Adaptive Video-Aware FEC-based Mechanism with Unequal Error Protection Scheme

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ABSTRACT

Real-time video services over wireless networks are becoming a part of everyday life and have been used to spread information ranging from education to entertainment content. However, the challenge of dealing with the fluctuating bandwidth, scarce resources and the time-varying error rate of theses networks, unveils the need for an error-resilient video transport. In this context, Forward Error Correction (FEC) approaches are required to provide the distribution of video applications for wireless users with Quality of Experience (QoE) assurance. This work proposes an adaptive cross-layer Video-Aware FEC mechanism with Unequal Error Protection (UEP) scheme to enhance video transmission in wireless networks, while increasing the user satisfaction and improving the usage of wireless resources. The benefit and impact of the proposed mechanism are demonstrated by using simulation and assessed through objective and subjective QoE metrics.

Categories and Subject Descriptors

H.4 [**Information Systems Applications**]: Miscellaneous; D.1.8 [**Multimedia and Visualization**]: Adaptive Multimedia

General Terms

Adaptive Video Mechanism

Keywords

Forward Error Correction (FEC), Video-aware FEC, QoE, Cross-layer, Unequal Error Protection (UEP)

1. INTRODUCTION

In the last few years, we have seen the emergence of multi-hop wireless networking technologies along with the rapid proliferation of a wide variety of real-time video services. Furthermore, the Internet is experiencing a considerable traffic growth that is in part led by those novel real-time video services. According to Cisco the video IP traffic will represent over 90% of the global IP traffic by 2015 [5]. This perspective is easily explained by the large amount of new forms of information and entertainment that are released everyday by thousand of users. This includes user-generated content, news websites, social networking communities as well as e-learning materials.

With the growth of video traffic, it is important to ensure good transmission quality, which may be affected by several factors that may affect video quality. Some of them are related to the video characteristics, such as codec type, bitrate, video format and the size of the Group of Picture (GoP) and, even, the content of the video. Apart from that, not all packets have equal impact on perceptual quality. There is a dependence between the type of information that the packet carries and the impact it has on the user perception of video quality. Hence, there is the need for an Unequal Error Protection scheme (UEP), in order to protect the most important information, to allow a good video quality distribution while introducing a reduced amount of redundant information. The video content also plays an important role during the transmission. Studies have shown that videos with slight movement have better resiliency to packet loss, meaning that with low packet loss rate, the impairment will be almost imperceptible. On the other hand, videos with rapid movement or with high levels of detail are more susceptible, hence the flaws will be more perceptible [13].

An important set of metrics is commonly used to assess video quality, enabling the identification of situations where a flaw is more noticeable. This is known as Quality of Experience (QoE), and it can be defined as how users subjectively perceived the quality of an application or service [22]. This means that the performance should be measured end-to-end and must reflect the user point of view. To this end, objective and subjective approaches are desired. Objective approaches use metrics that simulate the human vision system to identify and measure video impairments. Subjective approaches use human observers to rate video quality. It is known that subjective experiments provide the most factual QoE assessment, however, this method is time-consuming, expensive and, hard to do in real-time. Hence, subjective and objective approaches are complementary and not exclusive.

Since most of the video services are real-time applications, they demand for on-the-fly QoE approaches. Furthermore they need a steady and continuous flow of packets, which can be affected by a number of factors in wireless environments. In such networks, the channel conditions can change quickly over time due to noise, co-channel interference, multipath fading, and also, to the mobile host movement [17].

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SAC'13 March 18-22, 2013, Coimbra, Portugal.

Due to these several challenges, a Wireless Mesh Network (WMN) scenario was chosen for the assessment of the proposed schema. WMN have emerged as a relevant option for the next generation of wireless networks as it is self-configuring and it is easy to deploy. All those characteristics provide a cost-efficient way to have broadband Internet access, and it also provides a flexible and reliable wide coverage for a large set of applications [2]. Nevertheless, one of the major challenges in WMN is to fairly distribute the available bandwidth among the requesting nodes for real-time traffic [18]. Additionally, when the network grows, the number of concurrent transmissions will increase, causing serious interference problems. Therefore it is desirable to optimize the resource usage to avoid congestion and high packet loss rate, especially in resource-consuming applications like video streaming.

In order to overcome these transmission challenges, providing both good perceived video quality and low network overhead, the adoption of adaptable data protection approaches becomes critical. Forward Error Correction (FEC) schemes have been used successfully in real-time environments [19]. They aim to achieve robust video transmission by sending redundant data along with the original set. Therefore, if some original information is lost, the data can be recovered through the redundant information [16]. This scheme was chosen because, although it is possible to enhance video transmission with packet prioritization, link adaptation, video bitrate adjustment and other means, without using error correction, this improvement will only be attainable to a limited degree. An error correction mechanism is needed to ensure the video quality, whatever network adversity may occur. However, as aforementioned, resources might be limited and unfairly distributed. As means to reduce the amount of redundant information an adjustable FEC-based mechanism must use Unequal Error Protection (UEP) schemes [14]. This approach sets the amount of redundancy according to the relevance of the protected data, allowing the protection of the most important video details.

This paper proposes a novel adaptive cross-layer **VI**d**E**o-a**W**are FEC-based Mechanism with Unequal Error Protection scheme (ViewFEC) which aims to support video distribution to wireless users, while assuring QoE and optimizing the usage of wireless resources. Owing to the aforestated facts, the use of an adaptive video-aware FEC-based mechanisms is suitable to provide better video quality. One of the disadvantages is that it needs more bandwidth to send the redundant information data. To overcome this problem, ViewFEC is optimally configured to send redundant information only to sensitive data sets, which would cause bigger impact if they were lost. The proposed solution is assessed through simulation experiments with real video sequences, using subjective and objective QoE metrics.

The remainder of this paper is organized as follows. The related work is shown in Section 2. Section 3 describes our proposal and its evaluation is demonstrated in Section 4. Conclusions and future work are summarized in Section 5.

2. RELATED WORK

Several techniques have been proposed to enhance the quality of video over wireless networks. The Adaptive Cross-Layer FEC (ACFEC) mechanism uses packet-level error correction [7]. Through a cross-layer design, these packets are monitored at the MAC layer, and the number of FEC recovery packets is increased or decreased. However, no assessment of the network overhead is conducted. In addition, the aforementioned approach does not consider the video content, and it is well-known that this information has a direct influence on how the video is resilient to packet loss. Although the ACFEC mechanism seems to be a good solution when the network is healthy and there is sporadic packet loss, when network congestion occurs, this mechanism will generate more FEC redundancy packets, which will increase the congestion.

Another technique to enhance the quality of the video transmission is done through a forward error correction and retransmission-based adaptive source-channel rate control [8]. This scheme uses real-time monitoring of the decoder buffer occupancy and the channel state to calculate the optimal parameters for FEC redundancy. This information is regularly feedback to the video encoder at the server site, which proceeds with the adaptation of its own transmission parameters. Although the authors claim that there is an improvement in the QoE for end-users, the main objective of this scheme is to ensure the continuity of video playback under unpredictable channel variations and avoid unnecessary FEC redundancy. Information such as video content and frame type was not considered on the proposal definition [1]. This approach does not assess QoE metrics, as it relyies on packet loss values to predict QoE levels, and it does not measure the overhead introduced.

Other proposals to enhance video transmission over wireless local area networks are based on a method which adapts in real-time the amount of FEC redundancy and the transmission rate [3]. In order to adjust the FEC redundancy and the transmission rate, the receivers periodically send the packet error rate information to the Access Point (AP). Using this information, the AP can identify the worst channel's condition and then adjust the transmission rate and FEC. The application level FEC redundancy adaptation is done by multiple pre-encoded videos with different bit rates and FEC rate, so, in order to adapt theses parameters the system has to switch to a different bit stream. The need of a pre-processed video reduces the applicability of this solution. It also demands high processing power and storage space, since there is the need to encode multiple times the same video with different bit rate and FEC redundancy. Moreover, just the FEC overhead amount introduced by this mechanism was 48% (without taking into account the feed back messages overhead), which is more than 26% higher than our implementation, as evidenced in Section 4).

An additional proposal is using concurrent multipath transmission with path interleaving to improve video streaming [26]. The aforementioned techniques are combined with a dynamic FEC block length. The FEC block size is adapted according to the number of continuous and average of packet loss rate for each path, allowing sending concurrent interleaved data, with FEC protection, over multiple paths. This solution is based on network parameters and does not use video characteristics such as codec and frame type, GoP size, motion and complexity. Furthermore, the mechanism uses a buffer to cope with the impact of packet disordering due to the multipath transmission. This should increase delay and lead to the discarding of the packets by the encoder due to playback time out. In the same way as in above-named works, the network overhead is also not evaluated. For this reason, we proposed and validated the ViewFEC mechanism, which enhances the video transmission quality without adding unnecessary network overhead.

3. VIDEO-AWARE FEC MECHANISM

Motivated by the open issues identified in the previous section, this work proposes and validates the novel ViewFEC mechanism to enhance video transmission over wireless networks. In ViewFEC, decisions are made at the network layer resorting to two modules, the **C**luster **A**nalysis **K**nowledge bas**E** (CAKE) and the **C**ross-**LA**yer infor**M**ation (CLAM).

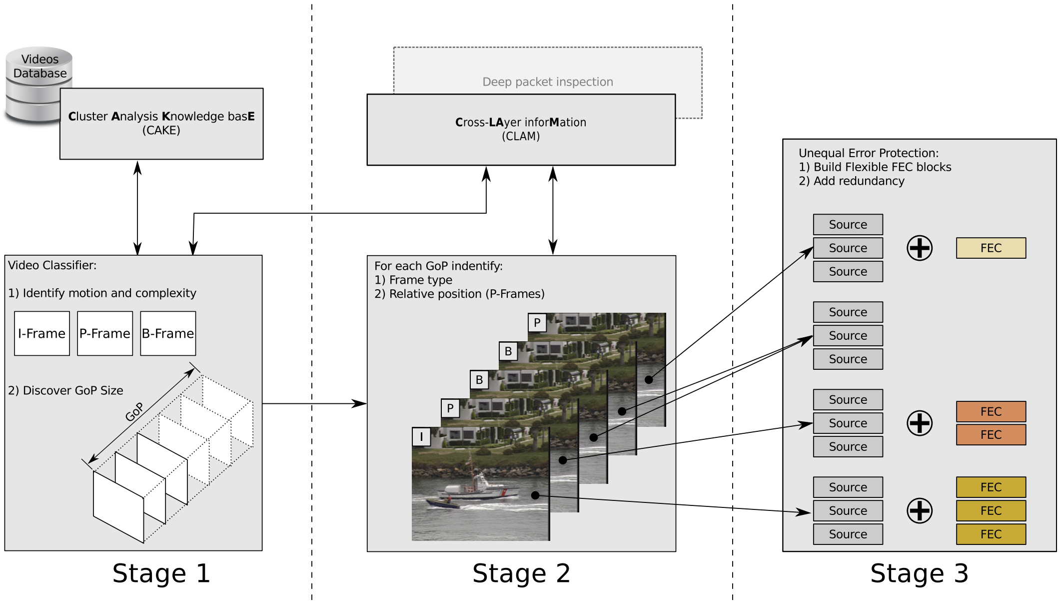


Figure 1: ViewFEC stages

Making the decisions at the network layer provides better deployment flexibility, because the ViewFEC mechanism can be implemented in access points, routers or in the video server. Through the analysis of collected information from these modules ViewFEC is able to estimate the optimal redundancy ratio needed to maintain a good video quality, without adding unnecessary network overhead.

Fig. 1 depicts the ViewFEC mechanism. At Stage 1, it uses a video classifier that fetches information from CAKE and CLAM modules in order to identify video characteristics such as motion and complexity levels, as well as GoP size. After that, at Stage 2, further details about the video sequence are gathered, namely type and relative position of the frames within its GoP. Finally, at Stage 3, the FEC blocks are built and an Unequal Error Protection redundancy is assigned to each one. A detailed explanation of each module will be given afterwards.

The CLAM module has three important functions. The amount of redundancy required to maintain a good video quality may differ depending on the output of these functions. The objective of the first one is to identify the GoP size. As presented before, in video sequences with longer GoP sizes, the impairment of I-Frame loss will be more noticeable by the end-user, than with a shorter one. This happens because it will take longer before the arrival of a new I-Frame that will fix the error, and thus the I-Frame needs more redundancy. The other function is used to identify the frame type. This is important because an I-Frame will have more redundant packets, since if it is lost, the impact on video quality will be bigger than the loss of other frame, e.g., a B-Frame. The last function identifies and calculates the relative position of P-Frames inside the GoP. P-Frames closer to the end of the GoP have less impact if lost, thus, they need less redundancy packets. These functions allow ViewFEC to improve the video quality without adding unnecessary network overhead and supporting more users sharing the same wireless link.

An additional benefit of ViewFEC is its flexible structure. Because of that, it is possible to modify the modules in order to obtain the desired outfit. For instance, if it is not possible to use a cross-layer design, the CLAM module could be swapped to one that would use another technique to obtain the information, i.e. packet and deep packet inspection. Through the packet header analysis of some protocols, like the User Datagram Protocol (UDP), Real-time Transport Protocol (RTP) and Transport Stream (TS), it is possible to acquire information about codec type, coding parameters, among others. However, the video content information is only accessible by using deep packet inspection, thus the necessity of both approaches.

CAKE optimizes the video transmissions (Fig. 1 - Stage 1), where it implements a database with video motion and complexity which is built off-line. The information provided by this module is acquired by performing a hierarchical clustering with Euclidean distance in order to classify video motion and complexity levels. This operation has to be performed only once during the setup phase of the mechanism. After that, through the relationship between the database information and the video sequences that are being transmitted in real-time, it is possible to identify key video characteristics, namely motion and complexity levels.

The selection of video sequences was performed according to recommendations of the Video Quality Experts Group (VQEG) [25] and International Telecommunication Union (ITU) [11]. Throughout our experiments, 20 videos were assessed. Ten videos were used to assemble the database and a different set of other ten videos were used to evaluate the ViewFEC mechanism. These videos cover different distortions and content, being representative of regular viewing material. Additionally, these sequences include colour and luminance stress, still and cut scenes, as well as motion energy and spatial detail.

Authors tend to classify the intensity of motion activity, comprising temporal and spatial complexity, into three categories, namely low, median and high [21][12]. This classification is shown at the cluster dendrogram in Fig. 2 at linkage distance (ld) 1. However, throughout the experiments, videos with medium and high complexity behaved roughly the same. Therefore, a different linkage distance was used. This means that only two distinct clusters were produced (Fig. 2 at ld 2).

The behaviour of these two clusters can be observed in the examples shown in Fig. 3, depicting two video sequences - Mobile (A) and Akiyo (B) - each one from a different cluster. To better visualize the results, only the first GoP of each video was considered (further information about the video codec characteristics can be found in Section 4). The Mobile video has contiguous scene modification and wide

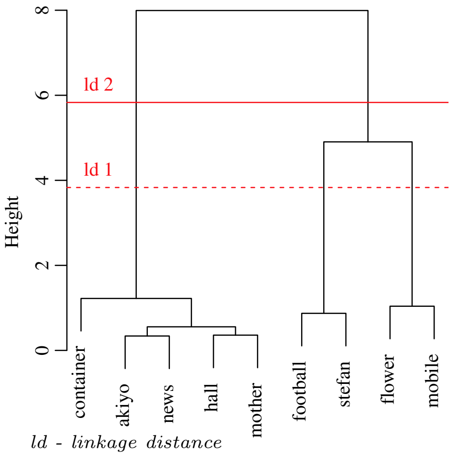


Figure 2: Cluster Dendrogram

angled camera, therefore high motion and complexity. Because of that, this video has larger frames and higher size difference between P- and B-Frames, as depicted by Fig. 3-A. The video sequence Akiyo has a small moving region of interest, almost only the face, and a static background. Consequently, it shows low motion and complexity and there is a smaller size difference between P- and B-Frames, as shown by Fig. 3-B.

Fig. 3 also depicts the structural similarity (SSIM) assessment results when frames are intentionally removed from the GoP. The measurement of this metric is fairly simple, however, it is consistent with the human visual system, given good results [28]. SSIM values were obtained by removing the frame which occupied that position, i.e., the first SSIM value was calculated without the first frame, and so forth. Through the analysis of these findings one can see that in the Mobile sequence, besides the fact that I- and P- frames are the most important, the frames closest to the beginning of the GoP have greater impact on the video quality when removed. On the other hand, the Akiyo sequence has a different behaviour, due to its lower motion and complexity levels which increases the resilience to packet loss [12].

Using the above-mentioned information, the output of the CAKE module identifies the motion and complexity levels of each GoP that is being transmitted. The GoP size is obtained from the CLAM module. Although the GoP size remains the same, these parameters are defined GoP by GoP (Fig. 1 - Stage 1) because it is possible to have different motion and complexity levels inside the same video sequence, as expected for Internet videos. At Stage 2, information about the frame type and relative frame position inside the GoP (for P-Frames), is obtained from the CLAM module. This information is important to identify video characteristics that will be needed, in the next stage, to configure the amount of redundancy.

Finally, at Stage 3, a tailored amount of redundancy is used to configure the FEC scheme. The ViewFEC mechanism has a modular structure allowing to change the FEC scheme if necessary. During the experiments Reed-Solomon (RS) code was used. This erasure code offers less complexity, and therefore better performance for real-time services [20]. A RS code is composed of n, s, and h elements as depicted in Fig. 4. The total block size, including the redundancy data, is represented by n, and s indicates the original data set size, thus the parity code is (n, s). The last parameter is h, it defines the amount of redundancy, which is the same as $h = (n\text{-}s)$. In order to recover all original data set s, at least (n-h) packets have to arrive successfully. The robustness to losses is determined by the size of h, and the error recovery against an average packet loss rate can be expressed as h/n or $(n\text{-}s)/n$.

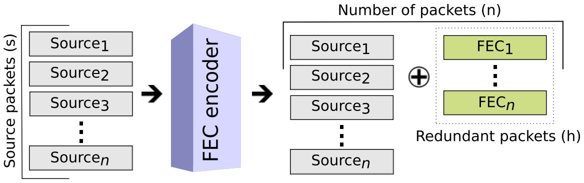


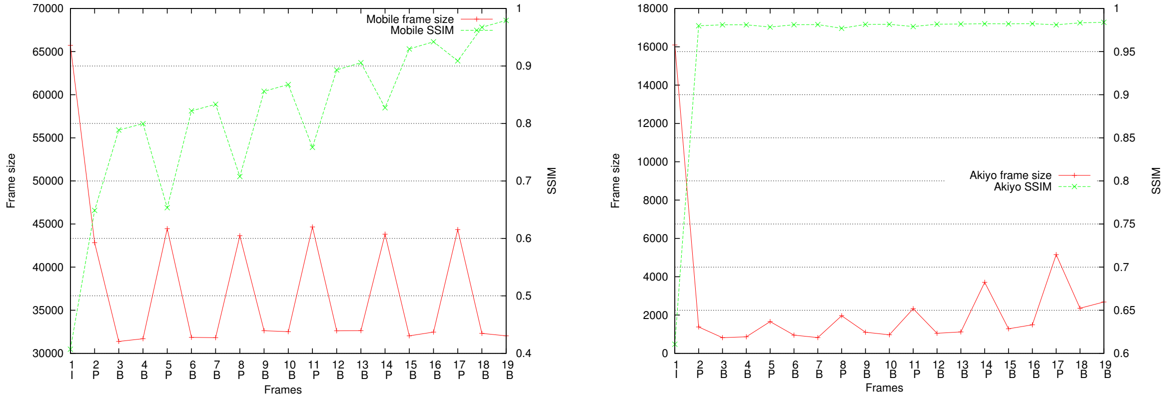
Figure 4: Forward Error Correction parameters

In the ViewFEC mechanism the parity code is adjusted in real-time. This means that both, n and h parameters are customized at Stage 3, according to video characteristics, obtained from CAKE and CLAM modules at Stage 1 and 2, respectively. The former parameter (n), is used to build the Flexible FEC Block scheme (FFBlock), and the latter parameter (h) holds the tailored amount of redundancy for each FFBlock. The FFBlock scheme is the division of I- and P-Frames into groups of packets. Each group can have a different amount of redundancy data. For this reason, instead of adding a unique redundancy rate to these frames, and consequentially to the video sequences, we are building a flexible structure in order to be adjustable to several types of video and different network conditions.

The amount of redundancy data defined by ViewFEC lies in the combination of video motion and complexity, frame position into the GoP, and frame type. This combination allows us to infer the spatio-temporal video characteristics, and therefore choose the optimal redundancy amount (h) for each FFBlock. In doing that, ViewFEC achieves better video quality, and also reduces the amount of data that needs to be sent through the network, decreasing the overhead. The reduction in the network overhead is very important because, as the network becomes larger, there is an increase in the number of concurrent transmissions, causing serious interference problems. This situation gets even worst if we add more overhead due to redundancy information. Therefore, if we manage to reduce the overhead, more users will be able to receive more videos with better quality, improving the overall system performance.

To illustrate the operation of the ViewFEC mechanism, Fig. 5 shows the pseudo-code of GoP size and motion detection, as well as the steps to assign a tailored redundancy amount. All the operations are done inside two loops. The first one, at line 1, will pass through all GoPs in a video sequence. The second one, at line 4, is inside the first and will walk through all the frames within a GoP, applying only the needed redundancy. At lines 2, 3, 5, and 11, it is possible to notice the access to CAKE and CLAM modules. There is an important difference in the treatment of I- and P-Frames, as it is possible to see at line 11, the redundancy amount of the P-Frame also depends on its relative position inside the GoP.

The amount of redundancy added by the ViewFEC mechanism in each GoP, R_{GoP}, can be calculated as shown in (1). FS_i represents the number of packets of the frame that is being transmitted and FT_i represents the frame type as depicted in (2). If $\gamma > 0$, it means that some level of redundancy will be added to that frame. For instance, a vector of (1,1,0) means that I- and P-Frames will receive redundancy, but not B-Frames. An additional configuration could be (2,1,0), which indicates that I-Frames should receive the double of the redundancy that is provided to P-Frames (if the others parameters were the same). This configuration could be used if there is a necessity to further improve the video quality even if this leads to an increased overhead in the network. The motion and complexity lev-



(A) Mobile video sequence *(B) Akiyo video sequence*

Figure 3: Frame size x QoE (SSIM)

```
for each GoP
   CAKE.getGopMotion(GoP)
   CLAM.getGopSize(GoP)
   for each frame
      case (CLAM.getFrameType(frame))
         I-Frame:
            buildFFBlock(frame)
            addRedundancy(frame)
            sendFrame(frame)
         P-Frame:
            CLAM.getRelativePosition(frame)
            buildFFBlock(frame)
            addRedundancy(frame)
            sendFrame(frame)
         B-Frame:
            sendFrame(frame)
      end case
   end for
end for
```

Figure 5: ViewFEC pseudo-code

els are described by C_{GoP} as in (3). If the mechanism is using two distinct video clusters, the values could be, for instance (1,0.5). In this way, the cluster with high motion and complexity levels would receive the double of redundancy than the cluster with low levels. On the other hand, if there is a necessity to use more levels, another option would be to use (1,0.5,0.25), which means that three levels of motion and complexity will be addressed, high, medium and low, respectively. The last parameter in (1) is RP_i, defining the relative distance of P-Frames inside the GoP. Frames closer to the end of the GoP will receive a reduced amount of redundancy because the impact of packet loss will be smaller than a loss near the beginning of the GoP. Table 1 introduces the notation used in the equations.

Table 1: Adopted Notation

NOTATION	MEANING
R_{GoP}	ViewFEC redundancy amount per GoP
FS_i	Frame size in packets of number i_{th} frame
FT_i	Frame type of numer i_{th} frame
C_{GoP}	GoP motion and complexity level
RP_i	Relative position of number i_{th} P-Frame
N_{GoP}	Number of GoPs in the video sequence

$$R_{GoP} = \sum_{i=0}^{GoPSize} \left[FS_i \times FT_i \times C_{GoP} \times \frac{1}{RP_i} \right] \quad (1)$$

$$FT_i = \begin{cases} \gamma > 0 & \text{, } \textit{send frame with redundancy} \\ 0 & \text{, } \textit{frame without redundancy} \end{cases} \quad (2)$$

$$C_{GoP} = \begin{cases} 1 & \text{, } \textit{high motion and complexity} \\ 0 \leq \alpha < 1 & \text{, } \textit{otherwise} \end{cases} \quad (3)$$

The total amount of redundancy within a video sequence is the sum of each GoP redundancy (R_{GoP}). Where is possible to find the average amount of redundancy ($\bar{R}$) through (4).

$$\bar{R} = \frac{1}{N_{GoP}} \sum_{i=0}^{N_{GoP}} R_{GoP(i)} \quad (4)$$

4. PERFORMANCE EVALUATION AND RESULTS

The main objective of the ViewFEC mechanism is to reduce the network overhead added by FEC-based schemes, while maintaining videos with an acceptable quality level. In order to evaluate the benefits and impact of ViewFEC in WMNs, experiments were carried out using Network Simulation 3 (NS-3) [29]. The evaluation scenario is composed of six nodes distributed in a grid form (3x2), each node is 90 meters apart from the closest neighbour. Optimized Link State Routing Protocol (OLSR) was used as routing protocol, however, any other protocol may be used. A Constant Bit Rate (CBR) was set as background traffic at 800 kbps and ten video sequences were used in the evaluation scenario [6], with Common Intermediate Format (CIF) size (352x288), H.264 codec and 300 Kbps. The GoP size was set to 19:2, which means that every 19 frames we will have another I-Frame and after each two B-Frames will have one P-Frame. The decoder uses Frame-Copy as error concealment method, this means that the decoder will try to replace each lost frame for the last good one received.

Apart from the background traffic, a two-state Markov chain model was implemented to better reflect network environments in practice. This model is also known as Gilbert-Elliot loss model. It is used to produce more realistic simulation results because it simulates the burst loss pattern present on wireless channels [30].

In order to compare the results, three experiments with different schemes were used. The first experiment, to server as a baseline, was performed without any enhancement (Without FEC). The second was implemented with a non-adaptive Video-aware FEC approach (Video-aware FEC), where a fixed amount of data redundancy (80%) was statically added to both, I- and P-frames. The amount of data redundancy was defined based on a set of thorough experiments, that showed the best video quality improvement according to the network conditions defined in the experiment. Finally, the last experiment was built using the proposed adaptive approach with unequal error protection (ViewFEC). Each one of these three experiments was simulated 20 times with different packet loss patterns due to distinct initial seeds for random number generation used by the Gilbert-Elliot model.

The average loss was approximately 20%.

The video quality obtained in the different evaluation scenarios was assessed through objective and subjective measurements. Objective metrics use a set of indicators correlated to the user's perception of quality to perform the assessment, obviating human intervention. Two of the most widely adopted objective QoE metrics were used [4], namely Structural Similarity Metric (SSIM) [28] and Video Quality Metric (VQM) [23]. The objective quality assessment of the video sequences was done with EvalVid [15] and MSU Video Quality Measurement Tool (VQMT) [27].

Although objective tests can easily assess video quality, they fail in capturing all the details that might affect user experience,and thus, subjective evaluations are also desired. The Mean Opinion Score (MOS) is one of the most used approaches for subjective video evaluation [9][10]. It is recommended by the ITU-T and uses a set of people voting in video sequences, according to a predefined quality scale, to rate the quality. The MOS scale goes from 1 to 5, where 5 is the best possible score. The standard ITU-R BT.500-11 [9] with the Single Stimulus (SS) method was used in the subjective assessment. In this method, the viewers watch only once a video and then rate the quality using Absolute Category Rating (ACR) [10] scale (Bad; Poor; Fair; Good and Excellent) which is associated to the MOS scale. The SS paradigm was chosen because it is adequate to perform the quality assessment of emerging video applications [24].

The subjective experiments were conducted using a Desktop PC with Intel Core i5, 4GB RAM and a 21" LCD monitor, with an application that displays the video sequences and collects the user scores. All sequences are played in random order at the center of the screen. To not divert the observer's attention, a neutral gray background is displayed. 25 observers participated in the experiments, where they had normal vision and their age ranged from 18 to 45 years old. The observers included undergraduate students, postgraduate students, and university staff.

Fig. 6 shows the results of the subjective experiments. Without using a FEC-based scheme to protect the transmission, the average MOS was 2.05, which is considered poor video quality with annoying impairments. When using the non-adaptive Video-aware FEC and ViewFEC mechanisms, the MOS average values were 4.39 and 4.37, respectively. Theses values are between good and excellent quality, with perceptible but not annoying impairments. These results showed that one of the objectives of ViewFEC mechanism was reached, which was to maintain the video quality.

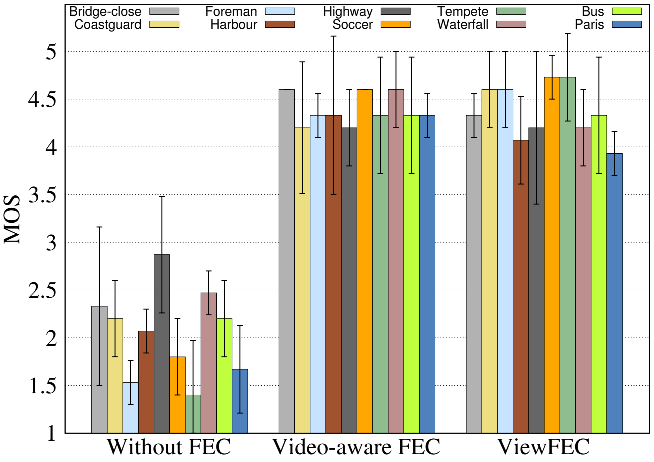


Figure 6: **Average MOS per video sequence**

To confirm the results found by the subjective measurement approach, objective metrics were also applied. Fig. 7 and 8 show the SSIM and VQM values. The SSIM average value without using FEC schemes was 0.33 and the VQM value was 8.68, representing low quality levels, confirming what was found by the subjective assessment. On the other hand, the SSIM average of the non-adaptive Video-aware FEC and ViewFEC mechanism was 0.88, and the VQM value was 1.81 and 1.77, respectively. These scores demonstrate a good video quality, once again, corroborating the subjective findings. The different video assessment values, which can be visualized in the results, are due to the unique characteristics of the video sequences. Small differences in motion and complexities level can influence the obtained values. Because of that, it is important to perform the experiments using various types of video.

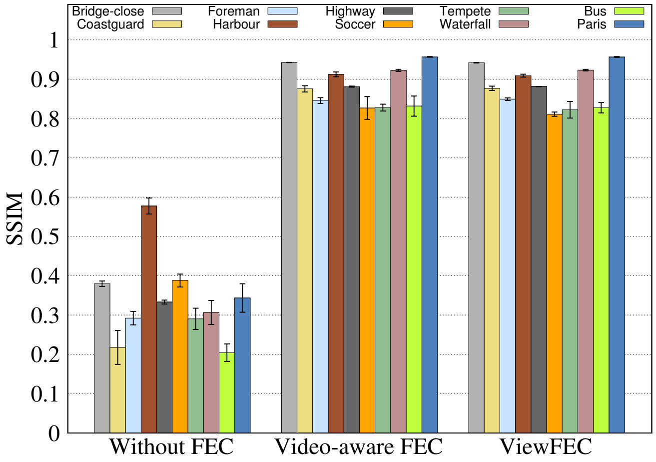


Figure 7: **Average SSIM per video sequence**

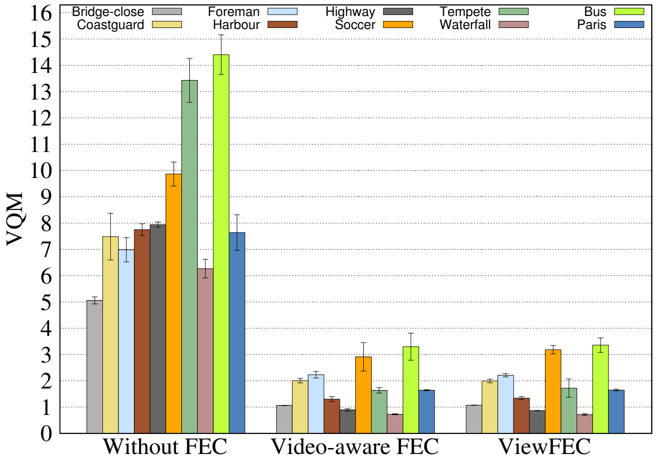


Figure 8: **Average VQM per video sequence**

All the QoE assessments applied demonstrated that the ViewFEC mechanism was able to maintain a good video quality. Nevertheless, the main goal of our mechanism was to reduce the network overhead. This is important in wireless networks, especially in WMN, due to the limited wireless channel resources, the unevenly bandwidth distribution and the interference caused by concurrent transmissions. Using the non-adaptive Video-aware FEC mechanism, the network overhead added was between 53% and 78% as shown by Fig. 9. On the other hand, when the ViewFEC mechanism was used, the network overhead remains between 34% and 47%. The ViewFEC mechanism imposes, on average, 40% less network overhead, with equal or slightly better video quality, as shown in Fig. 6, 7 and 8.

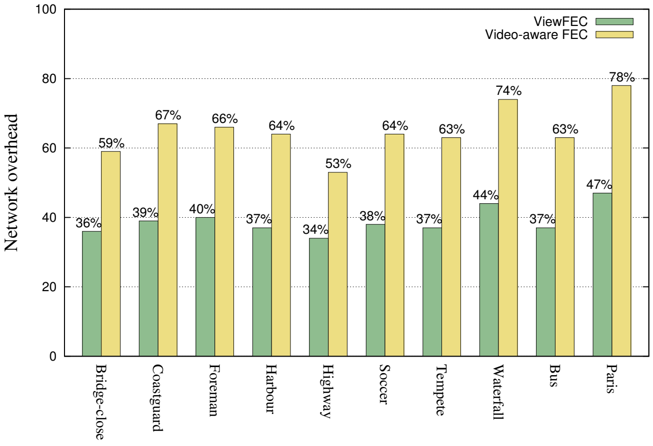


Figure 9: Network overhead (%)

The video sequence Highway had the smallest network overhead reduction (36%) and the Coastguard sequence had the biggest one (42%). In part, this can be explained by the size of the I-, P- and B-Frames. Fig. 10 shows the size of the frames of all videos. Analysing the Highway values, one can notice that over 61% of the packets belong to B-Frames, which are not considered in the non-adaptive Video-aware FEC neither in ViewFEC, because they lead to minor impairments if lost. This means that less than 39% of the packets are optimized by the ViewFEC mechanism, resulting in a smaller reduction of the overhead. Conversely, the Coastguard sequence has more than 46% of the packets in I- or P-Frames, which can be optimized, resulting in a greater network overhead reduction.

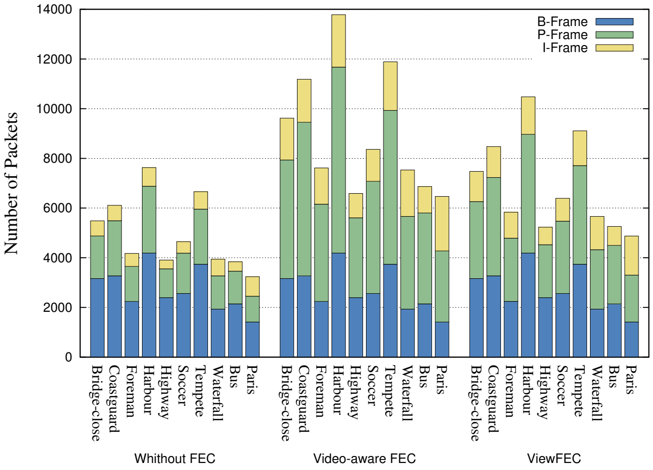


Figure 10: Network overhead in packets

Due to the lack of space, further analysis will be conducted only in the best case scenario, the Coastguard video sequence. In this case, additionally to the decrease of network overhead, it was possible to achieve over 70% of SSIM, VQM and MOS improvement, as shown in Fig. 7, 8 and 6, in comparison to the video sent without mechanisms to improve the quality (Without FEC). If compared to non-adaptive Video-aware FEC mechanism, ViewFEC still achieves better results with almost 2% improvement in video quality when the quality assessment is done through SSIM metric and 0.3% when VQM metric was used. The subjective approach also showed that ViewFEC achieved better results. Furthermore, the standard deviation is considerably smaller (using SSIM and MOS metric), meaning that ViewFEC gets closer results, which indicates a more stable and reliable mechanism. Accompanying the video quality enhancement and the decreased network overhead, ViewFEC also showed slightly better recovery rate, as it is possible to see in Table 2.

With the aforementioned results we are let to believe that our ViewFEC mechanism showed good results enabling an improvement on video quality over WMN. A mesh network is being used only as test scenarios, and we expect that our mechanism will show its real benefits once it is tailored to these kinds of networks.

5. CONCLUSION AND FUTURE WORKS

An effective method for making video transmission resilient to losses is critical for the success of video streaming over wireless networks. The adaptive Video-Aware FEC-based mechanism with Unequal Error Protection scheme provides the possibility to enhance video transmission without adding unnecessary network overhead, avoiding the consumption of the already scarce wireless resources. A series of controlled tests was performed considering video sequences with different types, complexities, and motions, in association with objective and subjective quality assessments. The simulation results show that the ViewFEC outperforms non-adaptive Video-aware FEC-based schemes in terms of recovery rate, video quality, and especially network overhead. Through the simulations was observed that the Flexible FEC blocks makes the video transmission more resilient to packet loss (with higher recovery rate), and therefore achieving better video quality. Also, we noticed that there is no need to protect all packets of a frame to obtain a video quality improvement because codecs are resilient to a certain amount of loss, especially at the end of the GoP. During the simulations, it was possible to perceive a network overhead between 34% and 47% (40% less than non-adaptive Video-aware FEC generated, on average). As aforementioned, the Flexible FEC block will make easier the development of other approaches that make use of the optimization opportunities that WMN offer, namely concurrent multipath transmission, network coding, path interleaving and, opportunistic routing.

Acknowledgment

This work was partially funded by the Portuguese Ministry of Science (scholarship contract SFRH/BD/79094/2011) and by FCT UBIQUIMESH project (PTDC/EEATEL/105472/2008). The authors would like to thank Andre Riker and the UFPA observers for their support in the subjective assessments.

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Table 2: Coastguard Recovery Rate

Parameter	**Video-aware FEC**	**Video-aware FEC**	**ViewFEC**	**ViewFEC**
	Worst Case	Best Case	Worst Case	Best Case
Packet Loss before FEC	26.18%	21.93%	24.30%	21.62%
Recovery Rate	40.22%	44.00%	40.58%	44.40%
Packet Loss after FEC	15.65%	12.28%	14.44%	12.02%
SSIM	0.872	0.883	0.862	0.887
VQM	3.147	2.943	3.085	2.923
MOS	3.4	4.6	4.2	4.8

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