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H.264 Encoder Parameter Optimization for Encoded Wireless Multimedia Transmissions

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ABSTRACT Wireless multimedia sensor network has been renewed to the distributed model by incorporating the single board computer (i.e., camera nodes and mobile beacons). The redesigned camera nodes, such as unmanned aerial vehicle and mobile beacon nodes are limited in terms of memory, computation power, bandwidth, and node power while the real-time processing requires the multimedia contents transmission over the wireless interface in the presence of all these constraints. To tackle this problem, advanced video compression schemes have been adopted by which bit rate overhead over the network is greatly improved. H.264/moving picture experts group (MPEG)-4 is a state-of-the-art video compression standard developed jointly by International Telecommunication Union Telecommunication Standardization Sector video coding experts group and ISO/Joint Technical Committee of International Electrotechnical Commission MPEG. The H.264 provides a number of tunable parameters (e.g., quantization parameter (QP) and number of reference frames (NoRF)) for tailoring the encoding process as per requirements. In this paper, we propose a framework consisting of a joint parameter cost function to find the best trade-off between QP and NoRF with the policy of controlling the bit-rate (BR) while maintaining reasonably good video quality without compromising on processing delay (PD) and nodal power consumption (NPC). The framework has been proposed by transforming the multi-objective problem into a convex optimization problem. It is shown that an optimal trade-off between these conflicting objectives can be achieved by choosing appropriate values for QP and NoRF. Results for optimal values of QP and NoRF with corresponding trade-off between BR, quality of multimedia contents, low PD and low NPC are presented.

INDEX TERMS Moving picture experts group (MPEG), peak signal to noise ratio (PSNR), video compression, video coding experts group (VCEG), wireless multimedia sensor network (WMSN).

I. INTRODUCTION

In the field of distributed wireless multimedia sensor networks (WMSNs), real-time processing with low latency is one of the central goals. Controlling the bit-rate (BR) of the captured video while not sacrificing the video quality beyond a certain minimum threshold and reducing the video processing delay (PD) is very important objective. The study has been published to narrate the problems of emerging distributed technology such as redesigned camera processing nodes and unmanned aerial vehicle (UAV) [1], [2]. Chmaj and Selvaraj [3] have elaborated distributed applications and their functional operation for UAVs. Constraints and parameters of interest of any distributed model based applications for UAVs highlighted in [1], [4]–[6]. The technique for video encoding has appeared as a prime solution for the rate control and reduction of data overhead in networks. The H.264/MPEG-4 AVC is a state-of-the-art video compression standard developed jointly by the International Telecommunication Union Telecommunication Standardization Sector video coding experts group (VCEG) together with the ISO/Joint Technical Committee of International Electrotechnical Commission moving picture experts group (MPEG) [7]–[9]. The H265 video encoding offers better results in encoding of multimedia data packets, but the incorporation of H264 is still high for commercial multimedia devices in comparison to the H265. The reason for the adoption is low computation cost used by H264 ncoder framework. Minallah *et al.* [10] have highlighted the computation cost analysis for both of video standards. The real time systems which demand low computation cost multi-threading and parallelization to reduce the computation complexity. Bahri *et al.* [11] have highlighted such solution by proposing an embedded approach with parallel computing using advance embedded processor platforms. Such systems are proposed for the implementation of H264 codes easily for a better functionality and real time performance. Many techniques has been proposed for controlling the BR of H.264 encoded videos [12]–[14]. There is an inherent trade-off between BR and distortion.

Nodes in WMSN are low power components and a controlled power consumption is highly sought after. In order to extend the network life time, it is imperative to minimize the PD. Another objective is to send a good quality video, in case of camera nodes, at a smaller BR in order to reduce the processing overhead.

Many schemes has been proposed to control and achieve the desired BR for H.264 encoding [15]–[18]. The problem rises when distributed model has been adopted as a real-time source to process and transfer video contents. Thus several solutions have been proposed to address the subject of interest. There are number of platforms by which software based H.264 encoder implementation is made possible and these applications have widely been used for research purposes. Sano *et al.* [19] have described the real time H.264 codec implementation. In [20], technique for selecting a small subset of transform coefficients which has the most significant impact on the quantization process has been discussed. They examine quantization decisions for the coefficients in this subset and QP.

Kwon *et al.* [21] discuss the achievement of good video quality by proposing the rate distortion (RD) model. Peraldo *et al.* [22] proposed RD model to sought out the tool for slice handling and controlling the BR. The discussed approach by Peraldo *et al.* [22] can help in predicting the optimal slice selection in favor of desired BR. Liao *et al.* [23] have proposed RD model to resolve the required number of coding bit for inter and intra frame model. Dilawari and Tahir [24] have dealt with the problem by proposing the distortion robustness and life time maximization model against the utilization. The proposed solution is based on basis of older version of encoding, i.e the H.264 encoding frame work. In [25], a joint optimization problem is formulated for lifetime and delay-robustness in WMSNs.

Based upon the observation that relationship between QP and true quantization stepsize is not linear in redesigned quantization scheme for H.264/AVC. Ma *et al.* [26] propsed a new RD model according to actual quantization stepsize and developed a new rate control scheme for H.264/AVC building upon this rate-distortion model. In [27], Czuni *et al.* discuss that to achieve efficient rate control, a good initial estimate for QP is important. By changing the initial value extensively, authors conclude that image quality fluctuates, then a method for selecting QP for each part of the video sequence is proposed. The proposed solution has been carried out under a fixed constrained of BR given that a base profile has been adapted for this model. The proposed scheme limits the handling of other parameters such as parameters of selection, QP and reference frames together.

TABLE 1. Surface fitting coefficients.

Bitrate (r)		PSNR (s)		PD (d)	
$c_0 =$	3925	$a_0 =$	66.3	$b_0 =$	8.219
$c_1 =$	-0.08708	$a_1 =$	-0.703	$b_1 =$	-1.37
$c_2 =$	2	$a_2 =$	29.46	$b_2 =$	0.01626
		$a_3 =$	0.01186	$b_3 =$	0.01008
		$a_4 =$	0.02	$b_4 =$	0.0008022

The above mentioned trade-off, BR and QP approaches do not investigate the optimal solution for all parameters altogether for a battery powered wireless equipped camera nodes, which are used for the transportation of data and has also been considered as prime importance in WMSNs. In fact, these parameters appear as key objectives for WMSNs in terms of complete quality of service (QoS) provisioning. Thus a framework is designed for finding the optimal solution of all parameters of interest in regard with distributed node model.

This paper is organized as follows. In Section II, we discuss the system model and explain the parameters of interest along with the reason of selecting these parameters. The impact of these parameters on the H.264/AVC encoder in terms of BR, peak signal to noise ratio (PSNR) and computational delay is also given. A model fitting approach which is used to approximate the relationship between BR, PSNR and processing delay with respect to QP and NoRF is discussed in Section II. In Section III, we develop problem formulation and construct a convex optimization problem and apply the Lagrangian and sub-gradient method to decompose the problem into subproblems. Finally, Section IV is ended up with concluding remarks.

TABLE 2. Parameters of interest.

Parameter	Range
s (dB)	20-50
r (Kbps)	15-600
Q	0-50 (Step size of 5)
k	1-15 (Step size of 3)

II. SYSTEM MODEL

Let's consider PSNR as s, BR as r, QP as Q, NoRF as k and NPC as P_n while the PD as τ with ranges as shown in table 2. Whereas NPC is the total power requirement at a node for processing and communicating of raw video captured at a multimedia node. In our discussion, we focus on video capturing and processing at a single node, so NPC is effectively the power consumed at a single node. NPC can be expressed as,

$$P_n = E_b^{(c)} r + E_b^{(p)} \left(\frac{R}{r}\right)^{\alpha}, \tag{1}$$

where $E_b^{(c)}$ is the energy requirement for per bit communication at a node while $E_b^{(p)}$ is the energy requirement for processing per bit. Both $E_b^{(c)}$ and $E_b^{(p)}$ depend on BR. Nodal power is the sum of $E_b^{(c)}$ and $E_b^{(p)}$ and $\alpha > 0$ depends upon the choice of compression algorithm.

For approximating the relationship between Q, r, s and k, we captured the empirical data by encoding a sample video. For the captured empirical data, JM Software is employed as a model fitting tool.

In this work, we focus on two tunable parameters, which are Q and k and three different observable quantities, which are s, r and τ. NPC is related to r as given in (1). H.264 has many tunable parameters for controlling the BR but, of course, a controlled low BR comes at the cost of degraded video quality. Though higher BR can afford a better quality video but penalizes in terms of NPC. Our objective in this work is to maintain a low BR as well as do not letting the video quality be compromised beyond a certain threshold while maintaining a low PD as well as low NPC in order to increase the network lifetime. There is a natural trade-off between s and r, while NPC is also defined by r and plays a deciding role in terms of extending the network lifetime. A low BR deteriorates the video quality and an enhanced video quality requires a high BR, hence more NPC reduces the network lifetime.

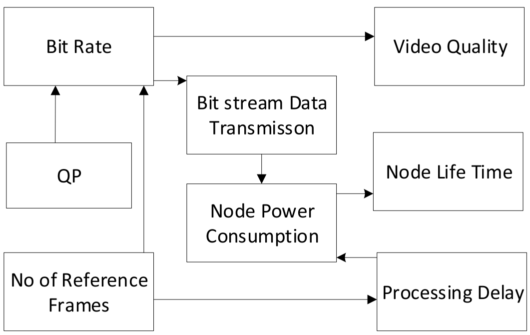


FIGURE 1. H.264 distributed node, parameters of interest.

A. SYSTEM PARAMETER SELECTION

H.264 standard comes with an abundance of encoding input parameters which can be employed for tuning encoding process as per the requirements. Figure 1 depicts that there are more than one parameters connected to each other in WMSN. We target to achieve a good BR while a better video quality, but this increases the transmission overhead, which introduces PD and bandwidth constraints. This single objective effects the node power to support the desire quality and BR transmission power.

Both parameters Q and k directly impact BR and video quality. It is observed from empirical data that QP drastically impacts the BR of the encoded video and also plays an important role in controlling the PSNR, which decides the quality of video. It is evident from Fig. 2 QP can be varied between a range from 0-50, while k can take on values from 1-15 inclusive. It is important to mention that compression ratio depends upon the video content. Figures 3 and 4 shown

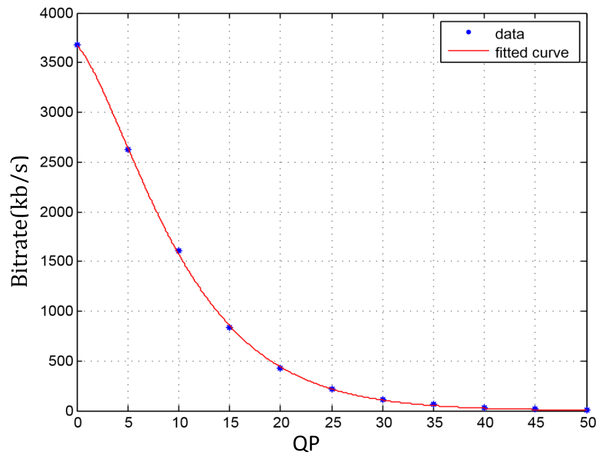


FIGURE 2. Quantization parameter versus bit-rate (kbps). Empirical data is simulated and a curve fit over the data.

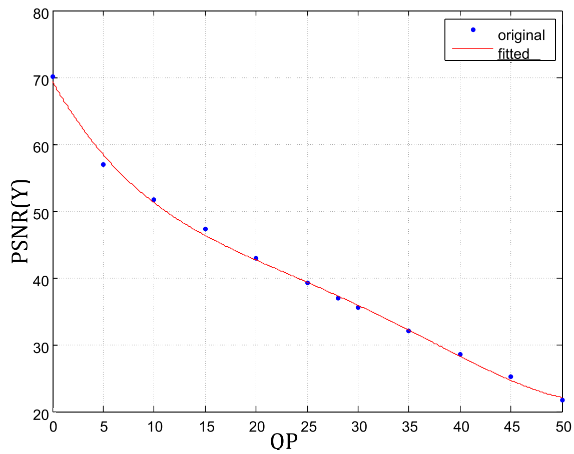


FIGURE 3. PSNR versus quantization parameter. Empirical data is simulated and a curve fit over the data.

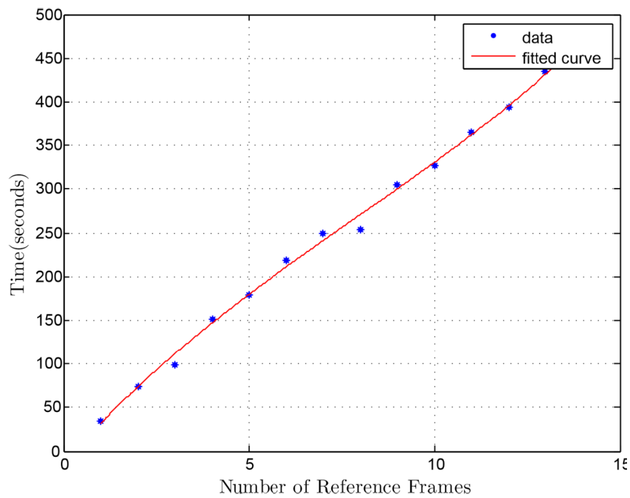
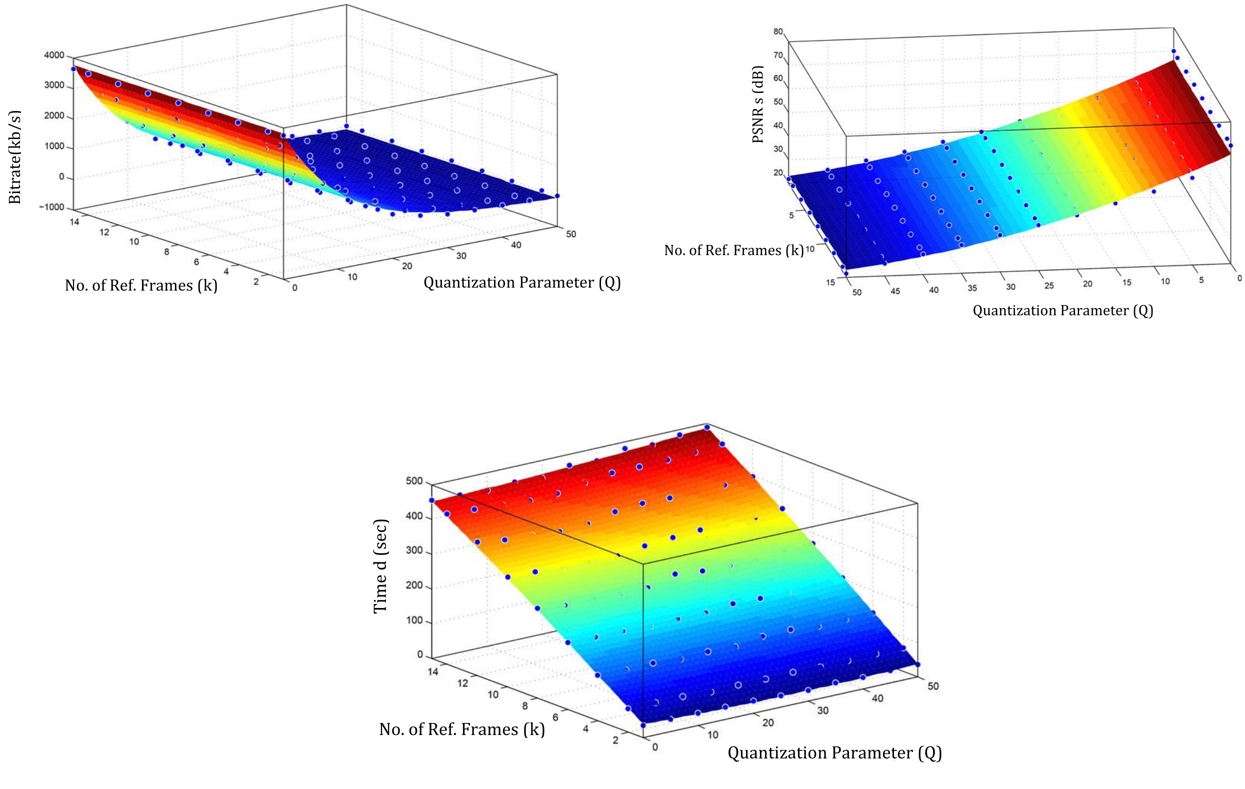


FIGURE 4. Time versus number of reference frames. Empirical data is simulated and a curve fit over the data.

the simulation made by implementing the curve fitting model over the empirical data generated from the encoder. These depict ranges of QP and NoRF used to find outcome in the



(a) (b) (c)

FIGURE 5. **Model fitting for (a) bit-rate r, (b) PSNR s and (c) processing delay d as a function of parameters Q and k.**

form of PSNR and time (in seconds). NoRF on the other hand are related with the prediction accuracy. One of the biggest improvements in H.264 is its ability of better and more accurate prediction than the previous standards such as MPEG-4.

H.264 supports I, P and B frames where P and B frames are encoded with the help of reference frames which are available to decoder and reside in decoded picture buffer (DPB). I frames are sent as these are without any motion estimation and prediction while P and B frames are subject of encoding. P frames are more compressible while B frames provide the highest level of compression. For encoding P and B frames, reference frames play a critical role in accurate predictions and facilitating the encoding process for H.264/AVC [29]. More available reference frames result in better prediction accuracy but at the cost of increased PD. Our selection of QP and NoRF for deciding a trade-off between r, s and τ depends upon the roles of these input parameters in the encoding process.

B. MODEL FITTING

Empirical data have been generated by encoding 100 frames of aforementioned foreman_qcif video while providing different values of selected parameters Q and k. Model fitting technique has been employed for approximating the relationship between different readings of r and s. Figure 5 captures the relationship between BR(r), PSNR(s) and PD(d) for different values of quantization level, Q and NoRF, k. It has been observed from empirical data that r and s both assume larger values for smaller Q.

BR(r) is affected not only by Q but by k as well. Different readings for r, PSNR(s) and PD(d) has been obtained over a range of Q and k using JM software. In Fig. 5(a), BR is plotted as a function of Q and k. Small circles represent the empirical data recorded using JM software. Now in order to come up with mathematical representation of BR, a surface is fitted through the empirical data. The surface plotted in Fig. 5(a) gives a good estimate of BR in terms of Q and k.

The mathematical model of surface representing BR r as a function of Q and k is given as,

$$r = c_0 e^{-c_1 Q} + c_2 k. \tag{2}$$

PSNR is also dependent on both Q and k. In this case another surface is fitted to provide mathematical representation of PSNR (s) in terms of Q and k. Figure 5(b) shows the empirical data obtained from JM software and the fitted surface for approximating the relationship of data. The fitted surface for PSNR (s) is expressed mathematical by,

$$s = a_0 + a_1 Q + a_2 k + a_3 Q^2 + a_4 k^2. \tag{3}$$

PD (d) is also plotted as a function of Q and k and again another surface is used to model the mathematical relation of time with Q and k. Figure 5(c) shows the empirical data as well as the fitted surface. The mathematical model of processing delay d from the model fitting is given by,

$$d = b_0 + b_1 Q + b_2 k + b_3 Q^2 + b_4 k^2. \quad (4)$$

where "a, b, and c" are the surface fitting coefficient whose values are given in Table 1.

III. PROBLEM FORMULATION

A multi-objective optimization problem is constructed to achieve the optimal trade-off between r, s and d. Using developed models of r, s and d based on Q and k as are given in Section II-B, the multi-objective problem is formulated as,

$$\begin{aligned} &\min \{(1-\beta)e^{\omega Q} + \beta P_n + \beta_1 d\}, \\ &\text{subject to: } S_{max} \geq a_0 + a_1 Q + a_2 k + a_3 Q^2 + a_4 k^2, \\ &\qquad r \geq c_0 e^{-c_1 Q} + c_2 k, \\ &\qquad d \geq b_0 + b_1 Q + b_2 k + b_3 Q^2 + b_4 k^2, \end{aligned} \quad (5)$$

where β is the weighting coefficient for the term involving Q. The primal objective is relaxed by adding the BR and delay constraints in (5) as a linear combinations to the multi-objective problem. The Lagrangian of (5) is given by,

$$\begin{aligned} &L(d, Q, k, \lambda, \phi) \\ &= \min\{(1-\beta)e^{\omega Q} + \beta P_n + \beta_1 d \\ &\quad + \lambda(c_0 e^{-c_1 Q} + c_2 k - r) \\ &\quad + \phi(b_0 + b_1 Q + b_2 k + b_3 Q^2 + b_4 k^2) \\ &\text{subject to: } S_{max} \geq a_0 + a_1 Q + a_2 k + a_3 Q^2 + a_4 k^2, \end{aligned} \quad (6)$$

where λ and ϕ are Lagrange multipliers.

A. QUANTIZATION PARAMETER MINIMIZATION

The minimization of Q can be given using (6) as,

$$\begin{aligned} &\min \{(1-\beta)e^{\omega Q} + \lambda c_0 e^{-c_1 q} + \phi(b_1 Q + b_3 Q^2)\}, \\ &\text{subject to: } S_{max} \geq a_0 + a_1 Q + a_2 k + a_3 Q^2 + a_4 k^2. \end{aligned} \quad (7)$$

B. JOINT NODAL POWER AND BIT-RATE MINIMIZATION

From (6), P_n and r can be given as,

$$\begin{aligned} &\min \{\beta P_n - \lambda r\}, \\ &\text{subject to: } P_{max} \geq E_b^{(c)}.r + E_b^{(p)}.\left(\frac{R}{r}\right)^{\alpha}. \end{aligned} \quad (8)$$

C. JOINT PD AND NoRF MINIMIZATION

The joint PD and NoRF minimization can be obtained from (6) as,

$$\begin{aligned} &\min \{\beta_1 d + \phi(b_0 + b_3 k + b_4 k^2 - d) + \lambda c_2 k\}, \\ &\text{subject to: } S_{max} \geq a_0 + a_1 Q + a_2 k + a_3 Q^2 + a_4 k^2. \end{aligned} \quad (9)$$

D. DUAL PROBLEM

Following sub-gradient updates are used to solve the dual problem in (5):

$$\lambda(i+1) = [\lambda(i) + \pi(i)(c_0 e^{-c_1 Q} + c_2 k - r)]^+ \quad (10)$$

$$\begin{aligned} \lambda(i+1) = [&\phi(i) + \pi(i)(b_0 + b_1 Q + b_2 k + b_3 Q^2 \\ &+ b_4 k^2 - t)]^+ \end{aligned} \quad (11)$$

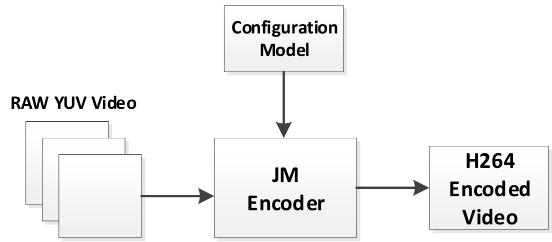


FIGURE 6. JM model for encoding.

IV. PERFORMANCE EVALUATION

The initial data has been captured by encoding the video frames using the available software resource for encoder *JM encoder model*. JM Software is a reference implementation of H.264 developed by Joint Video Team (JVT). JM Encoder Module (JM version 18.5) is used with the process flow as shown in Fig. 6 loaded with the configuration as given in Tab. 3 for encoding 100 frames of foreman_yuv.qcif with YUV 4:2:0 format and is available at [28]. We encode the video while operating the JM reference software in baseline profile leaving all settings for baseline profile intact and only changing the parameters of interest for tuning the encoding process. JM reference software can be operated with different configurations depending upon the specific encoding requirements.

TABLE 3. JM configuration parameters.

S.No	Parameter Name	Value
1	Input Video Format	YUYV
2	Total Frames	30
3	GOP Length	10
4	H264 Profile	Base & High

Figure 7 depicts the relationship between Q and R_{max} for different values of weighting coefficient β. A relaxation on R_{max} certainly means that video can be encoded at a higher BR. Higher BR results in smaller values of Q and a larger value of β forces Q to assume larger initial values and then decays, which is due to the relaxation on R_{max}. It clearly shows that β is the trade-off factor, a smaller value of β means that the video is encoded at higher BR while higher values of β results in encoding of the multimedia content at lower BR.

One of the objectives is to minimize the BR, we just concluded from Fig. 7 that BR decreases with increasing values of β but increasing β also results in video quality degradation, which can be seen from Fig. 8. Figure 8 expresses PSNR as a function of weighting coefficient β for different values of maximum BR R_{max}. Degradation in video quality with respect to increasing β allows the video to be encoded at a lower BR.

It is concluded from the fact that low BR objective has been achieved with the help of trade-off parameter β but at the expense of low video quality. An increased video quality requires higher BR, which can be achieved by adjusting

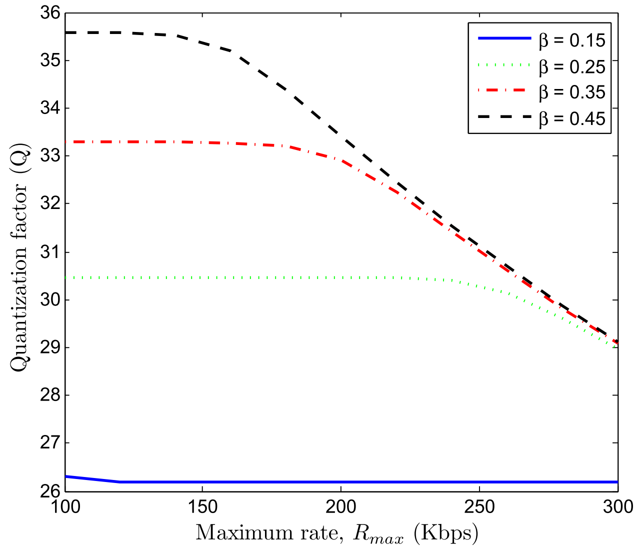


FIGURE 7. *Q* as a function R_{max} for different values of β.

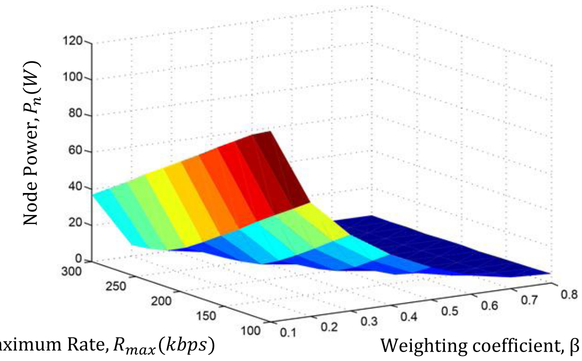


FIGURE 9. P_n as a function of R_{max} and weighting coefficient β.

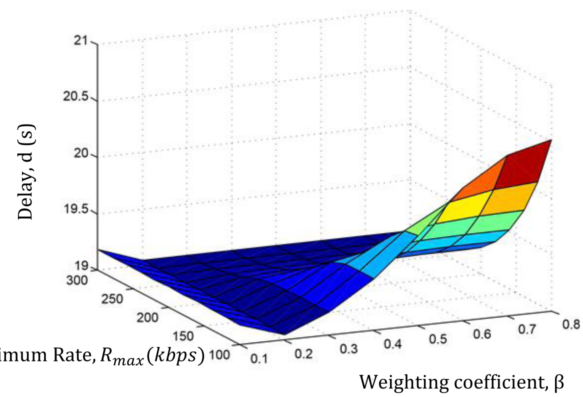


FIGURE 10. Delay d_s as a function of R_{max} and weighting coefficient β.

trade-off parameter β. It is obvious from Fig. 5 and Fig. 7 that low BR and high PSNR are conflicting objectives. Maximum BR (R_{max}) has an interesting effect on video quality, relaxing R_{max} increases PSNR and it can also be concluded from Fig. 8 that larger relaxation in R_{max} directs PSNR to become independent of β more quickly.

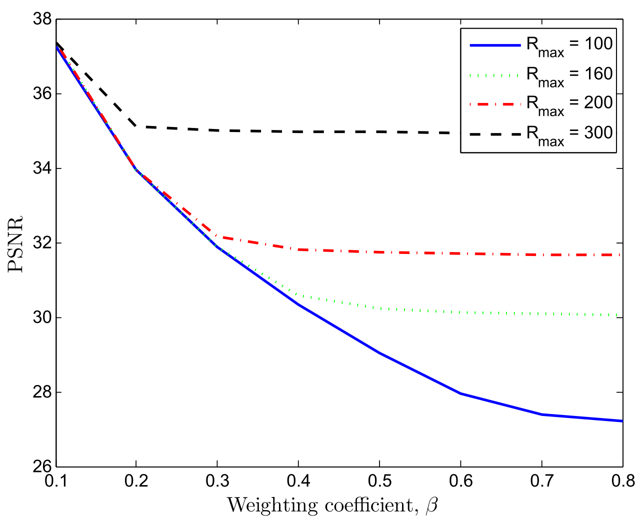


FIGURE 8. PSNR as a function of β for different values of R_{max}.

It is concluded from the previous discussion on Fig. 7 and Fig. 8 that increasing the value of weighting coefficient β decreases the BR as well as PSNR. Nodal power decreases at low BR, which is evident from Fig. 9. With an increasing weighting coefficient β, nodal power is also decreasing. So, less nodal power is required for encoding video at a lower quality. Decreasing β improves the quality of video and encoding is done at a higher BR but for this improved video quality, nodal power P_n is penalized and pays the highest in terms of trade-off for minimizing the overall objective function.

TABLE 4. Result parameters.

Parameter	Value
Per bit communication energy $(E_b^{(c)})$	0.35
Per bit processing energy $E_b^{(p)}$	0.0001
ω	0.1
Uncompressed sensed data rate R	100Kbps
Compression parameter (α)	.6

One should expect that relaxing upper bound R_{max} on BR should result in elevated values of NPC but it is observed that increasing R_{max} reduces the NPC. Referring back to (1) reveals that there are two component of nodal power, one of them is communication power consumption while the other one is the processing power consumption. Communication power is directly proportional to BR so increasing the BR results in increased NPC. On the other hand, processing power consumption has an inverse relationship with BR. Therefore, a higher BR results in lower processing power. Processing power is the dominant component in (1) because of $\alpha > 0$. Figs. 9 and 10 show the relationship of P_n and R_{max} and the relationship between d_s and R_{max}, respectively. The relationship can been analyzed using (8). The mathematical model for the optimization problem given in (6) represents the significance of joint relationship between the parameters by changing the value of β. The effect of changing the β

thus controls the other parameters described by sub problems given in Section III. The resultant parameters obtained are given in Table 4.

V. CONCLUSIONS

In this paper, we propose an optimal trade-off between QP and NoRF for encoding a better quality video at a low BR while keeping the NPC and PD at a minimum. It is seen that PSNR and BR show a directly proportional relationship but at the same time they are conflicting interests because a low BR is desirable but it comes at the expense of a degraded video quality and a better PSNR requires the multimedia content to be encoded at higher BR. In this work, we obtained relationship between parameters of interest such as BR, PSNR, PD and NPC using the model fitting techniques. We employed convex optimization along with Lagrangian and sub-gradient method to obtain an optimal trade-off between control parameters of interest. we show an optimal trade-off between QP and NoRFs for maintaining a reasonably acceptable video quality while at the same time maintaining a low BR, low NPC and low PD.

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