Wireless Video Quality Optimization: Unequal Error Protection versus Packet Size*

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Abstract. The advance of wireless networks is turning huge research interest from both industry and academia due to wide variety of services. But due to various reasons bit-errors, packet-losses and burst-packet-losses are very common in such type of networks. These losses have a very destructive effect on the quality of video at receiving end. Providing reliable and robust video streaming over wireless networks is the key issue. In this paper, we propose an Adaptive Unequal Error Protection (AUER) and Packet Size Assignment (PSA) scheme for Scalable Video Coding (SVC) based streaming over error-prone channel toward heterogeneous receivers. First the scheme calculates the quality of all candidate paths and then based on quality of path it decides adaptively the size and level of error protection for all packets in order to combat the effect of losses on perceived quality of reconstructed video. The results show that the proposed streaming approach can react to varying channel conditions with less degradation in video quality.

Keywords: Adaptive UEP, grey relational analysis, multi-path selection, scalable video coding, wireless networks.

1 Introduction

The last few years have witnessed a rapid growth in wireless multimedia applications and wireless networks became a very attractive field among both industry and academia due to wide variety of services. But due to varying nature of wireless networks bit-errors, packet-losses and burst-packet-losses are very common in such type of networks. Wireless transmission at high packet rates is often characterized by burst-packet-loss behavior, i.e. if one packet is lost there is more chance that consecutive packets will also be lost. Packets with errors not only can cause decoding failure but also can propagate to next frames along motions prediction path causing destructive effect on the quality of reconstructed video.

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Thus providing reliable and robust video streaming over wireless networks is quite difficult and challenging task.

Scalable Video Coding [1], an extension of H.264/MPEG4-AVC is a video coding technology that encodes the video at the highest resolution, and allows the bit-stream to be adapted to provide various lower resolutions. It provides the way to show graceful degradation of video quality while streaming over error-prone channels in wireless networks. Scalable encoded video data enables a decoder to decode selectively only part of the coded bit stream. The main idea behind the scalable video is to create a compressed bit-stream which can be used by different users according to their needs. The users can selectively decode the bit-stream according to their computational power and visualization capability to get the best quality video. The video data is coded into two types of layers, i.e. base layer and one or several enhancement layers. A base layer encodes the lowest temporal, spatial and quality representation of the video stream while enhancement layers encode additional information. So that the more layers that are used in the decoding process, the higher is the quality of the reconstructed video. SVC can be scalable in different ways, for example, it can be spatially scalable accommodating a range of resolutions on visualizing screen. It can be temporally scalable offering different frame rates and it can also be scalable in sense of Signal-to-Noise Ratio (SNR), offering video at different quality levels to accommodate the difference in bit-rates of the transmission channels.

In the past few years, the error control for scalable video coding has attracted much attention due to its importance and many studies have been proposed in literature. In scalable video bi-stream different layers have different importance so they should be protected unequally according to their importance. However, assigning unequal error protection to scalable video is more complex than non-scalable video due to layered structure of SVC. Many studies have been conducted to tackle the problem of UEP for SVC by appropriate consideration of the various frame types such as in [2], [3], [4]. Some researchers have focused on applying UEP to different layers according to their importance [5], [6], [7]. A novel adaptive unequal error protection for scalable video over wireless networks was proposed in [8]. Another adaptive systematic lossy error protection scheme was presented in [9] for broadcast applications in which the Wyner-Ziv (WZ) stream is obtained by frequency filtering in the transform domain. The scheme is based on frequency filtering and unequal error protection. The ratio of error resilience varies adaptively according to characteristics of the compressed bit-streams. The authors in [10] and [11] demonstrated that using content adaptive unequal error protection or feed-back aided unequal error protection can improve error resilience performance. A channel adaptive UEP scheme was proposed in [12], which adjusts the channel coding in the base station thus can benefit from efficient hardware implementation enabling energy efficient data streaming over wireless links. A joint source and channel UEP scheme for SVC streaming was proposed for high speed packet access networks in [13]. The proposed approach uses the video priority information along with channel quality information to set the channel coding rate in order to maximize the video quality. Inspired by these previous work, in this paper we propose an Adaptive Unequal Error Protection and Packet Size Assignment schemes for Scalable Video Coding based streaming over Wireless Mesh Networks (WMNs). In the proposed scheme the nodes are able to send periodically their state information to all of their neighbor nodes. Thus, base on node's state information first the source node calculates the quality of all candidate paths using Grey Relational Analysis (GRA) and then based on quality of path it decides adaptively the size and level of error protection for all packets in order to combat the effect of losses on perceived quality of reconstructed video. The results show that the proposed streaming approach can react to varying channel conditions with less degradation in video quality.

Rest of the paper is organized as fellows: section 2 presents our proposed scheme for transmission of SVC-based streams over wireless mesh networks based on adaptive UEP and packet size assignment. The simulation results are presented in section 3. Finally we conclude in section 4.

2 Proposed Scheme

Media streaming over the wireless mesh networks has become a reality with the development of media compression methods such as scalable video coding. In this works, we consider a wireless mesh network in which our objective is to maximize the perceived video quality through adaptively assignment of unequal error protection and packet size based on path quality. The nodes are fixed relatively in WMN and can run a measurement module to measure the performance of the links from one WMN node to its neighbors. The WMN also runs a link-state protocol so that each node is aware of the latest state in all WMN links. The relationships between nearby nodes are relatively settled and topology is usually stable. First based on node state information of nearby nodes the scheme calculates the quality of all available candidate paths based on grey relational analysis and secondly based on quality of the path it assigns adaptively unequal error protection and packet size to all packets of scalable video bit-streams.

2.1 Selection of Path

Our proposed scheme provides two stage unequal error protection for SVC-based video streaming. The first stage is based on appropriate path selection for different layers according to their importance and the second stage is based on assigning adaptive unequal error protection and packet size. In proposed scheme the nodes are able to send their state information periodically, so source node gets the state information and calculates the network topology based on grey relational analysis between source and destination. Grey method was developed by Deng [14] and has been widely used to solve the problems of uncertainty under the discrete data and incomplete information. It is used to analyze the relationship grad from discrete sequence and select the best sequence. One of the sequences is defined as reference sequence presenting the ideal situation. The grey relationship between the reference sequence and the other sequences can be determined by calculating the Grey Relational Coefficient (GRC) according to the level of similarity and variability. The sequence with the largest GRC is the most desirable one. The major advantage of GRA method is that the results are based upon the original data with simple calculations. This technique is also effective for calculating the quality of paths in wireless networks. GRA is usually implemented by following six steps:

1. Classifying the networks parameters by two situations (smaller-the-best, larger-the-best)
2. Defining the upper and lower bounds of the parameters
3. Normalizing the parameters
4. Defining the ideal situation
5. Calculating the GRC
6. Ranking the available paths according to the GRC values

For the purpose of selecting appropriate paths for different layers, we consider the network-layer metrics such as delay ζ, jitter θ, loss rate σ and throughput α. Delay, jitter and lose rate belong to the smaller-the-best category while throughput belongs to larger-the-best. Before calculating the GRC, the data need to be normalized to eliminate the dimensional units. Assuming that n possible network paths $(P_1, P_2, \ldots, P_n)$ are compared, and each network path has k parameters, the upper bound (u_j) is defiend as max $\{P_1(j), P_2(j), \ldots, P_n(j)\}$ and the lower bound (l_j) as min $\{P_1(j), P_2(j), \ldots, P_n(j)\}$, where *j = 1, 2, . . . , k.* For smaller-the-best parameters the normalized value of $P_i(j)$ parameter can be calculated as follows:

$$P_i^*(j) = \frac{(u_j) - p_i(j)}{(u_j) - (l_j)} \tag{1}$$

Similarly, for the larger-the-best parameters the normalized value $P_i(j)$ can be calculated as follows:

$$P_i^*(j) = \frac{p_i(j) - (l_j)}{(u_j) - (l_j)} \tag{2}$$

Network path attributes can be represented as a row matrix, where the elements of the matrix are the normalized values of k different network path attributes.

$$P = \Big[P^*(1), P^*(2), P^*(3), \ldots, P^*(k)\Big] \tag{3}$$

While $P_i^*(j)$ parameters are maximized in 1, the most preferable network path can be always described as $P_1^*(j) = 1$, where *j = 1,2, . . . , k,* and k is the number of network path parameters used for the decision making. Using the behavior of the normalizing algorithm, the ideal network path can be determined as S = [1, 1, 1, . . ., 1]. If there are N available network paths to choose from, the previous row matrix (3) can be extended to a *N x k* matrix, which contains all the parameters that play role in the appropriate network path selection procedure. The matrix can be determined as follows:

$$P_N = \begin{bmatrix} P_1^*(1), P_1^*(2), P_1^*(3), \ldots, P_1^*(k) \\ P_2^*(1), P_2^*(2), P_2^*(3), \ldots, P_2^*(k) \\ \ldots\ldots \\ P_N^*(1), P_N^*(2), P_N^*(3), \ldots, P_N^*(k) \end{bmatrix} \tag{4}$$

The final step is to calculate the GRC as follows:

$$GRC_i = \frac{1}{\sum_{j=1}^{k} w_j \,|\, p_i^*(j) - 1 \,|+ 1} \tag{5}$$

Where w_j is the weight of each parameter and i $(1 \leq I \geq N)$ is the network index. The path with the largest GRC is the most appropriate path. The source node calculates the GRC for all available paths. As in SVC bit-stream different layers have different priority, the base layer has highest priority and enhancement layer one has lower priority than base layer and enhancement layer two has lower priority than enhancement layer one and so on. So according to priority of layers appropriate paths are assigned to each layer in such a way that base layer stream has highest priority so therefore, it should be transmitted through the highest quality path (the path with highest GRC value) and while highest enhancement layer has lowest priority so it should be transmitted through lowest quality path (the path with lowest GRC value), means more important data are transmitting through more reliable path with less error rate. The path with the largest GRC is the most reliable path and vice versa. Thus the scheme ranks all candidate paths according to their robustness based on GRC values.

As shown in table 1, during simulation we had four candidate paths and we calculated the quality of each path and ranked them according to their robustness. Thus according to table 1, the most robust path is path three and the worst path is path one. The two is the second robust path and path four is the third one. As we used SVC-based streams with one base layer and two enhancement layers in our simulations, so therefore, we selected the first three most robust paths for video streaming which are P_3, P_2 and P_4 for base layer, enhancement layer one and enhancement layer two respectively, and ignored all other paths (path one in this case). Means more important data through more robust path with less error rate probability. So this is the first stage of providing UEP in our proposed scheme.

Table 1. Parameters for appropriate path selection decision making

Path	GRC	delay (ζ)		jitter (θ)		loss rat (σ)		throughput (α)	
		ms	norm	ratio	norm	ms	norm	mbps	norm
1	0.25	159	0.00	0.200	0.00	07	1.00	09	0.00
2	0.45	062	1.00	0.040	0.81	29	0.00	72	1.00
3	0.46	087	0.74	0.003	1.00	09	0.91	21	0.19
4	0.42	140	0.20	0.015	0.94	17	0.55	69	0.95

2.2 Adaptive UEP and PS Assignment

Now after the appropriate paths are assigned to each layer, the second step is to assign adaptively UEP and packet size to all layers based on path quality. The bit-streams of all layers are interleaved into one Block Of Packets called (BOP) as shown in Fig. 1.The transmitted packets are the rows of the BOP. The source data with length r_i in layer i are grouped into k_i packets, where $i = 1 \sim l$, with column width of s_i. The n is number of packets and the remaining $n - k_i$ packets in the BOP are filled with channel coding redundancy. Therefore, k_i specifies the protection level of the layer i. The BOP buffer size r is assumed to be enough to satisfy delay and buffer constraints for real-time streaming. The length of packet header is s_h. If the number of packets n is known, then the packet size $s= r/n$.

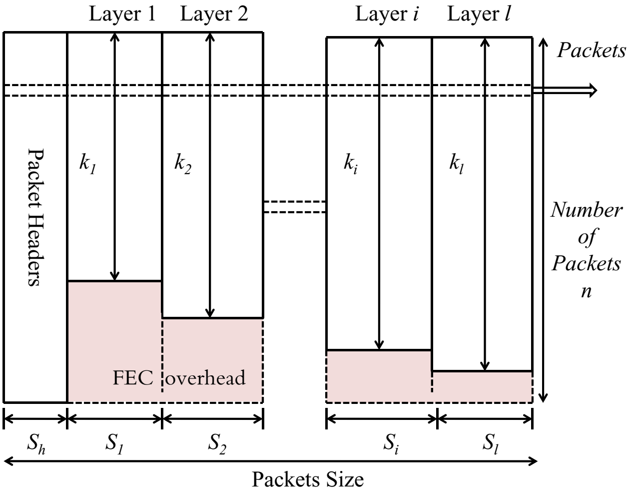


Fig. 1. Date structure of Block Of Pictures (BOP)

Now the first constraint obtained from BOP data structure for forward error correction assignment is as follows:

$$S = S_k + \sum_{i=1}^{l} S_i = S_k + \sum_{i=1}^{l} \frac{r_i}{k_i} \tag{6}$$

Each group of pictures (GOP) can be packed into a fixed number of block of pictures. In our proposed scheme, one GOP is equal to one BOP. In SVC bit-steam different layers have different priorities; therefore, SVC-based encoded video explicitly requires an unequal error protection scheme, yielding another restriction for forward error correction assignment as follows:

$$0 \leq k_1 \leq k_2 \leq \ldots \leq k_l \leq n \tag{7}$$

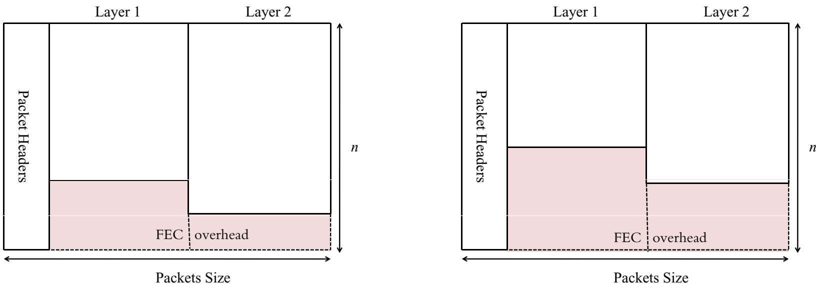
We elucidate four different adaptive assignment schemes in this section for scalable video transmission over error-prone wireless networks and finally suggest the best one through simulation results in section 3. The four schemes are as under:

1. Fixed Packet Size with Fixed Unequal Error Protection (FPS + FUEP)
2. Fixed Packet Size with Adaptive Unequal Error Protection (FPS + AUEP)
3. Adaptive Packet Size with Fixed Unequal Error Protection (APS + FUEP)
4. Adaptive Packet Size with Adaptive Unequal Error Protection (APS+AUEP)

Fig. 2 shows the BOP structure of FPS+AUEP, APS+FUEP and APS+AUEP under bad and good channel conditions. In Fig. 2(a,b) the packet size and number of packets are fixed, but the unequal error protection is adaptive. Due to error-prone nature of wireless networks, when the channel condition is bad, it calls for an increased forward error correction ratio as shown in Fig. 2(b). The variations in BOP structure under different channel conditions shown in Fig. 2(c,d), where the packet size is adaptive and forward error correction is fixed. Normally small packet size are suitable under bad channel conditions to reduce the packet error rate resulting in improved video quality at receiving end but increasing the number of packets means increasing the header overheads. However, the packet size used in simulation was less than 1500 bytes because of the Maximum Transmission Unit (MTU). Finally, the Fig. 2(e,f) represents the BOP structure under different channel conditions for adaptive packet size and adaptive forward error correction. However, how much forward error correction protection should be added and what should be the packet size are key issues. Both of them are directly related with perceived video quality at destination node. In our proposed scheme both the packet size and protection are based on channel conditions. For adaptive assignment of UEP and packet size the algorithms use table 2 for decision making. As we can see in table 2 that based on quality of path the error protection and packet size are assigned to different layers of SVC adaptively according to their importance. For example during good channel conditions when the GRC value is around 1, which means the path is almost same as ideal path. The probability for error occurrence is around zero. There is almost no need for error protection redundancy. And furthermore, we can increase the packet size to maximum limit in order to reduce the overhead

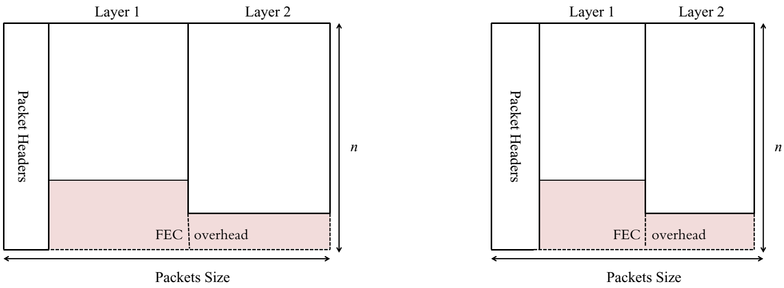
Table 2. AUEP and PS assignment under different channel consditions

GRC	Base Layer		E-layer 1		E-Layer 2		E-Layer 3	
	UEP (%)	PS (bytes)	UEP (%)	PS (bytes)	UEP (%)	PS (bytes)	UEP (%)	PS (bytes)
0.9-0001	03	1024	00	1096	00	1168	00	1240
0.8-0.89	06	0952	03	1024	00	1096	00	1168
0.7-0.79	09	0880	06	0952	03	1024	00	1096
0.6-0.69	12	0808	09	0880	06	0952	03	1024
0.5-0.59	15	0736	12	0808	09	0880	06	0952
0.4-0.49	18	0664	15	0736	12	0808	09	0880
0.3-0.39	21	0592	18	0664	15	0736	12	0808
0.2-0.29	24	0520	21	0592	18	0664	15	0736
0.1-0.19	27	0448	24	0520	21	0592	18	0664



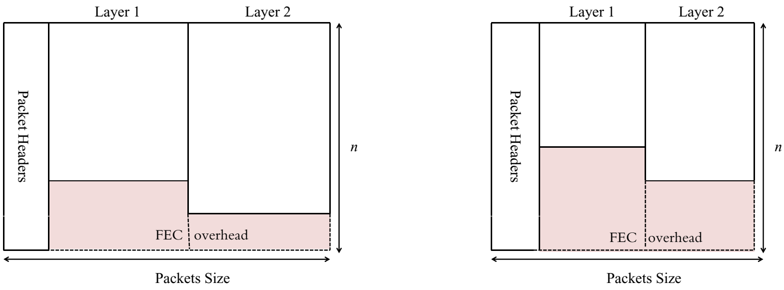
(a) Good channel conditions (AUEP+FPS)

(b) Bad channel conditions (AUEP+FPS)



(c) Good channel conditions (FUEP+APS)

(d) Bad channel conditions (FUEP+APS)



(e) Good channel conditions (AUEP+APS)

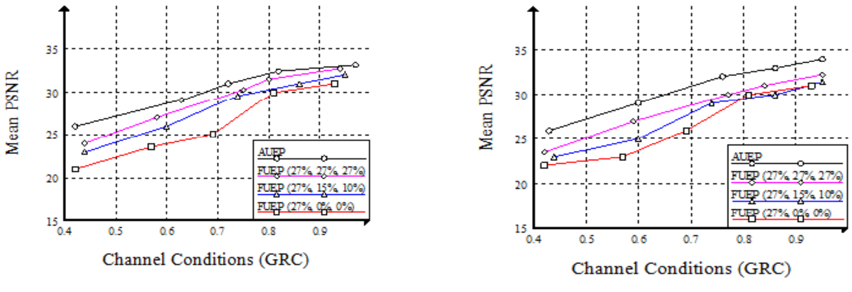
(f) Bad channel conditions (AUEP+APS)

Fig. 2. BOP structure under different channel condition

due to packet headers. While on the other hand during bad channel conditions, such as in case when GRC value is around 0.1, which means the path is unreliable. Obviously there is a call for increased ratio of error protection as well as small packet size.

3 Experimental Results

In this section, we present simulation results in order to evaluate the performance of proposed scheme in different scenarios. We used NS2 network simulator for SVC-based streaming over wireless mesh network. We used SVC bit-streams with one base layer and two enhancement layers. We have all necessary information about all nodes in the network. Twelve nodes are used to construct a wireless mesh network with one source node and three receiver nodes in the range of 100 x 100 Sqm. The total simulation time was 900 seconds. For video encoding, we used the SVC reference software Joint Scalable Video Model (JSVM 9.14). We encoded the two (foreman and crew) sequences with one base layer and two enhancement layers with GOP size of 8 at rates from 40kbps (base layer) to 150 kbps (highest layer), QCIF and 15 fps using SNR scalability. We also consider some background traffic in order to achieve different channel conditions.



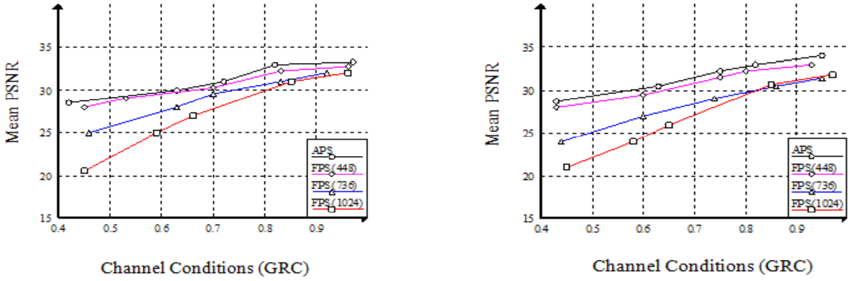
(a) Foreman Sequence

(b) Crew Sequence

Fig. 3. Performance comparison of proposed AUEP with other three FUEP schemes

3.1 Evaluation of AUEP + FPS

Initially, we considered the scenario in which UEP is adaptive and PS is fixed. The performance comparisons of proposed AUEP with three other fixed error protection schemes (such as protecting only base layer with fixed error protection, protecting all layers with fixed error protection and protecting all layers with fixed but unequal error protection) using foreman and crew sequences are shown in Fig. 3. The percentages in parentheses in the legends show the protection ratio for the base layer, enhancement layer 1 and enhancement layer 2 respectively. The simulation results explicitly show that only AUEP can cope with different channel condition with smoother degradation in perceived video quality. Furthermore, the non-adaptive schemes can be associated with providing strong protection under reliable channel conditions, which is useless and wastage of bandwidth, or providing weak protection under bad channel conditions resulting severe degradation in video quality. The results of Fig. 3 also show, if we consider the only two case AUEP and FUEP (27%, 27%, 27%) for all layers, the ratio of error protection for FUEP (27%, 27%, 27%) is more than proposed AUEP. But still the graph shows improved PSNR for proposed AUEP. This is due to appropriate path assignment to different layers, which means we are transmitting the base layer through more reliable path, hence resulting in improved video quality with lesser overhead.

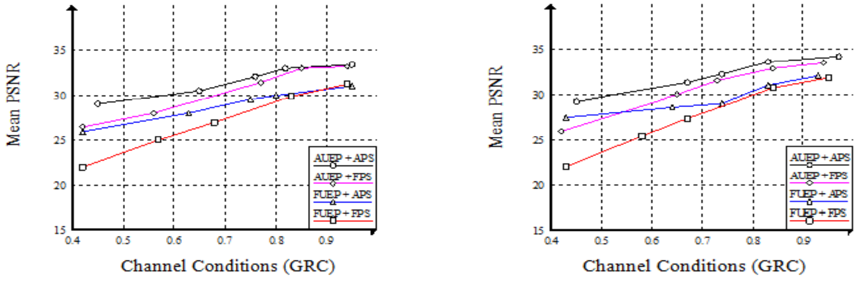


(a) Foreman Sequence (b) Crew Sequence

Fig. 4. Performance comparison of proposed APS with other three FPS schemes (448, 736 and 1024 bytes) under different channel conditions

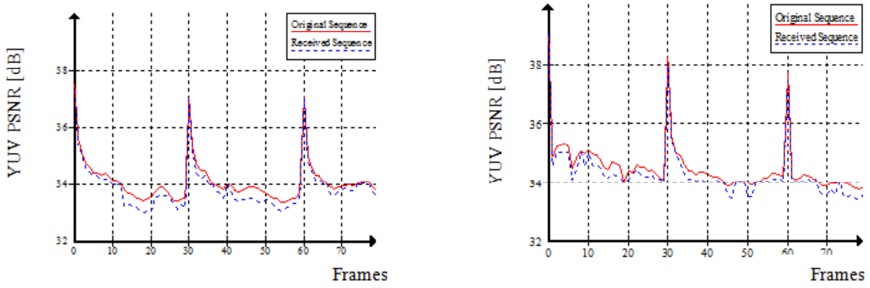
3.2 Evaluation of FUEP + APS

Secondly, we considered the scenario in which UEP is fixed and PS is adaptive. The performance comparisons of proposed APS with some other fixed packet size schemes using foreman and crew sequences are shown in Fig. 4. The non-adaptive fixed packet sizes were 448, 736 and 1024 bytes. Figure 4 shows that the length of the packet size severely influence the quality of reconstructed video. Only the adaptive packet size assignment can cope with varying channel condition with lesser degradation in perceived video quality. Furthermore, it is noted that in fixed packet size schemes, the packets are either too large with high packet error under bad channel conditions or too small with larger headers overhead during good channel conditions. As we can see under reliable channel conditions the packet size for our proposed scheme is larger than other two fixed schemes but still the proposed scheme outperforms the other schemes, again this achievement is due to selection of best quality path. The ratio for fixed UEP were 27%, 15% and 10% for base layer, enhancement layer one and enhancement layer two respectively.



(a) Foreman Sequence (b) Crew Sequence

Fig. 5. Performance ccomparison of four proposed schemes under different channel conditions



(a) Foreman Sequence (b) Crew Sequence

Fig. 6. PSNR graph for original and received sequences

3.3 Evaluation of AUEP + APS

The Fig. 5 shows the performance comparison of four unequal error protection and packet size assignment schemes over different channel condition using foreman and crew sequences. The results show that adaptive schemes perform better than fixed schemes under all channel conditions. The ratio of FUEP are 27%, 15% and 10% for base layer, enhancement layer 1 and enhancement layer 2 respectively and fixed packet size is 1024 bytes. We can see that protection level of FUEP is large under good channel condition, which is wastage of bandwidth while on the other hand packet's size for FPS is as well large under bed channel condition resulting in degradation of video quality. Finally, the results show that combination of AUEP with APS performs better than all other schemes under

(a) Original Sequence (b) Reconstructed Sequence

(c) Original Sequence (d) Reconstructed Sequence

Fig. 7. Perceived video quality for foreman and crew sequences

any channel conditions. Finally, we looked on the PSNR of both videos. The Fig. 6 shows the PSNR graphs of original and reconstructed videos of both foreman and crew sequences. The graphs show PSNR for only first 80 frames under AUEP + APS scheme. As we can see there is slight variation in video quality. And the Fig. 7 shows the perceived video quality of original and reconstructed videos for both sequences under AUEP + APS scheme.

4 Conclusion

In this paper we proposed AUEP + APS, AUEP + FPS, FUEP + APS and FUEP + FPS assignment schemes for SVC-based streaming over wireless mesh networks. All the schemes were simulated many times under varying channel conditions for two different sequences, foreman and crew. First the proposed scheme calculates the quality of all candidate paths based on node's state information and then ranks all candidate paths according to their robustness. The scheme assigns appropriate path to all layers according to their priorities. And then based on quality of path it decides adaptively the size and level of error protection for all packets in order to cope with the effect of losses under different channel condition. The results reveal that combination of Adaptive Unequal Error Protection with Adaptive Packet Size performs better than all other schemes under any channel conditions.

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