Improving Video QoE in Unmanned Aerial Vehicles Using an Adaptive FEC Mechanism

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Abstract. Unmanned aerial vehicles (UAV) are rising in popularity together with video applications for both military and civilian use. Because of that, it is necessary to address a set of challenges related to the device movement, scarce resources as well as high error rates, making evident the need for an adaptive mechanism to strengthen video transmissions. Adaptive Forward Error Correction (FEC) techniques are known to be suitable to enhance the Quality of Experience (QoE) of video transmitted over error-prone wireless networks with high mobility. This book chapter proposes an adaptive video-aware FEC mechanism that uses motion vectors details to improve real-time UAV video transmissions, providing both higher user experience and better usage of resources. The benefits and drawbacks of the proposed mechanism along with the related work are analysed and put up for test through simulations and evaluated using QoE metrics.

Keywords: Motion Vectors (MV) · Forward Error Correction (FEC) · Video-aware FEC · Fuzzy logic · QoE · Unequal Error Protection (UEP)

1 Introduction

The rapid growth of both, autonomous and nonautonomous unmanned aerial vehicles (UAV) [1], with the objective of video surveillance, exploitation, and reconnaissance is evident in the last years. The deployment of these vehicles is no longer exclusive of military and special operation applications, as the civilian use of small UAVs has also increased due to ease operation, robust, and cost-effective wireless networking technologies, such as 4G LTE. These devices can be helpful in a variety of situations. For example, in traffic surveillance, public parades, festivals, sports events, in short, at any event that brings together a large amount of people [2,3], the use of UAVs can be preferred over fixed video cameras due to

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their mobility and low cost operation in comparison to manned systems. Other applications are to cover large areas with no previous infrastructure, in natural disaster sites, rescue missions [4], as well as monitoring and inspecting critical infrastructures, such as power plants, long pipelines, large industrial areas, railways, harbours.

The benefits of UAV with video-capability are clear, however, even with proper equipment, robust data integration and visualization tools, poor-quality video streaming can compromise the usability of the system. These video streams are watched by humans, and a good quality is essential to, for example, identify faces, damaged power lines or pipes, as well as track conditions. However, it is known that real-time video transmission over wireless networks with Quality of Experience (QoE) support brings new challenges. It needs a steady and continuous flow of packets, which can be affected by a number of factors. First of all, these networks tend to have poor connectivity quality [5]. In addition, the channel conditions can quickly fluctuate over time owing to the high mobility of the nodes and terrain structures, as well as other wireless communication issues like noise, multipath fading, and channel interference [6]. Another challenge is to fairly use the available bandwidth [7]. It is critical to make an efficient use of resources preventing the induction of network congestion and high packet loss rate. This is especially important in resource-consuming services like video transmission. Furthermore, the video quality as perceived by the users is also important, a good clean image will help to identify persons, objects, and places, while providing a better chance to act accordingly in each case.

The quality of live video streams, in terms of QoE [8], is the overall acceptability of end-users and is related to, but differs from the extensively studied concept Quality of Service (QoS). Generally speaking, QoE quantifies the video quality according to the user perception and these characteristics must be taken into consideration in networking adaptation mechanisms. This need is even more evident in dynamic wireless environments with high error rates, such as, in UAV video streams. The optimized distribution of live video streams with QoE support is one of the main challenges in highly dynamic wireless environments. Choosing the proper adaptive redundancy control mechanism with QoE and network-awareness is decisive for an efficient use of resources, while increasing the video quality as perceived by end users.

Several factors can affect the video QoE. These factors are not restricted to network parameters as aforementioned, but also to the video characteristics, such as codec type, bitrate, the length of the Group of Pictures (GoP), as well as the video content, such as the degree of details and motion intensity [9]. Because of that, an adaptive redundancy control mechanism is required to improve the video quality in high dynamic and error-prone wireless networks, especially involving mobile nodes. A good way to quantify the motion intensity in a certain video portion (e.g., a frame or GoP) is to use the Motion Vectors (MV) in it. MV are a key part of the video compression, where they are used to store the changes from adjacent frames. This means that the changes can be related to the next frame or both previous and next frames. By using the information held by the MV, it is possible to quantify the motion intensity. Since each video sequence has its own characteristics in terms of motion and complexity levels, the adaptive redundancy control mechanism must recognize them and perform the protection in accordance with their importance. To do that, an Unequal Error Protection (UEP) scheme is desired to shield the most important information providing better QoE.

Through the use of an adaptive protection mechanism it is possible to protect the most important data, improving the video transmission and attaining both high video quality and low network overhead. To this end, Forward Error Correction (FEC) techniques have been used successfully in real-time video transmission services [10]. FEC enhances the video transmission by sending redundant data along with the original data set. Because of that, when a data loss occurs, the original data can be reconstructed using the redundant information [11]. However, the wireless resources are limited and often unfairly distributed. In order to overcome these problems and to allow multiple simultaneous transmissions, an adaptive cross-layer FEC-based mechanism is required. This mechanism should also be UEP- and QoE-aware to decrease the redundant information, while increasing the human perception. This is feasible by adjusting the amount of redundancy based on the content relevance from the QoE perspective, giving more protection to the most important data.

This book chapter describes a cross-layer adaptive video-aware mechanism that uses motion vectors details, FEC, and Fuzzy logic to improve the resilience of UAV (uavFEC) video transmission with both UEP and QoE-awareness. Even though some video-aware FEC-based mechanisms are found in the literature, as detailed in the related work, they tend to consume unnecessary bandwidth by sending QoE-unaware information. To address this issue, the uavFEC dynamically configures itself, using fuzzy logic, to send redundant information of only the most important data, improving the human experience when watching live video flows, while providing users and authorities (e.g., firefighters and paramedics) with a high perception of videos and allowing them to reduce human reaction times.

Fuzzy logic has been used in several video related mechanisms, such as to detect video shot boundaries in content-based video applications [12], to perform congestion control of real-time video stream in wireless networks [13], and also to perform a dynamic bandwidth and buffer allocation on multimedia traffic [14], as well as for QoE estimation of audio and video transmissions [15]. However, to the best of our knowledge, there is no proposal of an adaptive mechanism using fuzzy logic to handle in an abstract way the concepts of motion vectors to enhance QoE in highly dynamic and error-prone wireless networks. The uavFEC also uses the fuzzification process to cope with a number of video characteristics in order to find the specific degree of membership which corresponds the motion intensity of each video sequence. In doing that, it is possible to assign an optimal amount of redundant data only to QoE-sensitive data. This means that only the more sensitive video information will have an adjustable amount of redundant data, therefore ensuring a high video quality and downsizing the resource usage.

These are important features in highly dynamic networks that can be only achievable through the adoption of an adaptive mechanism. Another important advantage is the energy savings that are achieved by sending less redundant information, thus using less power. The proposed solution was assessed using real video sequences from small UAVs and objective QoE metrics.

The remainder of this book chapter is structured as follows. The related work is shown in Sect. 2. Section 3 describes uavFEC and its evaluation is presented in Sect. 4. Conclusions and future work are summarized in Sect. 5.

2 Related Work

Several mechanisms have been proposed to improve the video quality over wireless networks, however, to the best of our knowledge, there is no proposal of an adaptive video-aware mechanism to enhance the video transmission of UAVs. One of these proposals is the Adaptive Cross-Layer FEC (ACFEC) that uses a packet-level error correction [16]. It adopts a MAC layer loss counter, which is increased on each loss, and it is used to determine the amount of FEC redundancy. In doing so, when the wireless connections are good, the counter will held a small number, producing less redundant traffic. Nevertheless, a network overhead assessment was not conducted, proving difficult to determine the efficiency of the proposal. Additionally, the video characteristics are not considered, which are known to have a direct influence on the video resilience to packet loss and QoE.

Another approach uses a retransmission-based adaptive source-channel rate control [17]. This allows to track in real-time the decoder buffer occupancy and channel state, making possible to use the best redundancy amount. Despite the authors claim that it improved the QoE for end-users, no actual QoE metrics were used, they relay only on QoE prediction using packet loss information. Another point is that it does not measure the network overhead caused by the proposed scheme.

An alternative mechanism defines a dynamic FEC block length, which can be adjusted according with both, the number of continuous losses and the packet loss rate to improve video transmissions [18]. This approach only takes into consideration the network parameters, leaving out information about QoE and video characteristics which are very important in the adaptation scheme to define a correct amount of redundancy.

Another solution is the Cross-Layer Mapping Unequal Error Protection (CLM-UEP) [19]. This mechanism provides a tailored amount of redundancy based on the frame type and packet loss rate. However, this approach does not deal with important video characteristics, such as the frame position within the GoP and, especially, the motion intensity. As aforementioned, these video characteristics have a substantial influence in order to find the more appropriate amount of redundancy, consequently saving important device and network resources.

3 Adaptive Video-Aware Fuzzy Logic Mechanism

Considering the open issues aforementioned, in particular the lack of QoE- and video-aware proposals which include clear indicators of motion intensity, such as the motion vectors (MV), and the network state, this work proposes and evaluates a cross-layer adaptive video-aware FEC mechanism (uavFEC) based on MV and fuzzy logic. The primary goal is to enhance the video transmission of small UAV. This solution is an improvement of our previous work [20] and the main enhancements are described next.

Figure 1 depicts the overall operation of our mechanism. The video is captured, packetized, and delivered to uavFEC. After that, our mechanism will gather information about the video characteristics, such as the distance pointed by the motion vectors, frame type, GoP length, and relative position of P-Frames. These information are obtained through cross-layer techniques and loaded on the fuzzy interface engine to compute a suitable redundancy amount. Another important feature of uavFEC is the use of the network status to improve even further the amount of redundancy, allowing to enhance the video quality without adding unnecessary network overhead.

In order to conceive the uavFEC, first of all, a knowledge database needs to be created through exploratory analysis using hierarchical clustering. This database stores information about the relation between several video characteristics and their impact on the quality of the videos. Further details can be found in [20]. The combined use of this knowledge database and human expertise allows the definition of several fuzzy rules and sets. The offline process needs to be executed only once. Following this analysis, the information is loaded in the fuzzy interface engine and can be used in the real-time decision making process. This is an

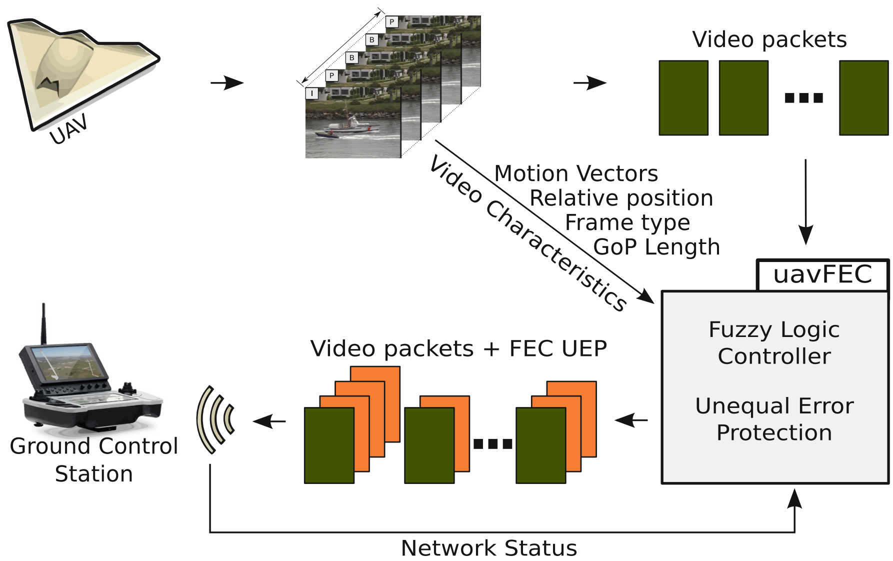


Fig. 1. uavFEC

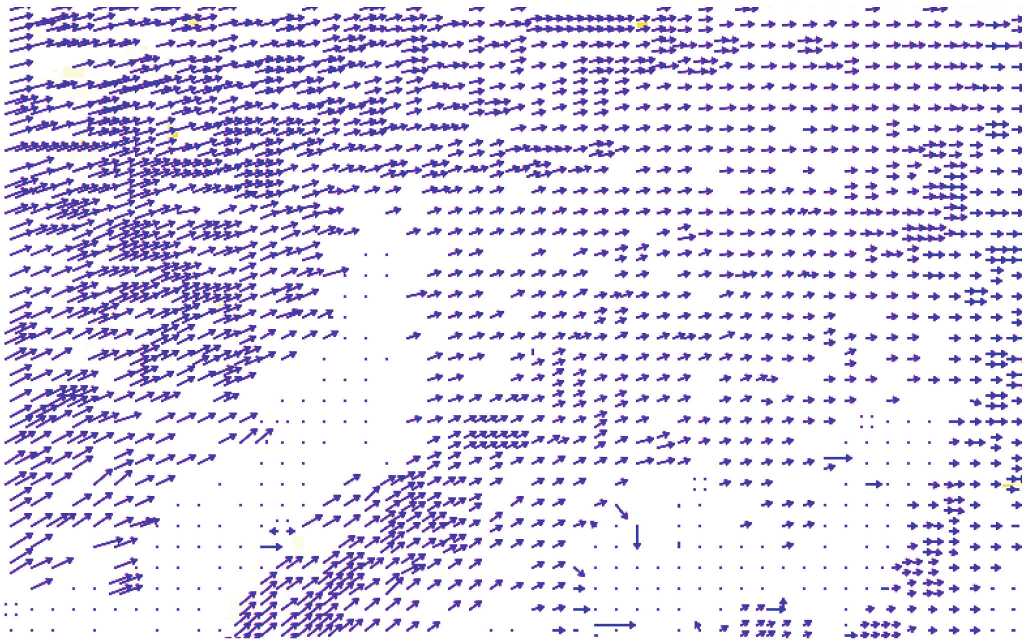
important step, since the real-time mechanism can be faster and more accurate, as fewer variables need to be handled.

uavFEC also uses the network state as one of the inputs to the adaptive mechanism. This information is jointly employed with the GoP length, motion vectors distance, frame type, and the relative position, to determine a suitable amount of redundancy. After that, using an improved UEP technique, a proper amount of redundancy will be added, sparing resources while increasing the video quality. A detailed description of the adaptive mechanism is presented below.

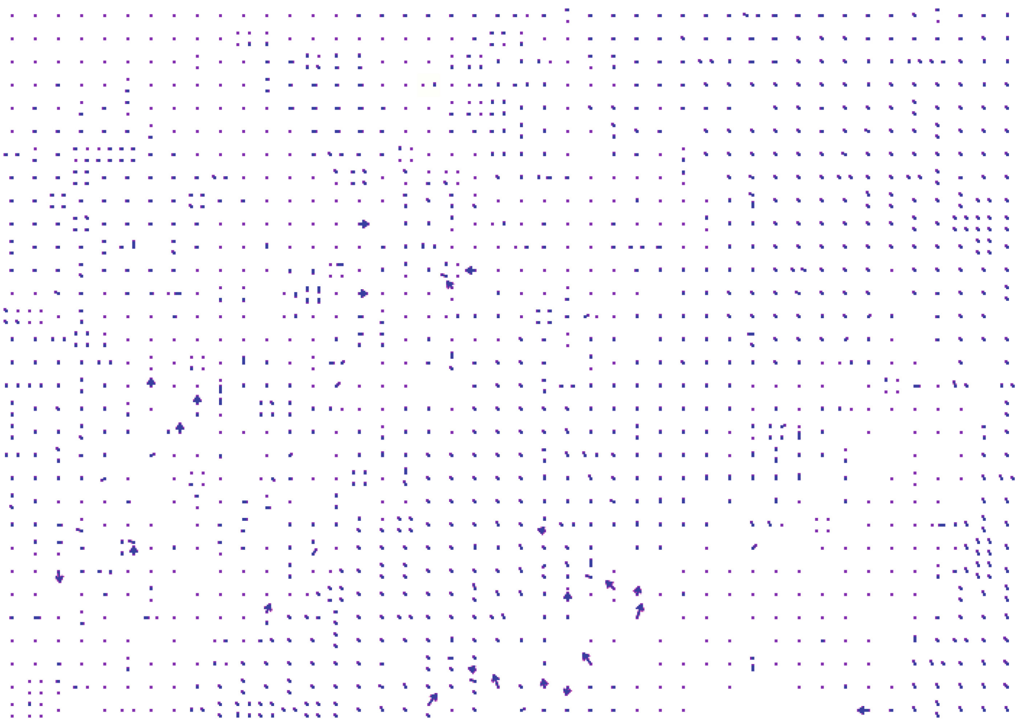
The use of fuzzy logic in the proposed mechanism allows it to be more comprehensive and dynamic, because it can take into consideration a larger number of video and network details and still be fast enough to operate in real-time schemes as expected in a highly dynamic UAV network. Additionally, fuzzy logic can be considered a problem-solving methodology that aims to define what the system should do rather than attempting to fully understand its operation. It adopts a simple approach to provide definitive conclusions relying on imprecise, ambiguous, or vague information.

In order to use fuzzy logic it is necessary to define several components, such as rules, sets, and membership functions. The rules define how the system behaves. The fuzzy sets, in contrast to classical sets that an element either belongs or does not belong to, are capable to have a degree of membership. At last, the membership functions are designed to represent the significance of each element in the fuzzy set.

The process of designing the fuzzy logic components that will be used in the uavFEC mechanism enfolds a series of exploratory analysis to define the behaviour and value of each one of them. The first step is to quantify the motion intensity. In order to do that, an exploratory analysis using hierarchical clustering with Euclidean distance was conducted. This is a statistical method of partitioning data into groups that are as homogeneous as possible. Motion vectors (MV) data is used to create these clusters. The idea of MV was obtained from classical mechanics and their vector-oriented model of motion. This model describes the movement of objects as simply as the sequence of small translations on a plane. To produce a large data base, the MV of several UAVs video sequences were extracted. Then, through Euclidean distance, it was computed how far each vector is pointing and summed together with all others in the same frame. This was used instead of just counting the MV, because one frame can have a lot of vectors pointing to a close distance where another frame can have less vectors, but pointing much farther away, thus presenting higher motion intensity. Figure 2 depicts an example. At frame #21 the UAV is turning right, thus, it is possible to see that the MV are longer than in frame #34, when the UAV finished the turn and starts hovering. The Euclidean distance sums of all MV in these frames are 109300 and 14117, for frame #21 and #34 respectively. However, the total number of MV in each frame is 4959 (frame #21) and 4963 (frame #34). This means that, even tough frame #34 has more MV, they are describing less motion than those stored at frame #21, more precisely, they are 7.74 times smaller.



Motion vectors of frame #21



Motion vectors of frame #34

Fig. 2. Motion vector comparative

```
fl::InputLVar* Motion = new fl::InputLVar("MotionIntensity");
 Motion->addTerm(new fl::ShoulderTerm("LOW", 10000, 30000, true));
 Motion->addTerm(new fl::TriangularTerm("MEDIUM", 21000, 80000));
 Motion->addTerm(new fl::ShoulderTerm("HIGH", 60000, 130000, true));
engine.addInputLVar(Motion);
```

Fig. 3. Motion intensity input set

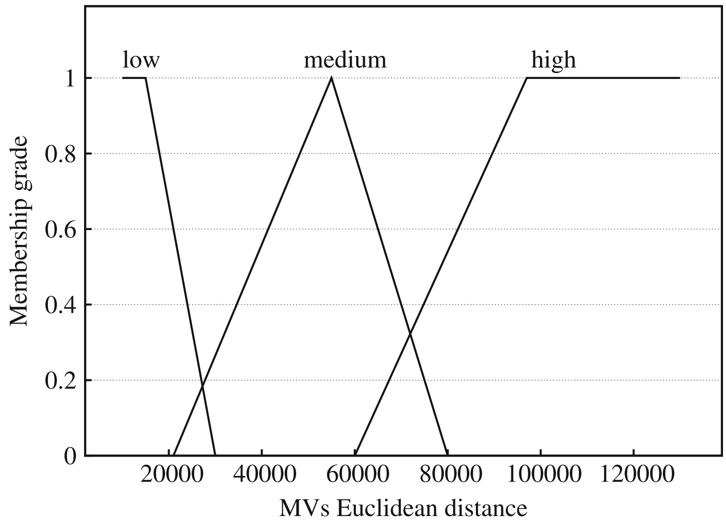


Fig. 4. Motion intensity membership function

```
fl::InputLVar* PLR = new fl::InputLVar("PacketLossRate");
 PLR->addTerm(new fl::TriangularTerm("LOW", 0, 15));
 PLR->addTerm(new fl::TriangularTerm("MEDIUM", 5, 30));
 PLR->addTerm(new fl::TriangularTerm("HIGH", 20, 100));
engine.addInputLVar(PLR);
```

Fig. 5. Packet loss rate input set

With the distance described by all MV in all frames, the sets must be defined. To do that, the frames were clustered together according to the motion intensity. Based on the linkage distance between the clusters, the motion intensity was divided into three clusters, namely “small”, “medium”, and “high”, as presented in Fig. 3.

After defining the sets, it is necessary to set up the membership functions. This definition is a complex and problem-dependent task. Because of that, it is preferable to use piecewise linear functions (formed by straight-line sections), because they are simple and more efficient with respect to computability and resource requirements. Figure 4 shows the graphical representation of our membership functions.

After delineating the motion intensity, the packet loss rate set must be defined. The aim of this activity is to quantify the packet loss rate against the video quality in terms of QoE. In other words, a loss rate of 10 % can be considered low in our approach, however, it might be unacceptable in other applications, such as a voice over IP call. To define this set, a number of network simulations with several packet loss rates as well as a broad collection of UAV video sequences were carried out, as shown in the Fig. 5. On average, the video quality was considered good when the network losses were between 0 % and 10 %. Between 5 % and 20 %, a tolerable video quality was perceived, but over 15 % the quality quickly decreased, soon becoming unacceptable. Because of that, three categories were defined, namely "low", "medium", and "high", as shown in Fig. 6.

Another stage is to delineate the redundancy set. The main goal of this set is to establish the output value which will be used to add the redundancy. Here again a combination of experiments and human knowledge in the field were used to specify what could be considered a "small", "medium", and "large" amount of redundancy. The values obtained and the graphical representations of the membership functions are displayed in Figs. 7 and 8, respectively.

After defining all the fuzzy sets, the IF-THEN structure must be created. This is a straightforward procedure, because if the transmitted video has low levels of motion activity (according to the motion vectors) and the packet loss rate is low as well, then the uavFEC will attribute also a low redundancy. The same procedure is valid for "medium" and "high" motion activities and packet loss rate as depicted in Fig. 9.

After defining the rules and sets, they need to be loaded in the Fuzzy Logic Controller (FLC). This activity has to be performed just once, during the system setup period (bootstrap). After the FLC definition, it will calculate the degree of membership of each input information, resulting in a precise amount of redundancy on-the-fly.

This is important because video transmission is delay-sensitive, meaning that if a frame is received after its decode deadline it cannot be displayed. Moreover, unlike neural networks or genetic algorithms, FLC does not need a period of online training or convergence, making it a proper tool for real-time control. Additionally, the calculations can be very simple, especially when triangular or trapezoidal membership functions are adopted [21], and even further reduce to a simple operation through fuzzy control surface.

4 Performance Evaluation and Results

The main goal of the uavFEC mechanism is to improve the perceived video quality without adding unnecessary network overhead, thus saving resources. The evaluation experiments were carried out by using the Network Simulator 3 (NS-3). The evaluation scenario is composed of up to four UAVs, equipped with a 4G LTE radio at 800 MHz. These UAVs can be operated in autonomous or nonautonomous mode. In a surveillance scenario, for example, it is possible to have

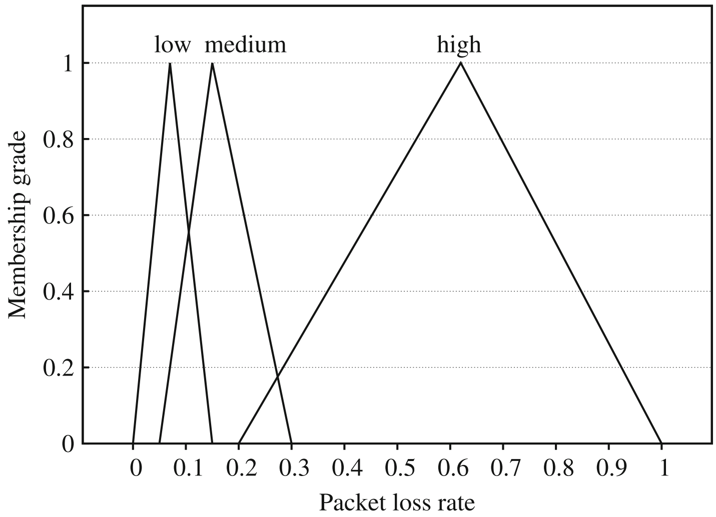


Fig. 6. Packet loss membership function

```
fl::OutputLVar* Redundancy = new fl::OutputLVar("RedundancyAmount");
 Redundancy->addTerm(new fl::ShoulderTerm("SMALL", 0.55, 0.70, true));
 Redundancy->addTerm(new fl::TriangularTerm("MEDIUM", 0.60, 0.80));
 Redundancy->addTerm(new fl::TriangularTerm("LARGE", 0.75, 1));
engine.addOutputLVar(Redundancy);
```

Fig. 7. Motion activity output set

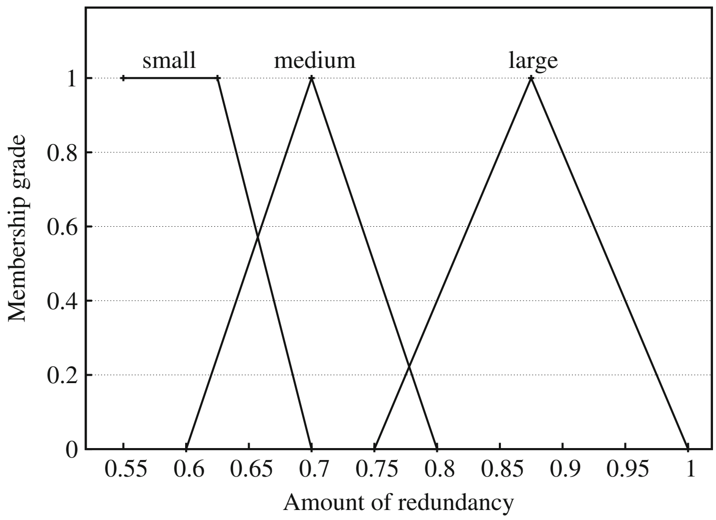


Fig. 8. Redundancy amount membership function

a human operating the UAV. This allows to have an instantly change of direction and speed during the pursuit of a suspect. Because of that, the mobility model was defined as random waypoint [22]. All UAVs are in line-of-sight and

```
fl::RuleBlock* block = new fl::RuleBlock();

block->addRule(new fl::MamdaniRule("
 if (Motion is LOW and PacketLossRate is LOW)
      then RedundancyAmount is SMALL", engine));

block->addRule(new fl::MamdaniRule("
 if (Motion is MEDIUM and PacketLossRate is MEDIUM)
      then RedundancyAmount is MEDIUM", engine));

block->addRule(new fl::MamdaniRule("
 if (Motion is HIGH and PacketLossRate is HIGH)
      then RedundancyAmount is LARGE", engine));
```

Fig. 9. Packet loss × redundancy amount rules

communicate directly with an ad-hoc connection to ground control station which was equipped with a portable base station and antenna. A set of twenty real UAV video sequences in high definition (720p), GoP length of 19:2, and H.264 codec were used. Due to the ad-hoc communication and the high definition videos, the flying range is limited to a radius of 900 m from the base station. A Frame-Copy error concealment method is active, this means that lost frames are replaced by the last good one received. The Packet Loss Rate (PLR) varies according to the movement of the UAVs, namely distance from the portable base station and velocity, and also due to concurrent transmissions of others UAVs. Because the aforementioned details, the PLR can range from 0 % to 45 %. Table 1 shows the simulation parameters.

In order to compare the results, five different cases were simulated. The first is without FEC, serving as baseline to compare with the others. The second case is a non-adaptive video-aware FEC-based approach. In this case, only I- and P-Frames are protected with equal amount of redundancy, which was set to 65 %. This amount was chosen because it provides a good tradeoff between video quality and network overhead under several PLRs. The next case is our previous work with a simple adaptive unequal error protection (ViewFEC) [20]. Another case is an implementation of the Cross-Layer Mapping Unequal Error Protection (CLM-UEP) [19]. The last case is our uavFEC mechanism. The set up simulation is composed of 20 real UAVs video sequences and 5 cases, each one was simulated 30 times with each video.

Figure 10 depicts the average Structural Similarity Metric (SSIM) for all video sequences when only one UAV is transmitting. The measurement of this metric is fairly simple, however, it is consistent with the human visual system, given good results [23]. In the SSIM, values closer to one indicate a better video quality. As expected, when the UAV is far away from the ground control station there is a decline in the video quality. In the baseline case, without FEC, a sharp decline in the video quality after 400 m is perceived. Conversely, the UAVs using a FEC-based mechanism are able to sustain a better video quality longer,

Table 1. Simulation parameters

Parameters	Value
Display size	1280 × 720
Display aspect ratio	16:9
Frame rate mode	Constant
Frame rate	29.970 fps
GoP	19:2
Codec	H.264
Container	MP4
Propagation model	FriisPropagationLossModel
UAV velocity	45–65 km/h (28–40 mph)
LTE Frequency band	800 MHz
LTE Mode	FDD
LTE Bandwidth	5 MHz
eNodeB Operating Power	22 dBm
Antenna Gain	16 dBi

and it is only noticeable after 500 m for case 2, and after 700 m for cases 3–5. Almost the same behaviour is shown in Fig. 11 which demonstrates the results for 2 UAVs transmitting simultaneously. One clear difference between these two scenarios is the increase in the standard deviation on the baseline case. This can be explained by the natural resiliency of some videos to packet loss due to different video characteristics. Video sequences with low motion intensity are more resilient to loss, and generally have better results in the QoE-aware assessment. On the other hand, videos with high motion intensity tend to have poor results.

As the number of video sequence flows begins to increase, the quality of the transmitted video starts to decrease sooner than before. Figures 12 and 13 depict this tendency. In the first two scenarios (with one and two UAVs), the uavFEC managed to keep the SSIM above 0.7 up to 700 m (other approaches only up to 600 m). However, with three and four UAVs, the uavFEC was able to maintain the SSIM over 0.7 only up to 600 m, after that, there is a sharp decline in the video quality in all of the assessed mechanisms. This can be attributed to a more congested network due to several transmissions together with the distance from the ground control station.

Figure 14 depicts the comparison of uavFEC and the related work (CLM-UEP) [19]. The graph shows the average percentage of QoE improvement against the amount of redundancy added by the mechanisms in all scenarios (from 1 to 4 UAVs). A positive percentage means that our mechanism had better QoE results than CLM-UEP. In all four scenarios, uavFEC presented a slight better video quality until 600 m, more precisely, on average between 0.59 % and 5.00 % better. The real advantage of uavFEC is noticeable after the 700 m, when it enhances

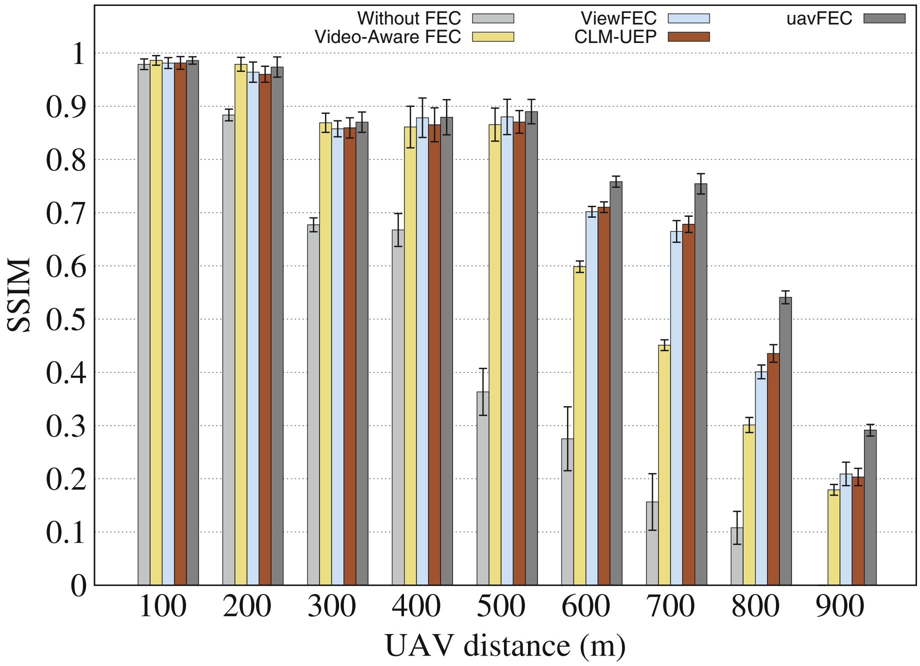


Fig. 10. SSIM QoE for all scenarios with one UAV

even further the video quality. The uavFEC was able to achieve improvements, on average, between 11.59 % and 28.52 % better than CLM-UEP. Taking this into consideration, it is clear that our mechanism performs better in higher distance, where the PLR is also higher. This gives uavFEC the capability to operate in wide coverage areas.

It is also shown by Fig. 14 the comparison of the amount of redundancy added by both, CLM-UEP and uavFEC. A negative percentage means that our mechanism adds less redundancy than CLM-UEP. In all four scenarios, uavFEC added less redundancy until 600 m, which was around 3.75 % and 15.12 % less on average, and still managed to transmit the videos with higher QoE. This means that the uavFEC was able to improve the video quality and at same time save resources. After 700 m, our mechanism begins to increase the redundancy. This happens because the uavFEC was developed to enhance the video quality over higher distances, which make the networks more susceptible to errors. Considering this, the mechanism will have to increase the protection of the most important video data, adding more overhead. For example, at 700 m our mechanism added on average 4.49 % more redundancy, and at 900 m added 10.19 %. Increasing the redundancy is an expected response of our mechanism to further improve the video quality, which can be confirmed through the QoE assessment in the same figure. In summary, the uavFEC provides a good tradeoff between video quality and network overhead.

A further analysis of Fig. 14 shows that up to 500 m both mechanisms had similar QoE results, with uavFEC having a modest higher video quality. The

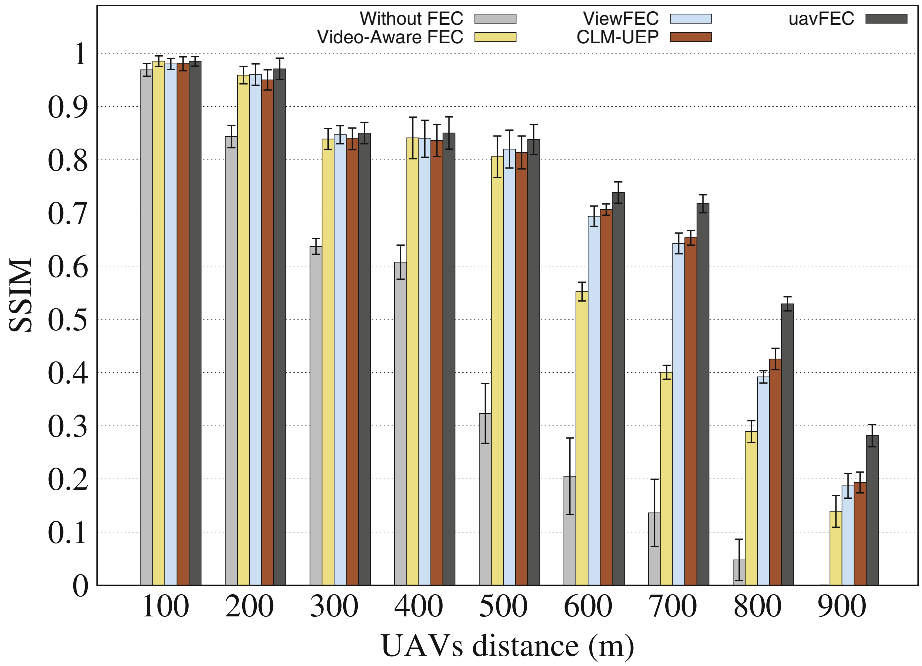


Fig. 11. SSIM QoE for all scenarios with two UAVs

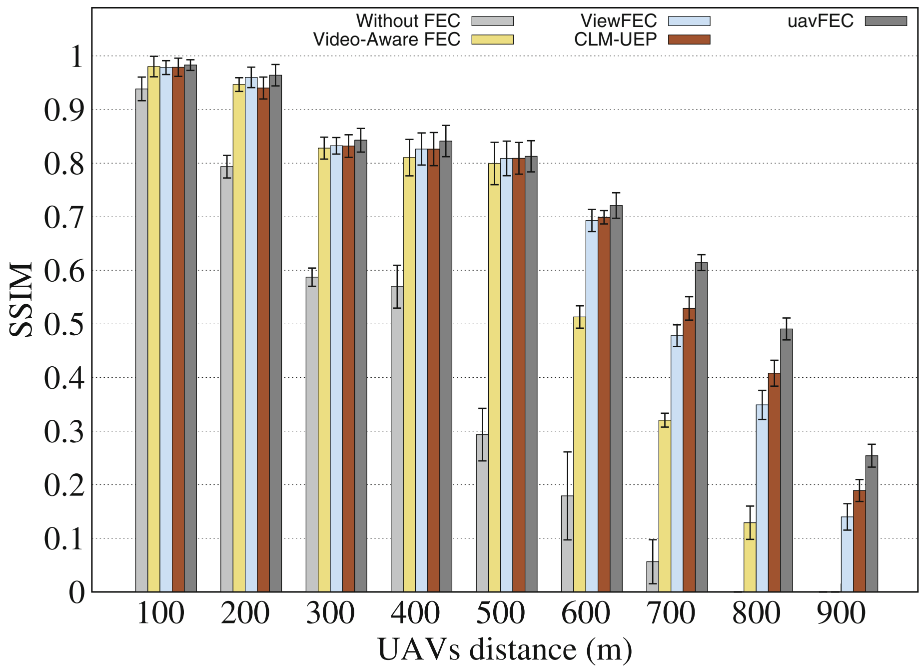


Fig. 12. SSIM QoE for all scenarios with three UAVs

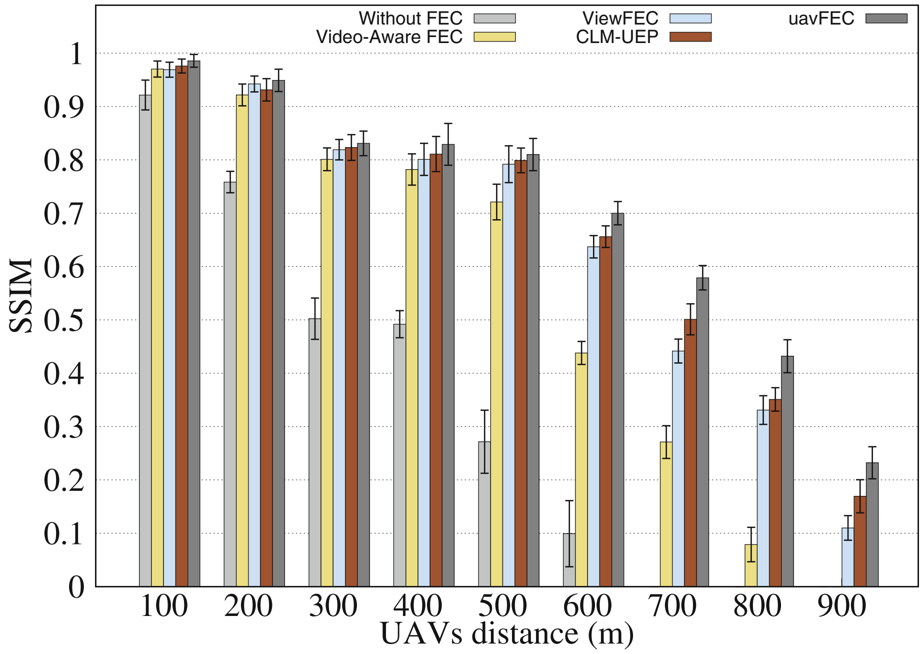


Fig. 13. SSIM QoE for all scenarios with four UAVs

major difference was the considerable smaller network overhead, this means that uavFEC, through its QoE- and Video-aware techniques, was able to add redundancy to the most important video data only. At 600 m, our mechanism still adds less redundancy than the related work, but it is already showing better results, with an improvement of 5.00 % on QoE. After this threshold, considering the increasing distance and in order to improve the video quality, our mechanism starts to add a larger amount of redundancy. The result of this approach, are videos transmitted on average with more than 28 % of better quality and adding no more than 11 % of redundancy in comparison to CLM-UEP. The main advantage of the uavFEC is that it uses the MV to infer the motion intensity of video sequences, allowing the mechanism to define an appropriate amount of redundancy and to find the more sensitive data that needs more protection. In doing that, it is possible to deliver videos with higher quality in terms of QoE.

Throughout the QoE assessment was demonstrated that the uavFEC mechanism enhances the video quality over several scenarios, having particularly good results over higher distances and with increased network traffic. Besides the video quality, the uavFEC was also designed to add as less as possible redundancy, to maintain a low overhead and thus saving resources. This is important due to the scarce wireless channel resources, the uneven bandwidth distribution as well as the interference by concurrent transmissions. The network overhead was computed by summing the size of all video frames transmitted by each mechanism. This means that, if the original frame size is subtracted, it is possible to find the specific amount of redundancy added only by the approaches. Two mechanisms assessed are non-adaptive, video-aware FEC and ViewFEC, and because of that

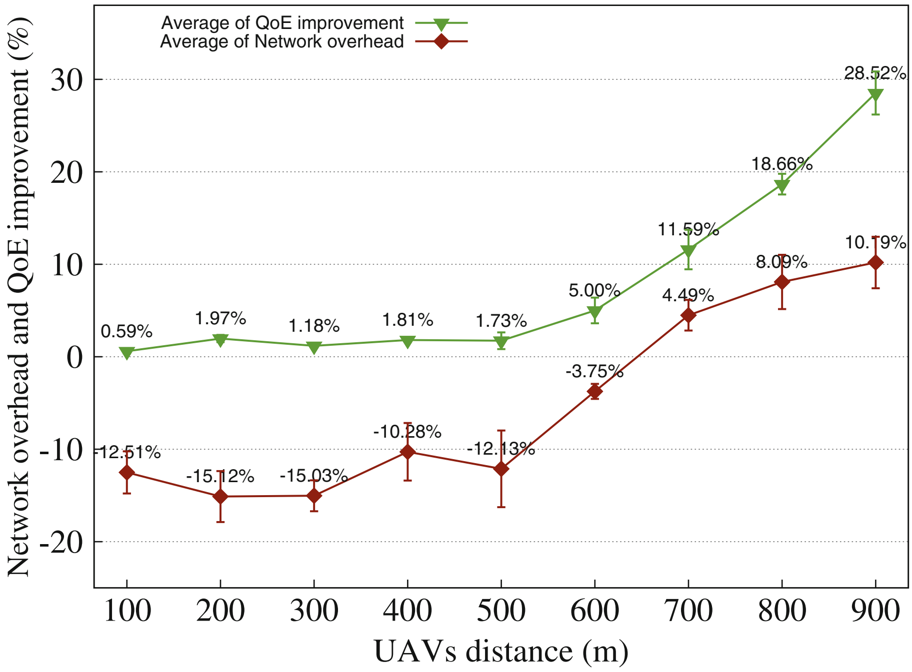


Fig. 14. QoE and Redundancy against UAV distance

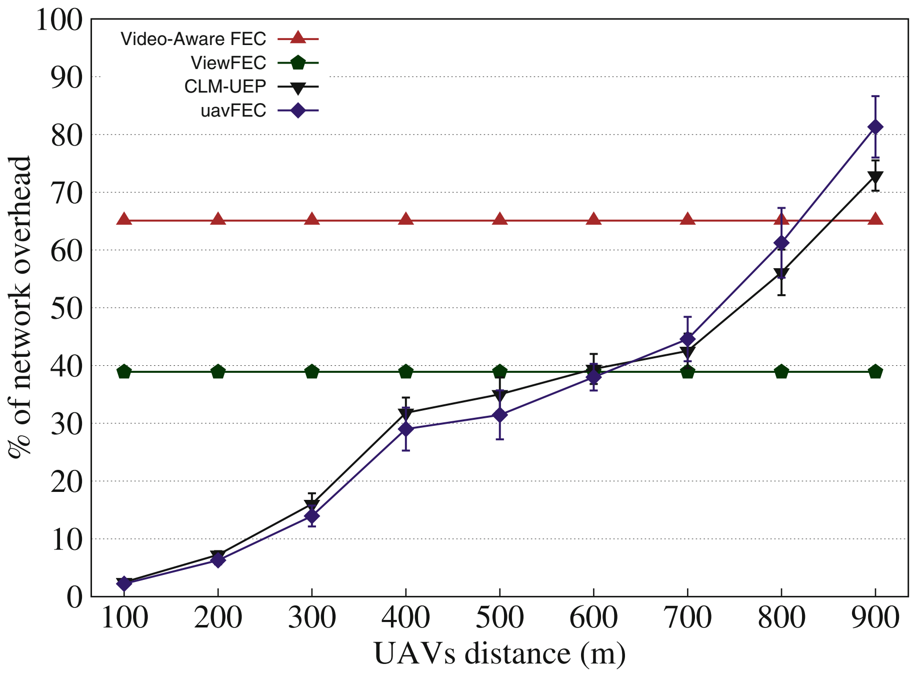


Fig. 15. Network overhead for all scenarios

they have the same network overhead in all distances, which was 65.10 % and 38.90 %, respectively, as shown in Fig. 15. These mechanisms are not appropriate because even when the UAVs are close to the ground control station they add a considerable amount of redundancy, wasting resources. The same figure depicts the results for uavFEC and CLM-UEP. Both mechanisms perform close to each other up to 600 m, but in average the uavFEC has lower network overhead. Over 600 m, the uavFEC starts to add more redundancy, increasing the network overhead, however, providing better video quality.

The uavFEC mechanism achieved good results making the video transmission more resilient to packet loss and thus, enabling a longer video transmission range for the UAVs. The results are particularly beneficial in higher distance with several UAVs, providing a better video quality of live video flows, allowing end-users such as, civilians and/or authorities, to have a high quality perception of videos and thus reducing reaction times.

5 Conclusion and Future Works

The growth of video delivery over UAVs requires a QoE-aware adaptive mechanism to enhance the video quality. The uavFEC provides the capability to improve video transmissions over high dynamic networks, maximizing the QoE without adding unnecessary network overhead. In doing that, it allows better use of the wireless resources for video delivery, especially over long-range transmissions. The impact and benefit of the uavFEC were demonstrated using a set of experiments, proving that the use of motion vectors details along with the network state is a good option to improve the video quality level in UAVs.

The experiments show that our mechanism (uavFEC) achieved a higher video quality up to 600 m adding considerable less redundancy, thus improving the quality without wasting resources. Conversely, over 700 m there is a mild increase in the network overhead, however, a much higher video quality is perceived. In practical terms, this is a good tradeoff between video quality and network overhead. This improvement was only possible due to the precise amount of redundancy that our mechanism adds to the most QoE sensitive data. As future work, more scenarios are going to be adopted, e.g., multi-hop networks, an evaluation of the impact of delay, as well as subjective QoE assessment. Additionally, an improved correlation between simulation values and the motion vectors will be addressed, techniques to improve the energy consumption and other mobility models are also going to be used.

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