Rate Partitioning for Optimal Quantization Parameter Selection in H.264 (SVC) based 4G Broadcast/Multicast Wireless Video Communication

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***Abstract*—In this paper we present a novel scheme for video quality maximization in the context of H.264 scalable video coding (SVC) based 4G wireless broadcast and multicast video transmission. A typical wireless multicast group comprises of multimedia clients with varying wireless link qualities. Thus, the conventional fair rate static video (FRSV) transmission scheme, which aims to achieve QoS fairness in multicast video transmission is rate and hence quality constrained by the BMG subscriber with the worst link capacity. Hence, we propose a novel rate partitioning based scalable video (RPSV) transmission framework to overcome this limitation. The proposed RPSV scheme optimally partitions the multicast group for transmission of the H.264 coded base and enhancement scalable video layers. This is based on the Medium Grain Scalability (MGS) feature for enhancement layer coding in H.264 SVC. We demonstrate that the optimal wireless link quality based BMG partition and the associated quantization, time-fraction parameters can be computed by solving a series of convex objective minimization problems. RPSV naturally leads to a significant enhancement in the net multicast group video quality by avoiding the rate bottleneck otherwise caused by the worst link user, while simultaneously resulting in QoS fairness by avoiding service starvation of the user with the poorest link quality. We compare the resulting video quality obtained from the proposed RPSV based quantization parameter adaptation paradigm with the performance of the simplistic FRSV scheme and demonstrate the superiority of the former.**

I. Introduction

A significant number of future mobile services envisaged in fourth generation (4G) LTE and WiMAX [1], [2] wireless networks are primarily based on reliable video transmission. These include applications such as High Definition (HD) video streaming, video conferencing, video on demand, mobile television, surveillance etc., which are gaining enormous popularity due to their immense utility. Further, with the ever-growing ecosystem of handheld devices such as mobile phones, smart phones, tablets, PDAs etc. which support such rich multimedia processing, the demand for such services is progressively increasing. Though 4G wireless technologies based on Orthogonal Frequency Division Multiple Access(OFDMA) promise high speed data transfers and in principle support the video based applications listed above, the erratic link quality arising out of the fast-fading and log-normal shadowing nature of the wireless channel [3] forces service providers to restrict the quality of video content to that supported by the worst channel capacity amongst the users subscribing to a Broadcast/ Multicast Group (BMG).

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The H.264 Scalable Video Coding (SVC) standard is a novel paradigm in video coding, ideally suited for the above wireless broadcast/ multicast video transmission context. The H.264 SVC codec enables the media server to extract and encode a video sub-stream in real time from the coded master-stream present in its local repository. Thus, the media server can adapt the quality of the video stream as is suitable to the rate supported by the users belonging to a BMG. This scalability aspect of H.264 SVC arises out of the ability to encode the video in a progressively layered hierarchical structure based on the temporal, spatial and SNR or Quality parameters[4]. In this context, a simplistic paradigm for quantization step-size based rate adaptation for wireless multicast video communication is given by the fair rate based static video (FRSV) transmission scheme. FRSV computes the parameters of the best video sub-stream to be extracted and transmitted as per the rate constraints imposed by the fading wireless channel. Thus, this scheme naturally results in fairness in QoS as it avoids outage in video streaming arising out of the variable wireless link quality.

However, the FRSV solution described above for broadcast/ multicast video transmission, while ensuring fairness, suffers from a capacity *bottle-neck* problem as the video quality is constrained by the link quality of the worst-channel user in each BMG. To overcome this constraint, we propose a novel H.264 SVC Medium Grain Scalability (MGS) based base-enhancement layer multicast group partitioning, similar in spirit to the one suggested in [5]. The Base Layer (BL) contains the core information about the video sequence transmission which guarantees a minimum video quality amongst all users of the BMG, thus ensuring fairness. The Enhancement Layer (EL) is exclusively transmitted to a select subset of users belonging to the BMG with higher link quality, thus resulting in superior video quality. Such a scheme based on multicast rate partitioning for scalable video (RPSV) coding maximizes the net video quality by avoiding the worst-case user bottleneck, while simultaneously ensuring fairness of QoS.

In this context of RPSV based multicast video transmission, we derive a framework for optimal quantization parameter selection based BMG partitioning technique to maximize the overall video quality. Further, we directly consider the rate vs quantization parameters derived from the H.264 JSVM reference codec and hence the proposed scheme is readily adaptable for scalable video streaming in a practical multicast/ broadcast scenario. We demonstrate that the computation of the optimal quantization and time-fraction parameters for rate partitioning reduces to the solution of a set of constrained convex objective minimization problems. Being convex in nature, the optimal solution can be computed in a relatively straight-forward manner employing the robust framework of convex optimization [6]. The optimal solution thus obtained comprises of a set of quantization step sizes for encoding the H.264 based base and enhancement layer sub-streams corresponding to the various video streams. Thus, the RPSV based framework naturally maximizes the sum video quality over all the video sequences being streamed by a media server to the respective BMGs.

The rest of this paper is organized as follows. In Section II we describe the framework for quantization parameter based video quality and rate characterization. We also elaborate the FRSV scheme for wireless BMG video transmission and derive the analytical expression for quantization parameter selection towards video rate adaptation. In section III we propose the optimal BL-EL video transmission based RPSV scheme in the context of the BMG system model. We derive the convex optimization framework for computation of the H.264 MGS layered video coding technique based optimal BL and EL quantization and time-fraction parameters. It is demonstrated therein that the optimal parameters can be computed as the solutions of a set of convex optimization problems. In section IV, we compare the performance of the proposed RPSV scheme with that of the simplistic FRSV scheme for various BMG video transmission scenarios and demonstrate the superior video quality of the former. Finally we present our conclusions in section V.

II. System Model

In this section we begin with an analytical parametric characterization of video content suited to the context of broadcast/multicast video transmission to multimedia clients. Characterization of video quality is a complex and challenging issue. Several advances have been achieved in this context in recent years as a result of significant research work towards modeling the video quality as a function of the basic parameters of a video sequence such as frame rate, quantization step size[7], [8] etc. Based on these results, we employ a quantization step size based quality characterization for optimal broadcast/ multicast based video transmission.

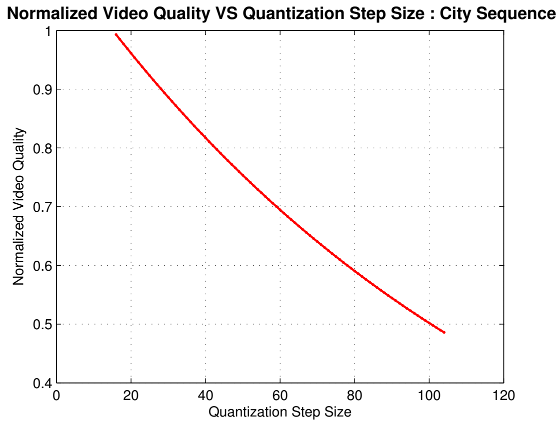

Fig. 1. Normalized Video Quality VS Quantization step size : City Video Sequence

Consider a video sequence master stream coded at a maximum frame rate of $f_{\max}$ and finest quantization parameter $q_{\min}$ corresponding to the highest quality. The normalized quality of an extracted video substream corresponding to a fixed frame rate $\tilde{f}$ as a function of the quantization step size q has been modeled in [8] by the following function,

$$\begin{aligned} Q(\tilde{f}, q) &\triangleq \left(\frac{1 - e^{-d \frac{\tilde{f}}{f_{\max}}}}{1 - e^{-d}} \right) \left(\frac{e^{-c \frac{q}{q_{\min}}}}{e^{-c}} \right), \quad (1) \\ &= \tilde{Q} \left(\frac{e^{-c \frac{q}{q_{\min}}}}{e^{-c}} \right), \end{aligned}$$

where the quantity $\tilde{Q}$ is defined as $\tilde{Q} \triangleq \left(\frac{1 - e^{-d \frac{\tilde{f}}{f_{\max}}}}{1 - e^{-d}} \right)$. The model parameters c and d above are specific to the video sequence under consideration and determine the rate of decrease in video quality with decreasing frame rate and increasing quantization step size respectively. Practical codecs constrain the quantization step-size to the range $16 \leq q \leq 104$. Hence, we set $q_{\min} = 16$ and $q_{\max} = 104$ as the minimum and maximum quantization step-sizes respectively. A plot of the variation of the normalized video quality as a function of the quantization step-size for the standard *City* test video sequence is shown in Fig.1. The results in [7] present the values of these parameters for several video sequences and outline a procedure for computation of these parameters based on normalized frame displacement (NFD) and normalized motion vector (NMV) features of the video sequence. For instance, the standard test sequence [9] *Akiyo* has the characteristic parameters $c = 0.11$, $d = 8.03$, while *Crew* has the values $c = 0.17$, $d = 7.34$. Thus the model parameters c_i and d_i, $1 \leq i \leq N$ can be computed for the N video sequences housed at the media server. Further, the variation in the bit-rate of the video substream as a function of the quantization parameter q at frame rate $\tilde{f}$ is given by the relation,

$$R(q) = R_{\max}\left(\frac{\tilde{f}}{f_{\max}}\right)^{b}\left(\frac{q}{q_{\min}}\right)^{-a}$$
$$= \tilde{R}_{\max}\left(\frac{q}{q_{\min}}\right)^{-a}, \quad (2)$$

where $R_{\max}$ is the maximum rate of a video sequence corresponding to coding at the minimum quantization step size $q_{\min}$ and the maximum frame rate $f_{\max}$ and $\tilde{R}_{\max}$ is defined as $\tilde{R}_{\max} \triangleq R_{\max}\left(\frac{\tilde{f}}{f_{\max}}\right)^{b}$ (i.e. maximum bit-rate at the fixed frame rate $\tilde{f} \leq f_{\max}$). A plot of variation in bit-rate with the quantization step size for test video sequence *City* is shown in Fig.2. The parameter a characterizes rate of reduction in bit-rate as the quantization parameter q increases. It is observed that the value of a is approximately constant over a wide range of video sequences and is thus set to the mean constant value of 1.2. The parameter b determines the rate of variation of the bit-rate as a function of the frame rate f. Video sequences of high motion content such as *Crew* etc. are associated with larger values of b when compared to sequences such as *Akiyo* etc. with low motion content. The rate function above can be determined apriori for each video sequence by encoding samples of the sequence with an H.264 (SVC) compatible encoder such as the Joint Scalable Video Model (JSVM) Reference Software 9.19.7 [10]. The value of the model parameter d can then be readily computed by extracting sub-streams for various values of f and employing the least-squares fitting method. Below we describe the suboptimal FRSV scheme for video transmission.

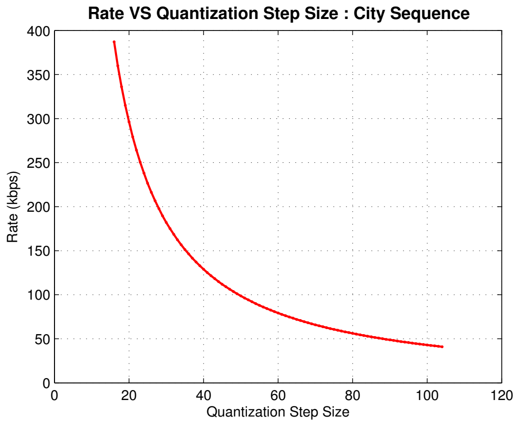

Fig. 2. Rate VS Quantization step size : City Video Sequence

A. Fair Rate based Static Video (FRSV) Transmission

In the presence of feedback from the BMG users regarding the wireless link quality of the subscribers in the BMG, the base station can adapt the quantization parameter for each BMG to ensure fairness in QoS for video transmission. Let $L^i_{\min}$ denote the instantaneous rate of the worst-case user in the i^{th} multicast group. The optimization problem for avoiding video streaming outage in all the BMGs thus ensuring fairness of QoS in each BMG is given as,

$$\begin{aligned}
&\max.\ \sum_{i=1}^{N} n_i \tilde{Q}_i\left(\frac{e^{-c_i\frac{q_i}{q_{\min}}}}{e^{-c_i}}\right)\\
&\text{subject to}\\
&\tilde{R}^i_{\max}\left(\frac{q_i}{q_{\min}}\right)^{-a_i} \leq L^i_{\min},\ \forall i\\
&q_i \geq q_{\min},\ \forall i\\
&q_i \leq q_{\max},\ \forall i
\end{aligned} \quad (3)$$

where n_i is the number of subscribers in the i^{th} BMG. The parameters $q_{\min}, q_{\max}$ are the minimum and maximum possible values of the quantization parameter as defined in the section above. It can readily be seen that because of the individual BMG rate constraint, the above problem decouples into N parallel optimization problems for each of the BMGs. Hence, a closed form solution for the unconstrained optimal quantization step-size $\tilde{q}^*_i$ of i^{th} BMG can be derived as,

$$\begin{aligned}
L^i_{\min} &= \tilde{R}^i_{\max}\left(\frac{\tilde{q}^*_i}{q_{\min}}\right)^{-a_i}\\
\tilde{q}^*_i &= q_{\min}\left(\frac{L^i_{\min}}{\tilde{R}^i_{\max}}\right)^{-\frac{1}{a_i}}
\end{aligned} \quad (4)$$

The optimal constrained quantization step-size for FRSV bounded between $q_{\min}, q_{\max}$ can be derived as,

$$q^*_i = \max\left\{\min\left\{\tilde{q}^*_i, q_{\max}\right\}, q_{\min}\right\} \quad (5)$$

Thus, adopting the optimal quantization parameter q^*_i by employing the channel information feedback results in fairness in QoS by serving the worst-case user $L^i_{\min}$ of each BMG. However, from (4) it can be seen that the worst-case user acts as a bottleneck by limiting the minimum i.e. finest possible quantization step-size. Hence, in the next section we propose the optimal rate partitioning based scalable video (RPSV) transmission scheme for sum video quality maximization.

III. Rate Partitioning based Scalable Video (RPSV) Transmission

RPSV utilizes the scalability feature of H.264 (SVC) MGS video coding technique to overcome the fundamental limitation in video quality arising out of the bottleneck caused by the worst-case BMG user. RPSV optimally partitions each BMG $\mathcal{S}^i$ into two distinct subsets based on the wireless channel qualities of the users. The base group $\mathcal{S}^i_b$ consists of users with poor channel qualities, while the enhancement group $\mathcal{S}^i_e$ comprises of users with fair channel qualities. The MGS video coding technique is now employed to encode the scalable BMG video sequence comprising of a Base Layer (BL) sub-stream and several enhancement layers (EL). The BL sub-stream constitutes the core component of the video sequence and is encoded using a coarse quantization step size. The BL is transmitted to all users in the BMG, thus ensuring fairness in QoS. The EL sub-stream on the other hand is an optional refinement component of the video sequence and is coded using a fine quantization step size. The EL is transmitted only to the BMG members in $\mathcal{S}_e^i$, thus delivering a video of higher quality to the fair channel quality users and avoiding the bottleneck caused by the worst-case user. This scheme for video transmission is described schematically in Fig.3. In the optimization framework that follows we approximate the video quality function in (1) with the affine model,

$$Q_i(\tilde{f}, q_i) \approx k_i q_i + l_i,$$

to make the optimization problem tractable. The above approximation models the function with more than 90% accuracy.

A. RPSV with Limited Number of Subscribers

Similar to the model in [5], we propose a time-division mechanism to multiplex the BL and EL sub-streams. The BL sub-stream is first transmitted for a fraction α_i of each transmission slot to all users in the i^{th} BMG followed by the EL sub-stream transmission exclusively to users in $\mathcal{S}_e^i$ for the remainder of the time slot. It can be readily observed that the wireless video transmission system in the RPSV paradigm is constrained by the data rate of the worst-case user for the transmission of BL segment only. By appropriately partitioning the BMG into $\mathcal{S}_b^i, \mathcal{S}_e^i$, the RPSV can successfully overcome the bottleneck caused by the worst-case user in FRSV. For this purpose, without loss of generality, we order the users of each BMG $\mathcal{S}^i$ according to the rates L_j^i, where the j^{th} user belongs to $\mathcal{S}^i$. Such an ordering can be done very efficiently as the the number of users in each BMG is limited. The optimal partition for this ordered set $\mathcal{S}^i$ can be equivalently formulated as choosing the optimal index p_i such that,

$$\begin{aligned}\mathcal{S}_b &= \{j \in \mathcal{S}_i, j \leq p_i\} \\ \mathcal{S}_e &= \{j \in \mathcal{S}_i, j > p_i\}\end{aligned}$$

Hence, the optimization framework can be conveniently expressed in terms of the partitioning parameter p_i for each BMG. The constrained optimization problem for optimal RPSV based video transmission to the BMGs can now be expressed as,

$$\max_{q_b^i, q_e^i, \alpha_i} \sum_{i=1}^{N} \tilde{Q}_i \left(p_i \left(k_i q_b^i + l_i\right) + (n_i - p_i)\left(k_i q_e^i + l_i\right)\right)$$

subject to

$$\tilde{R}_{\max}^i \left(\frac{q_b^i}{q_{\min}}\right)^{-a_i} \leq \alpha_i L_{\min}^i\,,\ 1 \leq i \leq N \tag{6}$$

$$\tilde{R}_{\max}^i \left(\frac{q_e^i}{q_{\min}}\right)^{-a_i} \leq (1-\alpha_i)\, L_{p_i}^i + \alpha_i L_{\min}^i, \forall i \tag{7}$$

$$q_b^i\,,\ q_e^i \geq q_{\min}\,, \quad 1 \leq i \leq N$$

$$q_b^i\,,\ q_e^i, \leq q_{\max}\,, \quad 1 \leq i \leq N \tag{8}$$

where q_b^i and q_e^i are the quantization parameters for encoding the BL and EL sub-streams respectively. From the rate constraints in (6) and (7) it can clearly be seen that

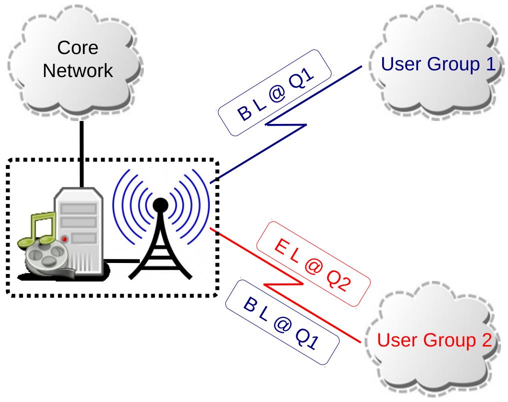

Fig. 3. Example Multicast Wireless Communication Scenario

while the BL is constrained by the worst-case user, the EL can be flexibly chosen through p_i to maximize the video quality. Thus, it significantly enhances the video quality by transmitting the EL sub-stream to the fair channel quality users. The above constrained optimization problem is convex given the partition index p_i. Further, it decouples into N parallel optimization problems for each BMG $\mathcal{S}^i$ due to the decoupled rate constraints above. Hence, it can be readily solved through the use of the log-barrier interior point method [6] combined with a line search over p_i to compute the optimal parameters $\tilde{q}_b^i, \tilde{q}_e^i, \tilde{\alpha}_i$ for each $1 \leq p_i \leq M_i$ and choosing the final set that maximizes the video quality objective. Thus, maximization of the quality of the transmitted video in the RPSV paradigm can be achieved very efficiently by solving a set of convex constrained optimization problems. Since, the objective and constraints are convex, the final solution can be found very reliably.

B. RPSV for Large Number of Subscribers

The above paradigm of RPSV for a finite number of users in each BMG $\mathcal{S}^i$ can be readily extended to the scenario with a large, possibly infinite number of users. In this context, Let $F_R^i(r)$, denote the cumulative distribution function (CDF) of the random link qualities of the users belonging to the i^{th} BMG i.e. $F_R^i(r)$ denotes the probability,

$$F_R^i(r) = P\left(l^i \leq r\right),$$

where l^i is the link quality of the users in the i^{th} BMG. Let $\bar{F}_R^i(r)$ denote the corresponding complementary CDF i.e. $\bar{F}_R^i(r) = 1 - F_R^i(r)$. The function $F_R^i(r)$ now captures a natural rate ordering on the set $\mathcal{S}^i$. Hence, the above optimization problem for rate partitioning can be readily extended to computing the optimal index $\tilde{r}_i$ for each BMG such that users with rate less than $\tilde{r}_i$ form the BL subgroup $\mathcal{S}_b^i$, while the rest in $\mathcal{S}_e^i$ form the EL subgroup. The constrained optimization problem for this scenario can thus be framed as,

$$\max_{q_a^i, q_b^i, \alpha_i} \sum_{i=1}^{N} \tilde{Q}^i \left(F_i(r_i)\left(k_i q_b^i + l_i\right) + \bar{F}_i(r_i)\left(k_i q_e^i + l_i\right)\right)$$

subject to

$$\begin{aligned}
&\tilde{R}^i_{\max}\left(\frac{q_b^i}{q_{\min}}\right)^{-a_i} \leq \alpha_i L^i_{\min}\,,\ \forall i\\
&\tilde{R}^i_{\max}\left(\frac{q_e^i}{q_{\min}}\right)^{-a_i} \leq \left(1-\alpha_i\right) L^i_{r_i} + \alpha_i L^i_{\min}\,, \forall i\\
&q_b^i\,,\ q_e^i \geq q_{\min}\,,\quad \forall i\\
&q_b^i\,,\ q_e^i, \leq q_{\max}\,,\quad \forall i
\end{aligned} \tag{9}$$

Again, similar to the discrete RPSV framework described previously, the above optimization problem is convex in the parameters q_b^i, q_e^i, α_i for a given rate partition point r_i. Hence, it can be readily solved by the standard log-barrier technique for constrained convex objective minimization, coupled with a line search over each r_i. For a faster computation, we propose a Gradient Ascent (GA) [11] based scheme to determine the optimal partition point $\tilde{r}_i$ and the corresponding optimal quantization step-sizes and time-fraction parameters. Let $Q_i\left(r_i^{(j)}\right)$ denote the optimal video quality corresponding to the to the rate partition point $r_i^{(j)}$ at the j^{th} iteration for the i^{th} BMG. The rate point $r_i^{(j+1)}$ corresponding to the $(j+1)^{th}$ iteration can be computed as,

$$r_i^{(j+1)} = r_i^{(j)} + \gamma \nabla Q_i\left(r_i^{(j)}\right) \tag{10}$$

where the value of step-size parameter γ is suitably chosen. We terminate the GA algorithm when the difference between the optimal values of the video quality objective functions corresponding to two successive iterations is less than or equal to 2 kbps. The above iterative algorithm can be initialized for each BMG with $r_i^{(0)} = L^i_{\min}$ and in practice is seen to converge rapidly to the final solution. Below, we present our simulation setup and results demonstrating the superiority of the proposed RPSV scheme over the single profile FRSV scheme.

IV. Simulation Results

We begin by considering the transmission of $N = 40$ video sequences to BMGs with a finite number of users. The video sequences are randomly selected from the local repository of the media server. We assume each BMG to be initially subscribed by $n_i = n = 5$ users, resulting in a total of $nN = 200$ users. We formulate the constrained optimization paradigm for rate partitioning based video quality maximization as described in (8). As demonstrated therein, the resulting problem can be solved conveniently by a convex solver for each of the N BMGs to compute the optimal values of the partition points $p_i, 1 \leq i \leq N$ and optimal SVC parameters $\tilde{q}_b^i$, $\tilde{q}_e^i$, $\tilde{\alpha}_i$. This scenario is repeated with a progressively increasing number of subscribers in steps of 5 users per BMG, eventually reaching $n = 50$ users per BMG, i.e. a total of 2000 users. In Fig.4 we compare the sum video quality obtained for the optimal RPSV and sub-optimal FRSV schemes. It can be readily observed that the total video quality obtained using RPSV scheme is higher than that obtained by the FRSV scheme. Moreover, the performance gap increases as the number of subscriptions in each BMG increase.

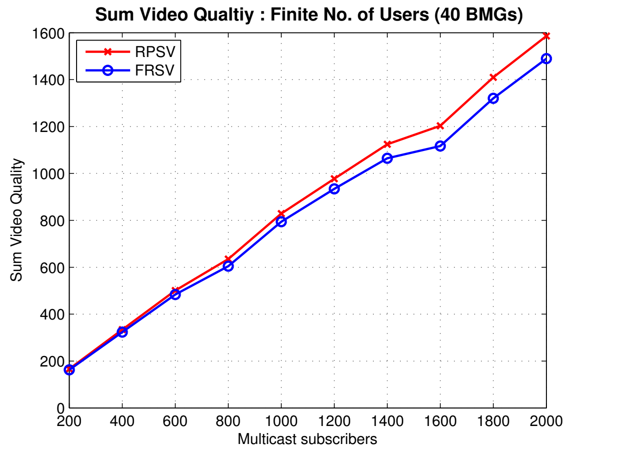

Fig. 4. Simulation 1 : Sum video quality - 40 BMGs with limited No. of users

Next we demonstrate the optimal normalized video quality obtained for RPSV based BMG transmission in the context of a large (possibly infinite) number of users, employing the optimization framework in (9). To clearly bring out the gains achievable from the optimization, we begin with 3 standard test sequences, namely *Akiyo*, *City* and *Crew* from the ensemble housed at the media server. The various model parameters pertaining to these sequences are tabulated below in table I. We compute the SVC coded video rates $\tilde{R}^i(q_{\max})$ and $\tilde{R}^i(q_{\min})$ corresponding to the maximum and minimum quantization parameters $q_{\max}$ and $q_{\min}$ respectively by evaluating the rate model mentioned in (2). Note that the rate $\tilde{R}^i(q_{\min}) > \tilde{R}^i(q_{\max})$, as the rate increases with decreasing quantization parameter owing to finer quantization. We set the lower and upper bounds on the wireless link capacities of each BMG as $L^i_{\max} = 1.8 \times \tilde{R}^i(q_{\min})$ and $L^i_{\min} = 1.8 \times \tilde{R}^i(q_{\max})$. The link capacity bounds $L^i_{\min}$ and $L^i_{\max}$ for each BMG corresponding to various test video sequences are listed in table II. The link qualities of the users in each BMG are assumed to be distributed uniformly randomly within the bounds $L^i_{\min}$ and $L^i_{\max}$.

We generate 60 equally spaced rate partition points between $L^i_{\min}$ and $L^i_{\max}$ and compute the optimal video quality for each rate partition point for all three test sequences. The plot of normalized video quality is shown as a function of the normalized rate partition point $\hat{r}_i = r_i / L^i_{\max}$ in Fig.5. It can be seen that the FRSV performance, which corresponds to the normalized rate partition point $\hat{r}_{\min} = L^i_{\min}/L^i_{\max} \approx 0.1$ is significantly lower than the optimal performance. It can also be observed that a significant improvement in video quality can be achieved by optimally choosing the rate partition points. Also, the typical value of the optimal normalized rate partition point

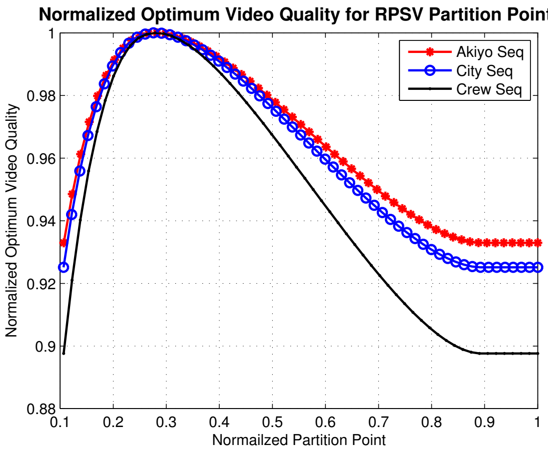

Fig. 5. Simulation 2 : Normalized optimum video quality for RPSV rate partition points

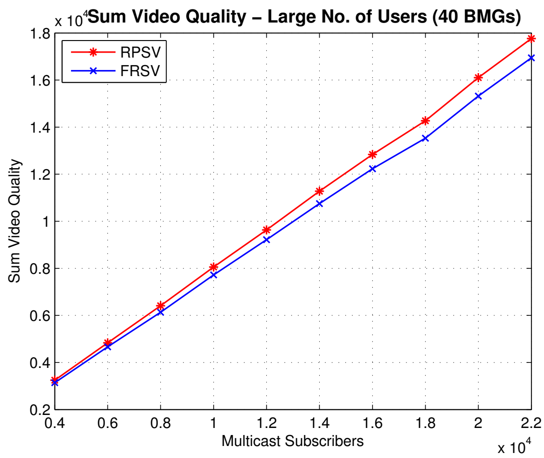

Fig. 6. Simulation 3 : Sum video quality - 40 BMGs with large No. of users

$\approx$ 0.3. Further, we observe from the plot that the curves are steeper for sequences with high motion content. This implies that for fast sequences such as *Crew*, if a large number of users are served only the base-layer at $L^i_{\min}$, the net video quality decreases sharply as compared to that for slow moving sequences, such as *Akiyo*. Therefore, the choice of optimal partition point is more critical for video streaming with high motion content.

Parameter	*Akiyo*	*City*	Crew
$\tilde{Q}$	0.9898	0.9851	0.9850
k	-0.0046	-0.0050	-0.0063
l	1.0	1.0	1.0
a	1.2	1.2	1.2
b	0.473	0.484	0.671
$\tilde{R}_{\max}(kbps)$	105.4766	361.6746	606.8848
$q_{\min}$	16.0	16.0	16.0
$q_{\max}$	104.0	104.0	104.0

TABLE I
MODEL PARAMETERS : TEST VIDEO SEQUENCES

Bit-rate (kbps)	*Akiyo*	*City*	*Crew*
$\tilde{R}(q_{\max})$	11.1599	38.2668	64.2111
$\tilde{R}(q_{\min})$	105.4766	361.6746	606.8848
$L_{\min}$	20.0878	68.8802	115.58
$L_{\max}$	189.9	651.0	1092.4

TABLE II
LINK CAPACITIES : TEST VIDEO SEQUENCES

Finally, we consider the transmission of $N = 40$ video sequences of diverse video content to BMGs which are subscribed by a large number of users. Similar to the setup described in the beginning for the finite BMG subscriber case, the video sequences are randomly chosen from the ensemble. We assume each BMG to be initially subscribed by 100 users, making a total of 4000 users accessing the media content. We adopt the GA based line search method described in (10) and solve a series of convex optimization problems to determine the optimal partition rate $\tilde{r}_i$, and the corresponding optimal quantization step sizes $\tilde{q}^i_b$, $\tilde{q}^i_e$ and time fraction parameter $\tilde{\alpha}^i$ for each BMG. We run the simulation by increasing 50 users/BMG until the total number of users reaches 22000. The sum video quality obtained using RPSV and FRSV for this setup is shown in Fig.6. Similar to the results in the finite subscriber case, the RPSV scheme can be seen to yield a superior performance to the FRSV scheme. Further, the solution converges rapidly in the GA based approach, usually within 10 iterative ascent steps.

V. CONCLUSION

In this paper we proposed a rate partitioning based optimal quantization parameter allocation problem in the context of H.264 scalable video coding for multicast video streaming services to heterogeneous wireless clients. We motivated the relevance of this problem in the context of 4G wireless communications and beyond. We demonstrated that the scenario of rate partitioning based scalable video (RPSV) transmission can be employed to partition each BMG into two user groups based on their wireless channel qualities and transmit the essential BL sub-stream data to all users in the BMG and only the optional EL sub-stream data to the user subgroup with fair channel conditions. Thus, this scheme avoids the bottleneck problem for fair rate based static profile video transmission (FRSV) while advantageously retaining the fairness aspect of QoS. Employing the sum video quality, it was shown that this scenario can be well captured by a constrained convex optimization framework. We demonstrated that this can be solved for both the finite subscriber and infinite subscriber scenarios conveniently using a convexity solver such as a log-barrier interior point method. Further, for the infinite subscriber case, we proposed a GA based algorithm to compute the optimal rate partition point for each BMG and the associated quantization and time-fraction parameters. We conducted simulations in multicast scenarios and compared the results of the RPSV based multicast video transmission scheme with that of the sub-optimal FRSV scheme. From the simulation results for both the finite and large number of subscriber scenarios, RPSV was shown to yield significant performance gains compared to FRSV.

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