PRICING BASED COLLABORATIVE MULTI-USER VIDEO STREAMMING OVER POWER CONSTRAINED WIRELESS DOWN LINK

[1,3]Zhu Li, [2,3]Jianwei Huang, and [3]Aggelos K. Katsaggelos

[1]Multimedia Research Lab (MRL), Motorola Labs, Schaumburg, Illinois, USA
[2]Dept of Electrical Engineering, Princeton University, Princeton, New Jersey, USA
[3]Dept of Electrical Engineering & Computer Science, Northwestern University, Evanston, Illinois, USA

ABSTRACT

Video streaming is becoming an important application in wireless communications. In a typical scenario, a base station needs to serve multiple video users with a total transmitting power constraint. How to make appropriate video coding decisions and allocate limited transmitting power among users to achieve optimal total utility is an interesting problem. In this paper we develop a pricing based down link power allocation scheme with collaborative video summarization among users. The scheme exploits the multi-user diversity in channel states and utility-resource tradeoff characteristics in video content to achieve better resource utilization. The computational complexity can also be distributed among video sources and base station. Simulation results demonstrate the effectiveness of the proposed solutions.

1. INTRODUCTION

Serving mobile users with wireless video content has been one of the driving forces in video coding and wireless communication research. Many efforts have been made trying to achieve better video quality and more efficient communication resource utilization in wireless video communication, e.g., [Zhang02], [Zhao02], [Zhang04], [Huang03], [Kim04], [He05].

The demand for video quality needs to be reconciled with the limited communication resources, especially for the currently deployed wideband wireless network, where the practical achievable data rates for video users is still very low. The video coding decisions need to be carefully coordinated with the communication resource allocation to achieve better efficiency.

Pricing has been recently used in allocating resources in wireless networks. Examples of related literature include power allocation in CDMA uplink transmissions [Sara02] and downlink transmissions [Zhang01, Lee02], as well as spectrum sharing models in licensed radio bands [Huang04]. However, most previous work focus on either voice users or rate adaptive data users, and the developed techniques do not apply directly to the case of multimedia wireless communications as considered here.

Under limited communication resource, the optimal video coding problem is very challenging, especially in the low bit rate case as we consider here. Instead of sending all video frames with severe quantization distortions as most previous work did, a better way of solution is through video summarization, [Li05a], [Li05b], i.e., select a subset of video frames that best represent the sequence, and encode them at higher quality than what is possible under a content-blind rate control scheme. We developed a summarization based solution for the interference-limited uplink problem in [Li05c], for low bit rate case.

In the down link wireless video problem with total transmission power constraint, video sources need to make frame selection and coding decisions, base station needs to allocate power function among users such that the total end-to-end user utility is maximized under the power constraint. In this paper, we develop a two-tier solution to achieve this. First, video sources and base station collaboratively find an optimal *average* power allocation for a sliding window on video contents, with distributed video summarization and pricing. Then base station computes the actual power function for each user over the sliding window with content aware joint scheduling.

The paper is organized as follows. In Section 2, we develop the pricing based video summarization –power allocation algorithm that achieves the socially optimal solution. In Section 3, we discuss the packet scheduling problem and develop a water-filling power scheduling solution. Simulation results are presented in Section 4, and we draw conclusion remarks and outline our future work in Section 5.

2. PRICING AND VIDEO SUMMARIZATION FOR POWER ALLOCATION

In a scenario where multiple video traffics are served in the wireless downlink with a total power constraint, instead of provision a constant bit rate channel for each user, which is rather wasteful, multi-user diversity in channel states and video contents can be exploited. The goal is to determine the transmitting power function of each user j, $P_j(t)$, for a time segment, $t_0+[0, T]$, such that the total user utility as received video quality is maximized (i.e., achieve the socially optimal solution). The first step is to compute the average power allocations among video users; this *base station problem* is expressed as,

$$\max_{P_1,P_2,\cdots,P_n} \sum_{j=1}^{n} U_j(P_j), s.t. \sum_{j=1}^{n} P_j \le P_{\max}, P_j \ge 0 \tag{1}$$

where n is the total number of video users, U_j is the utility function for user j, reflecting the utility derived from the video quality received by consuming transmitting power at level P_j for the time window. The utility function is assumed to be continuous, increasing and strictly concave. P_{max} is the total down link power constraint for the video traffic in the current window. The value of P_{max} may change over time to reflect the voice traffic load on the base station, in a typical mixed voice/video traffic scenario. The optimal solution to Eq. (1) can be found by maximizing the Lagrangian,

$$J(\lambda) = \max_{P_1,P_2,\cdots,P_n} \sum_{j=1}^{n} U_j(P_j) - \lambda\left(\sum_{j=1}^{n} P_j - P_{\max}\right), \tag{2}$$

for some optimal non-negative λ. The optimization in Eq. (2) can be achieved in a distributed, iterative fashion by charging each video source a price for its power consumption, λ^i, in iteration i, and let each user solve for the *video source problem*,

$$P_j^i = \max_{P_j} U_j(P_j) - \lambda^i P_j . \tag{3}$$

The utility U_j in this case is defined on the video summarization quality. Let a video segment of n frames be denoted by $V=\{f_0, f_1, \ldots, f_{n-1}\}$, and its video summary of m frames be $S= \{f_{l_0}, f_{l_1}, \cdots, f_{l_{m-1}}\}$, where $m \le n$. At the receiver side, reconstruct the sequence as $V_S' = \{f_0', f_1', \cdots f_{n-1}'\}$ by substituting the missing frames with the most recent frame that is in the summary S. The video summary quality, which is defined as the average distortion caused by the missing frames, is given as,

$$D(S) = \frac{1}{n}\sum_{k=0}^{n-1} d(f_k, f_k') . \tag{4}$$

Therefore, the optimization problem in Eq. (3) is equivalent to finding a video summary, S_j^*, that,

$$S_j^*(\lambda^i) = \arg\min_{S_j} D(S_j) + \lambda^i P(S_j, W, h_j) . \tag{5}$$

for the power price λ^i in current ith iteration. $P(S_j, W, h_j)$ is computed as the average power needed to transmit all video summary frame with bandwidth W and channel state h_j. Eq. (5) can be solved with a Dynamic Programming (DP) solution at video source, more detail can be found in our energy efficient video summarization work in [Li05b].

At the base station, the resulting power requests from video sources for current price are collected, and the new price is computed through a price tatonnement process,

$$\lambda^{i+1} = \max\{0,\ \lambda^i + \alpha[\sum_j P(S_j^*(\lambda^i), W, h_j) - P_{\max}]\} \tag{6}$$

In (6), if the requested power level is larger than the constraint, the price for power is revised up in the next iteration, and vice versa for the case requested power is below the constraint. A proof of the convergence of the price iterations can be found in [Srikant04]. In practice, iteration stops after the total power request is within certain error range of P_{max}. Notice that the computation burdens computing the optimal power levels in Eqs. (5) and (6) are distributed among base station and video sources.

The resulting power level allocations $\{P_j^*\}$ are just an indication of resource consumption level for delivering certain level of utility for each user. The actual transmitting power schedule for each user is computed with the method in Section 3.

3. JOINT POWER SCHEDULING WITH WATER FILLING

The pricing scheme allocates power among video traffics assuming a constant transmitting power, P_j^* for the given segment of time. In practice, since video summary frame packets have different packet size and delivery deadlines, the power function for each user, $P_j(t)$, is not constant, but we need to enforce the total power constraint: $P(t)=\sum_j P_j(t) \le P_{max}$ for all values of t belongs to $t_0+[0, T]$. An energy-efficient packet scheduler is developed next to deliver all packets on time with the total power constraint.

First, we sort the packets of all users in the increasing order of the delivery deadline. For the k-th packet belongs to user j, we denote the packet size, packet arrival time, and deliver deadline as, $\{B_k^j, t_k^j, T_k^j\}$, where $t_k^j < T_k^j$. The scheduler needs to compute a transmitting power function for each user, $Pj(t)$, over the given time window, such that both total power constraint and individual video packet delivery deadline requirements are met.

Then the scheduling is performed using a greedy water-filling power allocation algorithm. Let $P(t)$ be the committed total power function for processed packets so far, then to schedule packet k (from user j), with parameter $\{B_k^j, t_k^j, T_k^j\}$, we look at $P(t)$ in time $[t_k^j, T_k^j]$, and search on a water filling level L, such that the power function available for transmitting packet k is,

$$P_k^j(t;L) = \begin{cases} L - P(t), & t \in [t_k, T_k] \\ 0, & else \end{cases} . \tag{7}$$

The downlink capacity as a function of water filling level L for user j in $[t_k^j, T_k^j]$ can be computed as,

$$B(L) = W\int_{t_k}^{T_k} \log(1+\frac{h_j P_k^j(t;L)}{WN_0^j}) - \log(1+\frac{h_j P_j(t)}{WN_0^j})dt \text{ , (8)}$$

where h_j is the channel state for user j, $P_j(t)$ is the committed power profile for user j before scheduling the current packet k. A fast bi-section search on L can find the correct filling level L_k^* that gives $B(L^*)=B_k^j$. The process is illustrated in the Fig. 1, $P_k^j(t;L)$ is the shaded area bounded by $P(t)$ and L, between t_k^j and T_k^j.

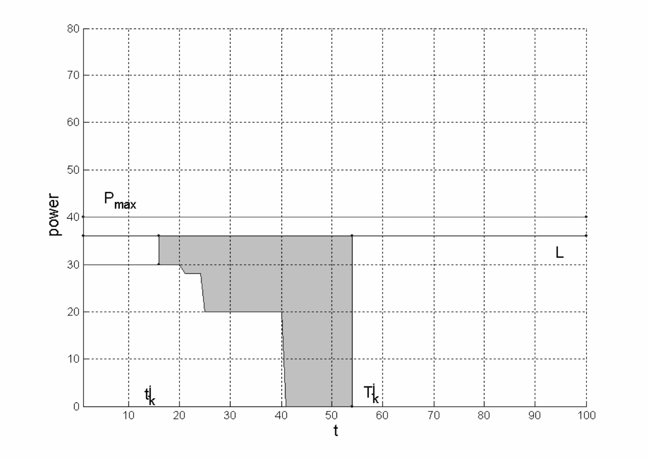


Figure 1. Water filling scheduling example

The algorithm schedules each packet in the order of delivery deadline, until the last packet's power function is computed. Then each user's transmitting power function is computed as,

$$P_j(t) = \sum_{k \in K_j} P_k^j(t; L_k^*) \text{ ,} \qquad (9)$$

where K_j denotes all packet numbers that are from user j. Notice that although the resulting $P_j(t)$'s may not be constant functions, the scheduling tries to utilize as much power as possible within the total power function $P(t)$.

4. SIMULATION RESULTS

To demonstrate the effectiveness of our proposed solutions, we set up a test with 4 different video clips with different content activity levels, and simulate the pricing controlled distributed summarization and packet scheduling.

Clips 1, 2 are segments from "foreman" sequence, frames 150-239, and frames 240-329, while clips 3 and 4 are frames 50-139 and 140-229 from the "mother-daughter" sequence, respectively. The channel gains are also different, given as, H=[0.75, 1.00, 0.80, 0.65]. This choices of channel states and content covers a range of activity levels and reflects diversity in marginal utility w.r.t. to transmitting power consumption, and are plotted in Fig. 2 for all 4 clips. At the summarization-power allocation phase, a total transmitting power threshold of $P_{max}=2.4$ is given, and the social optimal price is found as λ^* =101.45 through the tatonnement process.

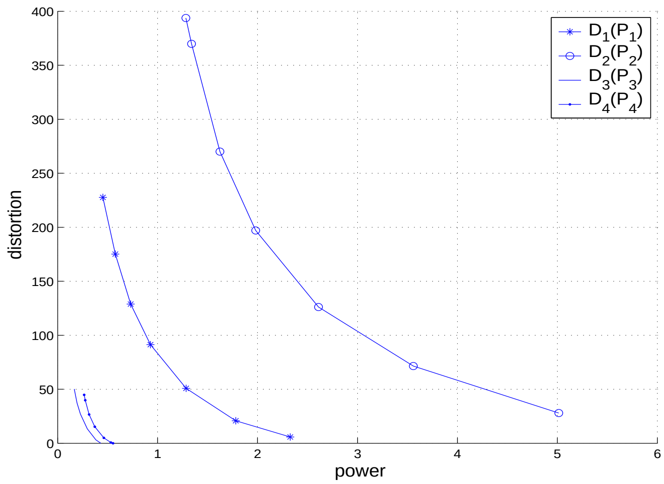


Figure 2. Utility-average power functions for different clips

The resulting video summary distortions are plotted below in Fig. 3. The vertical arrows indicate video summary frame locations in the sequence. The optimal price gives the best trade-off between total transmitting power and total video summary distortion. Clips 1 and 2 are coded at an average PSNR of *27.8dB*, and clips 3 and 4 at *31.0dB*. The resulting average bit rates for 4 clips are *20.1*, *43.3*, *8.1* and *9.4* kbps, respectively.

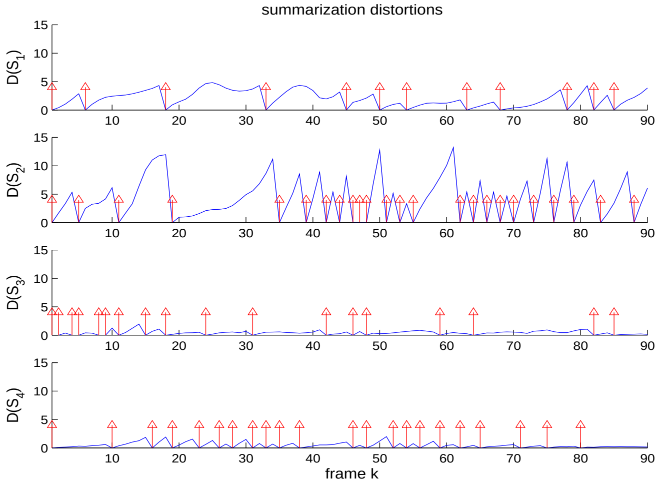
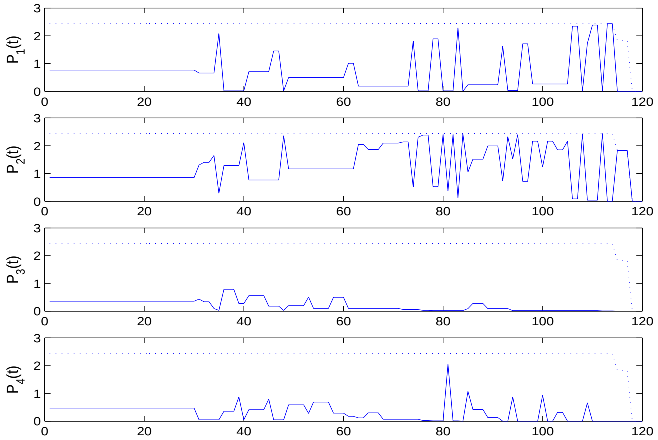


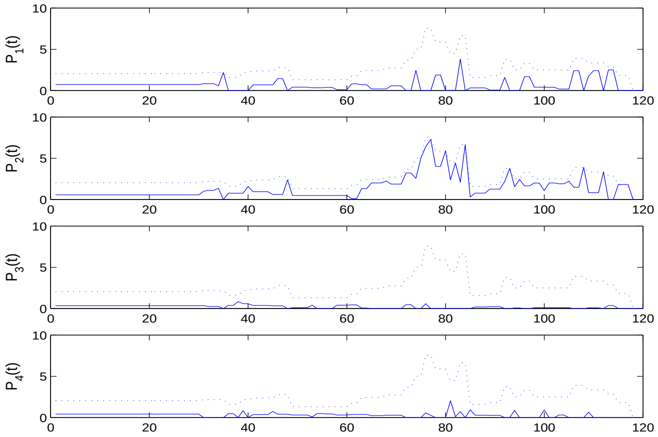
Figure 3. Resulting video summary distortion for P_{max}=2.4

With an initial delay of $t_0=1$ sec, the joint water-filing scheduler achieves a total power limit of $P_{max}=2.45$. There is a slight loss of power efficiency from the summarization-power allocation phase which only considers the average transmitting power.

The power allocation results, $P_1(t)$~$P_4(t)$, for the video summaries generated in Fig. 3 are shown in Fig. 4a. The dotted line are the total power function $P(t)$. Notice that each user's power function is not constant at all but the total power function is rather flat, which achieves better efficiency in utilizing the power available for video. As a comparison, the single user based, earliest deadline first serve (EDFS) scheduling [Li05b] results are plotted in Fig. 4b, which has a max power of P_{max}=7.56.



(a) Joint water-filling scheduling



(b) Single user based scheduling

Figure 4. Packets scheduling results

The pricing operating curve for the total distortion and power constraint P_{max} with summarization-pricing scheme for the 4 clips is also plotted in Fig. 5.

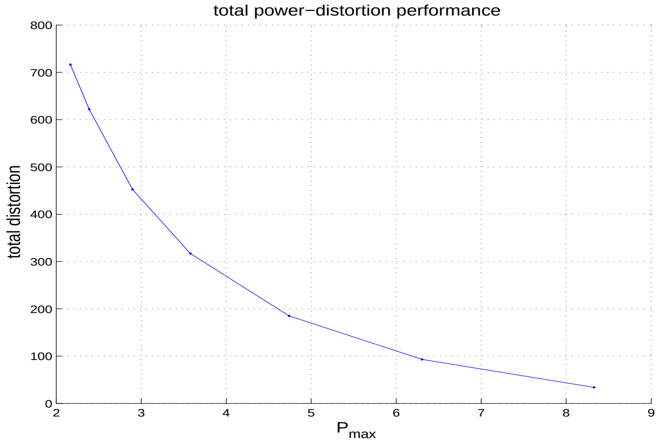


Figure 5. Total distortion-power constraint plot

5. CONCLUSION AND FUTURE WORK

In this paper, we developed a two-tier, distributed, pricing based power allocation and scheduling scheme for downlink video transmissions to achieve efficient communication resource utilization. Video summarization are performed at video sources to achieve good end-to-end video quality at low bit rate. The solution is socially optimal in the sense that it maximizes the total utility among users for the given power constraint. Simulation results demonstrate the effectiveness of the solution. It is suitable for deployment with current wireless infrastructure to serve down link video streaming with mixed voice/video traffic.

In the future, we plan to further improve the scheduling algorithm by considering delay tolerance and delay induced distortion modeling.

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