Downlink VBR Video Scheduling in Cellular Networks with Orthogonal Channels

Shiwen Mao, Yingsong Huang, and Yihan Li, Auburn University, Auburn, AL, USA
smao@ieee.org, yzh0002@auburn.edu, yli@auburn.edu

1. Introduction

With the wide availability of intelligent handheld devices and smart phones, there is a compelling need to support video in traditional cellular networks. Video applications not only are bandwidth intensive, but also involve user quality of experiences. It is foreseeable that the capacity of traditional cellular networks will be greatly stressed, while joint design and optimization of networking and control mechanisms across multiple layers would be necessary.

Among various forms of compressed video, *variable bit rate* (VBR) videos can offer constant and better quality over constant bit rate (CBR) videos given the same bit budget; a highly desirable feature for video applications. However, VBR videos also pose great challenges to network scheduling and control, due to the high variability and complex autocorrelation structure in VBR video traffic [1].

In an interesting work [2], Salehi, et al. applied majorization [3] to VBR video smoothing and developed a smoothness optimal algorithm, assuming a constant rate channel. In [4, 5], the authors study the problem of VBR video over wireless channels, both focusing on one VBR stream over a given time-varying wireless channel. In our prior work [6], we investigate the problem of supporting multiple VBR videos in a multi-cell network, where capacity is limited by inter-cell interference. We develop a reformulation-linearization technique (RLT) approach as well as a distributed algorithm based on dual decomposition.

In this work, we focus on the downlink of a cell with orthogonal channels, where the base station (BS) streams multiple VBR videos to mobile users in the cell. We consider buffer underflows (causing stalled display) and overflows (causing missing frames and error propagations in the following received and decoded frames) as user viewing performance measure, and aim to minimize the total power consumption at the BS.

In particular, we adopt a deterministic model for VBR video traffic that incorporates video frame and playout buffer characteristics, and formulate a *constrained stochastic optimization* problem. We show that the problem fits well with *majorization theory*, which concerns with partial ordering of real vectors and order-preserving functions [3], and develop a majorization-based solution framework.

For the case of a single VBR video session with relaxed peak power constraint, a power optimal algorithm with low complexity is developed. We prove the power optimality of the proposed algorithm and the uniqueness of the global optimum, and demonstrate that the proposed algorithm is also smoothness optimal. For the case of multiuser VBR video streaming, we develop a heuristic algorithm that selectively suspends some video sessions when the peak power constraint is violated. The proposed algorithms are evaluated with trace-driven simulations, and are shown to achieve considerable power savings and improved video quality over a conventional "lazy" scheme.

The remainder of this letter is organized as follows. In Section 2, we introduce the system model and problem formulation. The main results are summarized in Section 3. Section 4 concludes this letter.

2. System Model and Problem Formulation

We consider the downlink of a cellular network. There are N mobile users in the cell. A BS streams multiple VBR videos to the mobile users. Each user occupies a downlink channel, which is a spectral/time resource slot, the nature of which depends on the specific multiple access technique adopted. We assume that the downlink channels within a cell are orthogonal, due to perfect synchronization of the spreading codes or the use of guard times or frequencies.

We adopt a *deterministic model* for VBR videos that considers frame sizes, frame intervals, and playout buffers [2]. Let $D_n(t)$ denote the *cumulative consumption curve* of the n-th user, representing the cumulative amount of bits consumed by the decoder at time t. Given the playout buffer size b_n, we can derive a *cumulative overflow curve* for user n, $B_n(t)$, which is the maximum number of bits that can be received at time t without overflowing user n's playout buffer. Finally, we define *cumulative transmission curve* $X_n(t)$ as the total amount of bits

transmitted to user n at time t. The three curves are illustrated in Fig. 1.

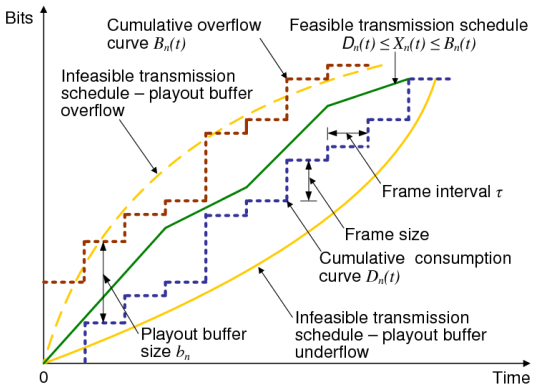


Fig. 1 Deterministic model for VBR video scheduling.

Generally $X_n(t)$ is a piece-wise linear curve. For a linear segment, its slop is the transmission rate for that period of time, which depends on the signal-to-noise ratio (SNR), or, the BS transmit power allocation to the session. A feasible transmission schedule should cause neither playout buffer underflow nor overflow, i.e., satisfying $D_n(t) \le X_n(t) \le B_n(t)$, for all t, n.

Therefore, the problem is to find the optimal feasible transmission schedules $\{X_n(t), 0 < t \le T_n\}$, for each user n, such that the total transmit power consumption can be minimized. We then formulate a *constrained stochastic optimization problem*, to minimize the expectation of the total transmit power under buffer underflow, overflow and peak power constraints [7].

3. Main Results

We find the formulated problem fits well with majorization theory, which provides order preserving results for inequality problems [3]. With such an interpretation, the problem is to find a rate vector that is majorized by all other feasible rate vectors.

We first prove that the objective function of the formulated problem is *Schur-convex* with the order-preserving property [3]. Secondly, we investigate the case of a single VBR video session with relaxed peak power constraint, for which a majorization-based power optimal algorithm with low complexity is developed. We prove the *power optimality* of the proposed algorithm and the *uniqueness* of the global optimum. In addition, we demonstrate that the proposed algorithm is also optimal with respect to smoothness [2].

Thirdly, we investigate the case of multiuser VBR streaming, where power allocations for the users are coupled with the peak power constraint. We develop a heuristic algorithm that selectively suspends some video sessions, which will not incur underflow in the next time slot, when the peak power constraint is violated.

The proposed algorithms are evaluated with trace-driven simulations, using VBR video traces from the Video Trace Library at Arizona State University, and are shown to achieve considerable power savings over a conventional "lazy" scheme. This finding is somewhat *counter-intuitive*, since the lazy scheme seems to be energy efficient by only transmitting the minimal amount of video data in each time slot.

Interested readers are referred to [7] for details.

4. Conclusions

In this paper, we studied the problem of downlink multiuser VBR video streaming in cellular networks. We formulate a constrained stochastic optimization problem aiming to minimize the BS power consumption and to avoid playout buffer overflow or underflow. We developed majorization-based algorithms to solve the formulated problem. The superior performance of the proposed algorithms over a conventional scheme is validated with trace-driven simulations.

Acknowledgment: This work is supported in part by the US National Science Foundation (NSF) under Grants CNS-0953513, ECCS-0802113, and IIP-1127952. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the foundation.

References

[1] M. W. Garrett and W. Willinger, "Analysis, modeling and generation of self-similar VBR video traffic," *ACM SIGCOMM Comput. Commun. Rev.*, vol.24, no.4, pp.269–280, 1994.

[2] J. Salehi, Z.-L. Zhang, J. Kurose, and D. Towsley, "Supporting stored video: reducing rate variability and end-to-end resource requirements through optimal smoothing," *IEEE/ACM Trans. Networking*, vol.6, no.4, pp.397–410, Aug. 1998.

[3] A. W. Marshall and I. Olkin, *Inequalities: Theory of Majorization and Its Applications*. New York, NY: Academic Press, 1979.

[4] T. Stockhammer, H. Jenkac, and G. Kuhn, "Streaming

video over variable bit-rate wireless channels," *IEEE Trans. Multimedia*, vol.6, no.2, pp.268–277, Apr. 2004.

[5] G. Liang and B. Liang, "Balancing interruption frequency and buffering penalties in VBR video streaming," in *Proc. IEEE INFOCOM'07*, Anchorage, AK, May 2007, pp.1406–1414.

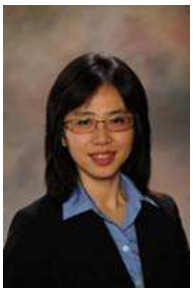
[6] Y. Huang and S. Mao, "Downlink power control for variable bit rate video over multicell wireless networks," in *Proc. IEEE INFOCOM'11*, Shanghai, China, Apr. 2011, pp.2561–2569.

[7] Y. Huang, S. Mao, and Y. Li, "Downlink power control for VBR video streaming in cellular networks: A majorization approach," in *Proc. IEEE GLOBECOM'11*, Huston, TX, Dec. 2011.

Shiwen Mao (S'99-M'04-SM'09) is an Associate Professor in the Department of Electrical & Computer Engineering at Auburn University, Auburn, AL. Before joining Auburn University, he was a research scientist with Virginia Tech from 2003 to 2006 and Polytechnic Univesity in 2006. His research interests include cross-layer design and optimization of wireless networks and multimedia communications, with current focus on cognitive radio networks, 60GHz mmWave networks, and free space optical networks.

He is on the Editorial Board of *IEEE Transactions on Wireless Communications* and several other journals. He chairs the Interest Group on Cross-layer Design for Multimedia Communications under IEEE Communications Society's *Multimedia Communications Technical Committee*. Dr. Mao received the NSF *CAREER Award* in 2010 and the 2004 *IEEE Communications Society Leonard G. Abraham Prize in the Field of Communications Systems*.

Yingsong Huang received the B.S. and M.S. degrees from Chongqing University, Chongqing, P.R. China, in 2000 and 2003, respectively. From 2003 to 2007, he joined Advantech Co., Ltd. R&D center, Beijing Branch, P.R. China. Since 2007, he has been a graduate student pursuing Ph.D. degree in the Department of Electrical and Computer Engineering, Auburn University, Auburn, AL, USA. His research interests include network congestion control and video communications.



Yihan Li received the Ph.D. degree in Electrical and Computer Engineering in 2004 from Polytechnic University, Brooklyn, NY in 2000. Currently, she is a Visiting Assistant Professor in the Department of Electrical and Computer Engineering, Auburn University, Auburn, AL. She was a Research Scientist in the Department of Electrical and Computer Engineering at Polytechnic University from 2004 to 2006, and a postdoctoral fellow in the Department of Electrical and Computer Engineering at Auburn University from 2006 to 2009. Her research interests include Scheduling in wired and wireless networks, wireless ad hoc networks and high-speed packet switching.