLinGO-MobiFANET, XLinGO, BLR, and original video in a scenario of UAV flying at different speed limits. The original video in the plot represents an errorless video transmission, which is used as a benchmark video quality, since there are no SSIM values



(a) XLinGO-MobiFANET t_1 (b) XLinGO-MobiFANET t_2

(c) XLinGO t_1 (d) XLinGO t_2

(e) BLR t_1 (f) BLR t_2

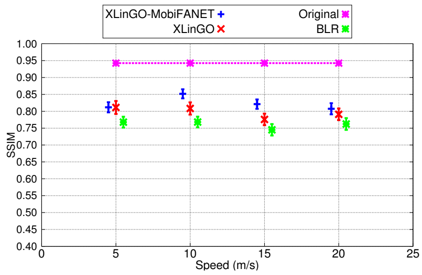
Fig. 10 Protocols Behaviour

higher than it. This is due to video coding and decoding process introduces impairments in the video quality even in the absence of packet losses [7]. In addition, this maximum value is different for each video, due to the motion and complexity level of each video. Thus, this maximum SSIM value helps to see exactly the quality loss due to packet losses.

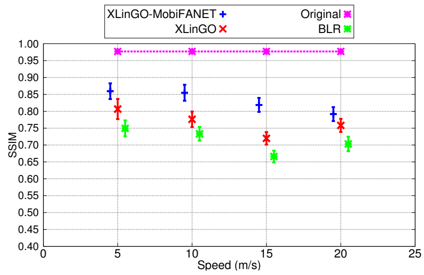
By analysing results of Figures 11(a), 11(b), and 11(c), we observe that XLinGO-MobiFANET delivered Container, UAV_1, and UAV_2 video sequences with a better quality than XLinGO and BLR, regardless the moving speed and video type. In addition, videos delivered by XLinGO-MobiFANET reduced less the SSIM compared to the original videos, which are the benchmark video quality level. Specifically, it delivered the Container with SSIM 12% lower than original video, the UAV_1 with SSIM 14% lower than original video, and UAV_2 with SSIM 27% lower than the original video. This is because the frame loss on the container video has lower impact on the quality level compared to UAV_1 and UAV_2, since container has a low motion level. [2]. For instance, Container and UAV_1 videos transmitted by XLinGO-MobiFANET has similar SSIM performance for UAV moving at 10 m/s, where Container reduced the SSIM in 9% and UAV_1 reduced in 12% compared to the original videos. However, the UAV_1 video transmitted by XLinGO-MobiFANET has a frame loss ration 25% lower than the Containers, as shown in Figures 12(a) and 12(b). In addition, UAV_2 has a higher motion level than UAV_1 caused by UAV instability during the flight, which worsen the SSIM even more in case of frame loss. Container, UAV_1, and UAV_2 videos delivered by XLinGO reduced the SSIM in 15%, 21%, and 43%, respectively, compared to original video. Finally, BLR delivered the Container, UAV_1, and UAV_2 with SSIM 19%, 27%, and 47%, respectively, lower compared to original video.

Figure 11(d) shows the SSIM values for all videos transmitted via XLinGO-MobiFANET, XLinGO, and BLR. We can observe that XLinGO-MobiFANET delivered videos with a high and constant SSIM compared to XLinGO and BLR regardless of the moving speed. Specifically, videos transmitted via XLinGO-MobiFANET increased the SSIM in 13% and 8% compared to BLR and XLinGO, respectively. This is because XLinGO-MobiFANET computes the ideal relay location, reducing the effects of UAV mobility and speed on the video quality level. BLR has poor SSIM compared to XLinGO and XLinGO-MobiFANET, since BLR considers only geographical information for routing decision, and thus in BLR operation, UAV mobility quickly breaks the communication links, since the relay node is closer to the radio range limit. On the other hand, XLinGO delivers videos with better SSIM compared to BLR, since XLinGO consider multiple metrics for routing decision, but it does not consider any mechanism to avoid route failure and void area, which reduce its video quality level.

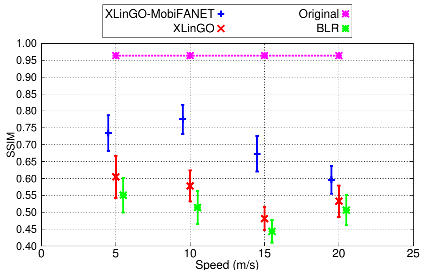
Figure 12 shows the frame loss rate for each videos delivered via XLinGO-MobiFANET, XLinGO, and BLR, which helps to explain the SSIM results of Figure 11. This is because video dissemination requires low frame loss to support video dissemination with satisfactory QoE [14]. For instance, XLinGO-MobiFANET reduced the overall frame loss by 50% compared to BLR and XLinGO. More specifically, a compressed video is composed of I-, P- and B-frames, which have different priorities, and the loss of priority frames, *i.e.*, I-frame, causes severe video distortions based on the user perspective [7]. Based on the simulation results, we concluded that XLinGO-MobiFANET reduced the losses of I-frames by 43% and 71% compared to XLinGO and BLR, respectively. Hence, it transmitted priority frames with high deliver probability compared to BLR and XLinGO, increasing the video quality.



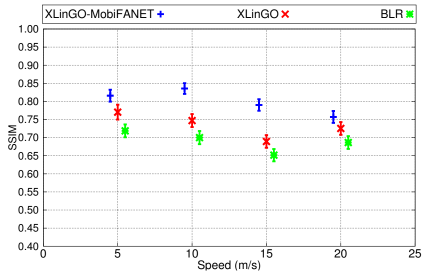
(a) Container



(b) UAV_1

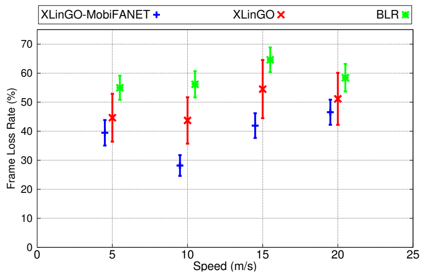


(c) UAV_2

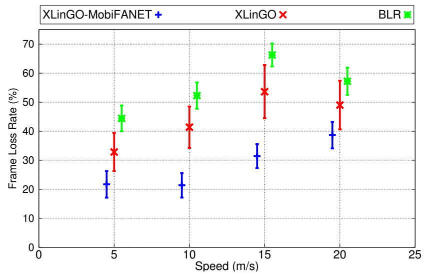


(d) All Videos

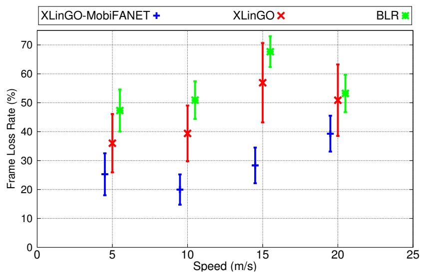
Fig. 11 SSIM for UAVs Flying at Different Speed and Transmitting Different Videos



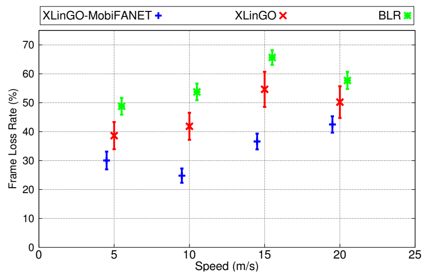
(a) Container



(b) UAV_1



(c) UAV_2



(d) All Videos

Fig. 12 Frame Loss for UAVs Flying at Different Speed and Transmitting Different Videos

5 Conclusions

This article showed the efficiency of the MobiFANET mechanism for supporting video dissemination with QoE gain on FANETs. MobiFANET works together with any geographic routing protocol and it takes into account geographical location and FANET mobility trajectory to establish the ideal relay location, keeping the network connectivity by mitigating the effects of UAV mobility, avoiding communication flaws, delays, and void area. Simulation results showed that XLinGO and BLR perform poorly compared to XLinGO-MobiFANET in a FANET scenario composed of UAVs flying at different speed. Hence, MobiFANET cooperates to provide multimedia transmission with QoE, as required in many safety and security FANET scenarios.

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