In-Network Quality Adaptation for SVC Video in ICN-Enabled Cellular Network

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Abstract

Video quality adaptation is one of the most important parameters for Quality of Experience (QoE). In legacy video streaming, video quality is adapted entirely by the end user. Network status prediction is important in video quality selection. However, at the user side, exact network status prediction is not possible and this phenomenon is more severe in cellular network where network status is changing drastically in magnitudes of milliseconds. In this paper, we propose video quality selection at the network edge like Base Station/ Small-cell Base Station (BS/SBS). The User Equipment (UE) request chunk of a video. The BS/SBS tries to maximize quality of the requested chunk taking the available resources in consideration. Our performance analysis shows that the proposed mechanism provides better quality video to the users.

1. Introduction

The current TCP/IP based Internet is an end-to-end communication structure where the networking-nodes/routers are dump devices which forwards traffic from source to destination and vice versa. Content/Information-Centric Networking (ICN/CCN) [1-5], which is the future Internet architecture, enables the networking nodes to be intelligent devices and take decision for arranging users requested data and caching etc. On the other hand, currently, the video quality selection is done entirely by the end user, which is good in the existing Internet architecture. However, prediction of the network status at the end user is not always accurate and in cellular network, this prediction is more difficult in cellular networks because of the scarce network resources [6], [8] that changes drastically in magnitude of milliseconds.

Recently in [7] Liang, et al. has proposed that SDN controller provide assistance to the User Equipment (UE) regarding the network status for video quality selection. However, still, the UE doesn't have idea of the available resources in the current resource allocation frame. In this Paper, we have proposed that the video quality selection is performed in the network edge i.e., the Base Station (BS). The UEs provide two extra information to the BS with data request packet called Interest in CCN. The extra information provided to the BS are: mean quality and variation in quality for the S downloaded segments of the current video. These parameters are discussed in detail in section 3.

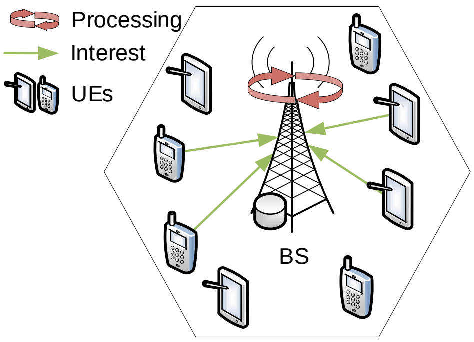

Figure 1: *Network Diagram*

In the evaluation, we have shown that the proposed mechanism achieves significant performance improvement in delivering video quality to the requesting users.

2. System Design

In our proposed mechanism, each video is consisted of (1, 2… S) segments. Moreover, each video is available in ($q_1, q_2 ... Q_n$) qualities. As shown in Fig. 2, there are two important parameters for quality selection with the user i.e, the play head and already downloaded video in the buffer. UE sends the mean quality $m_n^s(q_n)$ and variation in quality $\omega_n^s(q_n)$ for the S downloaded segments of the video to the BS. The BS finds the requested chunk either in its cache or request it from the service provider's server via the backhaul network. As shown in Fig. 3, BS tries to provide the best possible quality for the requested chunk taking the available resources and deadline in consideration. Rate that is achieved by each user is:

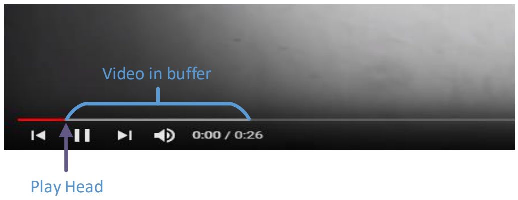

Figure 2: *Video play status*

$$R_n(t) = \phi_n^k(t) B_k log_2 \left(1 + \frac{h_{0,n}^k P_o^k}{B_k \sigma_n^2}\right). \qquad (1)$$

3. Problem Formulation

In this paper, our objective is to maximize the user QoE for which we need to increase the rate that a user achieves. We are considering the following for achieving the objective:

1. For each segment, QoE depends upon the number of layers delivered to the users.
2. With the successful delivery of each layer the quality of the video will increase and hence the utility of the user.
3. QoE reaches to its maximum when all the layers for a segment are delivered or the user gets the video that its device can support.

Below given quadratic function which is defined over $0 \le q^{BL+ELs} \le q^{\max}$ meets these requirements and thus can be called as an individual users utility function:

Utility for a user:

$$U_n(SoQ) = \omega_n(t) SoQ_{n,s} \left(\frac{SoQ(t)}{SoQ_{n,s}} - \frac{1}{2}\left(\frac{SoQ(t)}{SoQ_{n,s}}\right)^2 \right). \qquad (2)$$

Where State of Quality (SoQ(t)) is the user satisfaction at time t. We can relate it to Peak Signal to Noise Ratio (PSNR). $SoQ_{n,s}$ is the demand of the layer quality of the user device for the chunk s.

$$SoQ_n(t+\Delta t) = SoQ_n(t) + \frac{R_n(t) \times \Delta t}{l_n^s} \qquad (3)$$

The mean rate, that a user achieves, is $mean\,rate = {l_n^S}/{\sum_{t=1}^{T} t}$

Layer Selection: BS/SBS does the selection of the layers according to the users' achievable rates as follow:

$$V(m_n^S(q_n)) \times l_n^s \le R_n(t) \times \Delta t \qquad (4)$$

Where the left-hand side is representing the total data to be downloaded for the quality q_n. By maximizing the rate we can increase the video quality and hence the SoQ. Our main optimization problem is as follow:

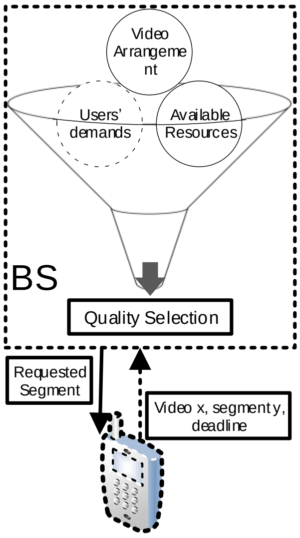

Figure 3: *In-Network quality selection mechanism*

Algorithm 1: *Heuristic Algorithm for Quality Maximization*

Input: $m_n^s(q_n)$, $\omega_n^S(q_n)$

Repeat:

- SBS updates fraction of time for each UE:

$$\phi_n^k(t) = \left[\frac{SoQ_{n,s} - SoQ_n(t) - \frac{\lambda l_n^s SoQ_{n,s}^2}{\Delta t \omega_n(t) q^{\max}}}{\frac{B_k r_n^k \Delta t}{l_n^s}} \right]_0^{\frac{R_{n,\max}}{r_n^k B_k}} \qquad (11)$$

- SBS update congestion control of the backhaul:

$$\lambda^{(\tau+1)} = \lambda^{(\tau)} - \beta\left(\sum_{n=1}^{N} \phi_n^{k,(\tau)}(t) - R_{\max}\right) \quad (12)$$

where λ is Lagrangian multiplier for the constraint (8); β is the step size satisfying the convergence of the algorithm

Until: Convergence satisfaction

Output: Select layers of the requested video for each UE based on the achieved data rate.

$$OPT:$$

$$\underset{\phi}{Max.} \sum_{n=1}^{N} U_n(t+\Delta t) \qquad (5)$$

$$Subject\ to:$$

$$R_n(t) \in [0, R_{n,\max}] \qquad (6)$$

$$q_n^s(R_n(t)) \in Q_n^s, \qquad (7)$$

$$\sum_{n \in N} R_n^t(\phi) \le R_{\max}. \qquad (8)$$

Where constraint in eq. (6) is ensuring that a user achieves rate from zero to the maximum achievable rate. Constraint in eq. (7) is ensuring to select quality within the valid quality set. The last constraint in eq. (8) is to ensure the total user's achievable rate is within the limit of the SBS's backhaul capacity.

4. Proposed Solution

We have used Lagrangian multiplier to derive a closed form solution for the optimization problem given in (6). Due to the space constraint, we cannot show the full solution here and leave it for the extended version of this research study. Algorithm 1 is comprehensively representing our solution.

5. Performance Evaluation

In this section, we present a scenario-based performance analysis of our proposed scheme. The real simulation results will be presented in the extended version of this study. Table 1. is showing the results (PSNR) of the proposed mechanism, in a scenario of an SBS and 4 UEs, versus the greedy based algorithm. There are total 30 Resource Blocks (RBs) with the SBS. According to the distance from the SBS UEs are having different gains, ranging from 2 to 4 RBs for downloading one layer of a video in a time slot. UEs are changing their position in each time slot. Table 1 is showing results for 4 time slots. Greedy algorithm assigns maximum resources to the Ue with the best gain and moves to the next best after all the layers are delivered to the first user. While the proposed solution maximizes the system welfare.

6. Conclusion and Future Work

In this paper, we presented video quality selection at the network edge. We made a little modification in the video requesting packet, by sending extra information along with the segment request, which can be easily accommodated in the ICN, the future Internet architecture. Having these parameters, the network edge i.e., the BS/SBS is in the best position to maximize the quality as it knows and manages the network resources. In future, we aim to extend our formulation and provide a mathematical model for the solution. Furthermore, we aim to perform simulation for the proposed mechanism considering the real environment parameters.

Table 1: *Selected Quality, Proposed vs Greedy*

Time	Solution	UE 1	UE 2	UE3	UE4
t1	Greedy	55	55	30	0
	Proposed	51	46	40	40
t2	Greedy	55	55	55	0
	Proposed	51	51	51	46
t3	Greedy	30	0	55	55
	Proposed	40	40	46	46
t4	Greedy	0	55	55	30
	Proposed	40	55	40	40

7. Acknowledgement

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