JOINT MEDIA-CHANNEL AWARE UNEQUAL ERROR PROTECTION FOR WIRELESS SCALABLE VIDEO STREAMING

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ABSTRACT

In this paper, we propose a joint source-channel unequal error protection scheme for scalable video streaming over capacity constrained high speed packet access (HSPA) networks. Conventional link adaptation schemes in HSPA networks use the modulation and coding scheme (MCS) that achieves a preset channel frame error rate. Our scheme utilizes video priority information along with channel quality information to set the channel coding rate that maximizes the cumulative coding rate of channel coding and application layer unequal error protection. Performance evaluations show that that under the same constraints our scheme results in an average performance improvement of 0.5dB in video PSNR for different channel conditions and different video sequences.

***Index Terms*—** Wireless scalable video streaming, unequal error protection, modulation and coding schemes.

1. INTRODUCTION

The advances in wireless and mobile network technologies are triggering an accelerated growth in wireless video streaming applications that are bandwidth-intense, delay-sensitive, and loss-tolerant [1]. However, these services continue to suffer from the unreliability of the wireless link which results in a degradation in received video quality.

In order to cope with the unreliability of wireless channels, modern packet access networks, such as high speed downlink packet access (HSDPA) in UMTS, employ a series of modulation and coding schemes (MCS) that can be updated every transmission time interval (TTI) of 2ms. The update process, known as link adaptation, assigns a MCS according to the reported channel condition from the mobile device [2]. The choice of MCS affects the media application's available throughput, vulnerability to packet loss due to channel fading, and the stability of the user scheduling policy employed at the base station when multiple users are being serviced [3]. However, the link adaptation process can only adjust the MCS in the PHY to achieve a predetermined level of reliability. Higher reliability is usually achieved at the cost of lower transmission bit-rates, which in turn result in lower throughput. One solution to the aforementioned problem is Scalable Video Coding (SVC) which provides spatial, temporal, and SNR scalability ensuring a graceful degradation in video quality when faced with channel fluctuations [4, 5]. However, within a TTI, current link adaptation schemes can only assign a single MCS to a coded video stream. As a result, all layers are allocated the same error protection level which loses the benefit of scalability. Unequal error protection of media substreams is possible at the PHY layer however, these solutions are unreliable and suffer heavily from inter-symbol-interference [6]. Therefore, application layer Forward Error Correction (FEC) remains a more reliable means of protecting important sub-bitstreams such as the base layer in scalable video coding. Unequal Erasure Protection (UXP) is one example of FEC techniques that are being promoted for the protection of scalable video data from losses during transmission [5].

In this paper, we present a joint application and channel aware unequal error protection scheme for wireless scalable video streaming that uses video priority and channel quality information to improve channel utilization. Our technique allows the link adaptation scheme to deviate the channel coding rate from the predefined modulation and coding assignment in order to maximize the cumulative coding rate of PHY and application layer error protection for each scalable video layer, while minimizing the corresponding video distortion. Performance evaluations comparing our proposed scheme with conventional MCS assignment have shown that under the same constraints our scheme results in an average performance improvement of 0.5dB in video PSNR for different channel conditions and different video sequences.

The remainder of this paper is organized as follows: we present in Section 2 the general streaming system in which we apply our approach. Section 3 illustrates the proposed scheme of using joint UXP-MCS allocation to improve system utility. In Section 4 we demonstrate the improved performance of our scheme compared to conventional MCS allocation. Finally, we present our conclusions in Section 5.

2. SYSTEM DESCRIPTION

We consider a wireless 3G system similar to HSDPA in which the physical layer can choose between several modulation and coding schemes (MCS) in order to adapt the transmission according to channel quality information (CQI) received from the mobile device. The system can support multiple video users by allocating different time-slots to different users, such that, time is the resource that is shared among all users. Therefore, at every time-slot, only one user can utilize the channel resources within a cell, and the temporal-share allocation τ_u of a user u is regarded as the fairness requirement in the system [3]. We assume that the streaming server has access to U pre-encoded scalable video streams intended for delivery to U clients/users. The link/MAC layer receives feedback from each mobile device reporting the user's signal to noise ratio (SNR) to the base-station which estimates the channel quality. Link adaptation is then performed by continuously adjusting the modulation and coding parameters every 2 ms, corresponding to the basic HS-DSCH transmit time interval (TTI) [2]. The server receives channel quality information from the link/MAC layer in terms of frame error rate (FER) and estimated channel capacity for each user.

2.1. Video Distortion Model

Let $u \in \mathcal{U}$, where $\mathcal{U} = \{1, 2, ...U\}$, be the video/user index. Each FGS scalable video indexed by u is characterized by a bit-rate $x_u \in [L_u, H_u]$, where L_u is the base-layer bit-rate and H_u is the maximum video bit-rate which includes all enhancement layers. We define the pair $\{R_u(x_u), D_u(x_u)\}$ as the protected video bit-rate and the total video distortion after channel loss, respectively, such that

$$\begin{aligned} R_u(x_u) &= (1+\gamma)R_{\mathrm{UXP}}(x_u) \\ &= \textstyle\int_{L_u}^{x_u} \frac{n}{k_u(s)} ds \\ D_u(x_u, p_u) &= D_{\mathrm{enc}}(x_u) + D_{\mathrm{loss}}(x_u) \\ &= \alpha_u + \frac{\theta_u}{x_u - \beta_u} + \textstyle\int_{L_u}^{x_u} \left(\frac{\theta_u}{(s-\beta_u)^2}\right) p_u(s) ds \end{aligned} \tag{1}$$

where $D_{enc}(x_u)$ is the video encoder distortion model used in [7] with parameters α_u, θ_u, and β_u, $D_{\mathrm{loss}}(x_u)$ is the distortion due to channel loss, $p_u(x)$ is the error protection failure rate.

2.2. UXP error protection

The effectiveness of UXP for the protection of scalable video has been demonstrated in [5]. UXP is a Forward Error Correction (FEC) scheme that is based on Reed-Solomon (RS) codes. Under UXP, video packets of a group of pictures (GOP) are grouped together into a transmission block (TB). Each row of a TB constitutes an (n, k) RS codeword, where n is the length of the codeword in bytes, k is the number of data bytes (coded video bytes), and $n - k$ bytes are parity bytes, where $\frac{n}{2} < k \leq n$. Each column of a TB is then encapsulated in an RTP packet, which enables UXP to correct up to $n - k$ packet erasures. In [5], different protection classes are defined for each FGS enhancement layer, higher layers receiving less protection than lower FGS layers and the base layer. In [8], we developed a rate-minimized UXP allocation scheme specifically designed for scalable video protection. We adopt this scheme in the remaining sections of this paper and give a brief overview below.

Let $q \in \mathcal{Q}$, where $\mathcal{Q} = \{1, 2, ...Q\}$, be the video packet (NALU) quality level index, and $x_u(q)$ be the bit-rate of level q NALUs. Also, let $p_u(.)$ be the UXP code failure rate of class q. We find the dimension k_q for codewords of class q by minimizing the following regularized cost function:

$$k_q^* = \arg\min_{k_q} \frac{n}{k_q} x_u(q) + \omega_q p_u(k_q, p_c), \tag{2}$$

where p_c is the channel FER, ω_q is the regularizing parameter and can be expressed in terms of the relative distortion contributed by all packets belonging to the priority level q. The choice of k_q results in a UXP coding rate $r_u^q = \frac{k_q}{n}$ for class q. The UXP failure rate p_u is given by

$$p_u(r_u^q, p_c) = \sum_{i=n(1-r_u^q)}^{n} \binom{n}{i} p_c^i (1-p_c)^{n-i}. \tag{3}$$

3. JOINT UXP-MCS ALLOCATION

In this section we present a joint channel and application layer error protection allocation scheme. There exists a trade-off between maximizing the coding rate and minimizing the error rate. Conventional link adaptation mechanisms do not account for application layer error protection and generally assign the modulation and coding scheme that roughly corresponds to a channel FER of 10%. For streaming systems that additionally employ application layer error correction, there exists a concatenation of error correction codes that operate independently. Therefore, we set out to find the optimal joint source-channel error protection allocation that maximizes the coding rate while minimizing the application layer packet error rate (PER). Figure 1 better illustrates the process.

Let r_c and r_u be the channel coding rate and application layer error protection (UXP) coding rate, respectively. Without loss of generality, we consider a single class of UXP correction codes in this discussion. The cumulative coding rate r_{total} resulting from the concatenation of channel coding and UXP is expressed as: $r_{\mathrm{total}} = r_c \times r_u$.

Let ρ, p_c, and p_u be the un-coded channel error rate, the channel FER after coding, and the application layer packet error rate (PER) due to UXP failure, respectively. Note that the uncoded channel error rate ρ is a function of the channel SNR as reported by the mobile device. For a target p_u defined by the UXP allocation scheme described in section 2.2, we wish to find the optimal channel FER p_c^* that maximizes r_{total} as shown in (4)

$$p_c^* = \arg\max_{p_c} \{r_c(p_c, \rho) \times r_u(p_u, p_c)\}. \tag{4}$$

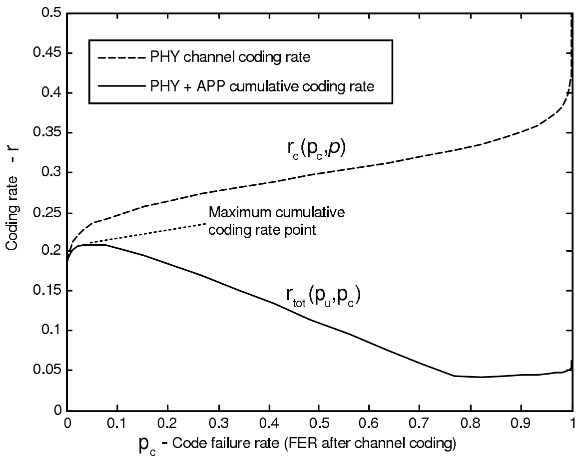

Fig. 1. Example of the optimal operating point (p_c, r_{total}) that maximizes the cumulative throughput r_{total} while satisfying the UXP error requirement p_u. The dotted curve shows the channel coding rate r_c as a function of the FER p_c. The solid line shows the cumulative coding rate $r_{\text{total}}(p_c, p_u, \rho)$ as a function of p_c for a target UXP rate p_u and an uncoded channel rate ρ.

The maximization in (4) is performed for each class of UXP independently. Consequently, the admissible bit-rate of the optimized scheme would be greater than that in conventional schemes that choose the MCS that corresponds to a 10% FER. Since both schemes have the same target UXP failure rate p_u as dictated by (2), it is easy to see from (1) that the increase in coding rate delivered by our proposed scheme reflects directly as a reduction in video distortion and an improvement in received picture quality.

After determining the optimal channel FER p_c^* and corresponding channel coding rate r_c*, rate allocation is performed at the streaming server by extracting the video bit-rate x_u for each user u according to the following:

$$\begin{aligned} &\min_{x_u} D_u(x_u, p_u) \\ &\text{s.t. } R_u(x_u) \le \tau_u r_c^* C, \end{aligned} \tag{5}$$

where C is the uncoded channel capacity given by the modulation scheme, and τ_u is the temporal share of user u. Note that the choice of modulation is governed entirely by the observed channel SNR of user u [2].

4. SIMULATIONS AND RESULTS

In this section, we study the performance of our joint UXP-MCS protection allocation technique compared to that of conventional techniques that select the MCS that roughly achieves a channel FER of 10%. For our performance testing, we encoded five video sequences: Bus, Foreman, Crew, Mobile, Harbor, and Football in CIF resolution at 15 frames per second in SVC using JSVM6 available from [9]. The encoded streams are composed of an H.264/AVC compatible base layer and 2 FGS enhancement layers.

We simulate the lossy channel using the 3GPP off-line simulator listed in the "Common conditions for SVC error resilience testing" [10]. We consider channel capacities of 1.8Mbps, 3.6Mbps, 5.3Mbps, 7.2Mbps, and 10.7Mbps which correspond to five possible transport formate and resource combinations (TFRC) in an HSDPA system corresponding to 10% FER defined in [2]. We have extended this list to include additional channel coding rates that achieve FERs of 2% and 4% as shown in Table 1. TFRCs 3, 6, 9, 12, and 15 correspond to the conventional modulation and coding schemes defined in [2]. Table 2 shows the cumulative coding rates of the base and enhancement layers of sequences Bus, Football, and Mobile and Calendar achieved by TFRCs 1 through 9.

Table 1. Extended List of Modulation and Coding Schemes

TFRC	SNR-range (dB)	Modu-lation	FER	Data Rate (15 Codes)
1			2%	1.52 Mbps
2	-10 – 10	QPSK	4%	1.63 Mbps
3			10%	1.8 Mbps
4			2%	3.32 Mbps
5	10 – 15	QPSK	4%	3.43Mbps
6			10%	3.6 Mbps
7			2%	5.12 Mbps
8	15 – 18	QPSK	4%	5.23 Mbps
9			10%	5.3 Mbps
10			2%	6.64 Mbps
11	18 – 21	16QAM	4%	6.86 Mbps
12			0%	7.2 Mbps
13			2%	10.24 Mbps
14	21 – 30	16QAM	4%	10.46 Mbps
15			10%	10.7 Mbps

Table 2. Comparison of cumulative coding rates for TFRCs.

TFR	Bus Cumulative coding rate			Mobile and Calendar Cumulative coding rate		
	Base	FGS1	FGS2	Base	FGS1	FGS2
1	0.1978	0.2027	0.206	0.1978	0.2027	0.206
2	**0.2018**	**0.2089**	**0.2124**	**0.2018**	**0.2089**	**0.2124**
3	0.1953	0.207	0.2129	0.1953	0.207	0.2148
4	**0.4321**	**0.4429**	**0.4501**	**0.4321**	**0.4429**	**0.4501**
5	0.4244	0.4393	0.4468	0.4244	0.4393	0.4468
6	0.3906	0.4141	0.4258	0.3906	0.4141	0.4297
7	**0.665**	**0.6832**	**0.6943**	**0.665**	**0.6832**	**0.6943**
8	0.6471	0.6698	0.6812	0.6471	0.6698	0.6812
9	0.5859	0.6211	0.6387	0.5859	0.6211	0.6445

The maximum coding rate for each layer in an SNR region is emphasized in bold. The table shows that the maximum coding rates are achieved at lower channel FERs than the conventional 10% as it was evident in the example in Figure 1.

Figure 2 shows a comparison in the PSNR performance of our proposed joint UXP-MCS allocation scheme and the conventional MCS allocation scheme for streaming the Football sequence. The figure shows that our proposed scheme results in a performance improvement ranging between 0.1dB to 0.7dB for the different channel SNR regions. Similar improvement can be seen in the other sequences where the average performance improvement is around 0.4dB. Note that this comparison is fair since the two schemes are constrained by the same uncoded channel capacity C and the same temporal share τ_u for each user. These results emphasize the significance of employing joint application layer and PHY layer channel coding schemes to maximize the throughput of each user.

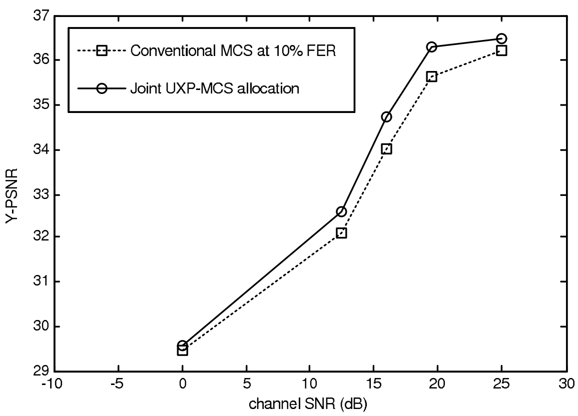

Fig. 2. Comparison of PSNR performance of the Football sequence between the proposed joint UXP-MCS allocation and the conventional MCS allocation for different channel SNR regions. The points are plotted in the middle of each SNR region specified in Table 1.

5. CONCLUSION

We have presented in this paper a joint media-channel aware unequal error protection scheme that improves the throughput of wireless video streaming systems with adaptive modulation and coding capability. Our scheme utilizes video priority information along with channel quality information to set the channel coding rate that maximizes the cumulative coding rate of channel coding and application layer unequal error protection. Performance evaluations comparing our proposed scheme with conventional modulation and coding allocation schemes show that under fair conditions, our scheme results in performance improvement that range between 0.1dB and 0.7dB. Moreover, we have shown that for different video sequences have varying motion and detail levels, our scheme achieves an average improvement of 0.5dB in PSNR compared with the conventional scheme.

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