Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Computer Communications 29 (2006) 1917–1926
computer communications
www.elsevier.com/locate/comcom

# An opportunistic video scheduling algorithm over shared wireless downlink

Junhua Tang *, Liren Zhang, Chee-Kheong Siew

*School of Electrical and Electronic Engineering, Nanyang Technological University, Nanyang Avenue, Singapore 639798, Singapore*

Received 16 March 2005; received in revised form 7 October 2005; accepted 19 October 2005
Available online 28 November 2005

**Abstract**

This paper presents a novel video scheduling algorithm for streaming MPEG video over multi-user shared wireless link, in which video sessions are scheduled based on both location-dependent channel condition and instantaneous frame delay. This algorithm also employs a pro-active frame discard mechanism to discard potential problematic frames. The numerical results show that the proposed algorithm is able to significantly improve link throughput and guarantee long-term fairness.


*Keywords:* Opportunistic scheduling; Video streaming; Wireless downlink

## 1. Introduction

The transmission of variable bit rate (VBR) video packets imposes great challenges to the wireless network infrastructure, where the wireless link typically has limited bandwidth and relatively high bit error rate [1]. In this context, video scheduling is particularly important to make efficient use of the limited wireless bandwidth to provide quality of service (QoS).

In the domain of video scheduling in wireless networks, Refs. [2–6] are some of the works reported in the literature. In [2], a priority round robin scheduling with dynamic reservation update and error compensation is proposed for wireless ATM network to allocate time slots to a mixture of constant bit rate (CBR), variable bit rate (VBR), and unspecified bit rate (UBR) traffic. Limitation of this work is that channel condition is not explicitly considered in determining the service order of connections, which results in low link throughput. In [3], a set of scheduling schemes are presented for multimedia traffic in wireless ATM network, to allocate time slots to virtual circuits carrying CBR, real-time VBR, and non-real-time VBR traffic. However, the scheduling (slot allocation) is mainly based on traffic characteristics, e.g., traffic type, system traffic load, time of arrival, time of expiry, and burst length, without explicit consideration of channel condition. Liu e al. [6] presents an optimal channel allocation algorithm for layered video broadcasting over cellular networks with the objective to maximize a defined utility, where the receivers' interests and bandwidth are assumed to be stationary and available by long-term statistics. In [5], two scheduling policies, namely Shortest-Queue-Oriented-OFDM-TDMA(SQOOT) and Shortest-Processing-Time-Oriented-OFDM-TDMA(SPTOOT) are proposed for scheduling MPEG-4 video over OFDM-TDMA wireless downlink [7]. For both policies, the access point maintains a separate queue for each wireless terminal. In SQOOT, the shortest queue has the preference to transmit its data because it is expected that it needs the shortest time so that the delays for other wireless terminals can be kept small. In SPTOOT, the scheduler checks the queues and current channel states of all active wireless terminals and calculates the processing time needed for the remaining data of the wireless terminals. The preference for transmitting data is then given to the wireless terminal with the shortest processing time.

* Corresponding author. Tel.: +65 6790 4509; fax: +65 6792 2971.
*E-mail address:* ejhtang@ntu.edu.sg (J. Tang).

0140-3664/$ - see front matter 
doi:10.1016/j.comcom.2005.10.021

This paper proposes a video scheduling algorithm with joint consideration of time variant channel condition and instantaneous frame delay over a multi-user shared wireless downlink. The proposed opportunistic video scheduling algorithm (OVSA) consists of three parts: (1) an exponential scheduling rule that dynamically determines the service order of video sessions based on both user observed channel condition and the frame delay, (2) a pro-active frame discard mechanism that discards video frames before they are transmitted if the expected delivery time of the frames is later than the play back time, and (3) an adaptive rule for scalable videos to manage the long-term throughput of individual video sessions in an effort to guarantee the long-term fairness among competing sessions. The performance of OVSA is evaluated using real-life MPEG traces, and the results have demonstrated that OVSA can significantly improve link throughput compared with approaches without channel-aware scheduling, while guaranteeing long-term fairness to competing sessions.

## 2. Problem definition

Considering a packet cellular network, in which the base station performs the scheduling of video packet transmissions for $M$ mobile hosts randomly located in the cell. Host $i(i \in \{1, 2, \ldots, M\})$ has an established connection denoted as session $i$, over the downlink from base station to the mobile host. The transmission time of the downlink is divided into fixed-duration slots [8]. For time slot $t$, define $X_i(t)$ as

$$X_i(t) = \begin{cases} 1, & \text{slot } t \text{ is assigned to session } i, \\ 0, & \text{otherwise.} \end{cases} \tag{1}$$

Transmission cost $\upsilon_i(t)$ is defined as the cost to transmit a data unit to mobile host $i(i \in \{1, 2, \ldots, M\})$ at time slot $t$. Hence lower "transmission cost" represents better channel quality. For example, the transmission cost can be defined as the length of code in variable coding systems or the transmission power in a CDMA system. Therefore, the total transmission cost of the downlink after $N$ time slots can be written as

$$\kappa(N) = \sum_{t=1}^{N} \sum_{i=1}^{M} X_i(t)\upsilon_i(t). \tag{2}$$

Clearly, the minimization of total cost $\kappa(N)$ is an important objective of wireless scheduling algorithms. However, this may affect the QoS for video streaming over wireless link, since minimization of $\kappa(N)$ may pose prolonged delay on video packet, which subsequently results in high discarding ratio of video packets at the receiver end. Therefore, video scheduling algorithm must also take into account video packet throughput in terms of the number of video packets that are successfully delivered and played back at the receiver end in a second.

As shown in Fig. 1, in the video server, pre-stored video frames are sequentially numbered. At the receiver, video sequence is played back at a fixed rate $1/T$ frames per second, where $T$ is the playback time of a frame. Since the channel quality over the wireless link is a variable and the frame size in MPEG video is also a variable, each frame may use different number of time slots to be transmitted over the downlink, which introduces variable delay at the receiving mobile host. To absorb such variable delay, a playback buffer with a space of $B$ frames is required at the receiver end. A video frame may be discarded due to the following two reasons: (1) the playback buffer overflows and (2) the video frame arrival time is behind the playback time due to prolonged delay. Thus, $b_i(k)$ is defined as a 0–1 variable to indicate whether the $k$th frame of flow $i$ is successfully delivered and played back, that is

$$b_i(k) = \begin{cases} 1, & \text{if frame } k \text{ issuccessfully played back} \\ & \text{at the receiver,} \\ 0, & \text{otherwise.} \end{cases} \tag{3}$$

Then the total video packet throughput over the wireless link is given as

$$\beta = \frac{\sum_{i=1}^{M} \sum_{k=1}^{K_i} b_i(k)}{N'}, \tag{4}$$

where $K_i$ is the total number of frames in flow $i$, and $N'$ is the total number of time slots taken to transmit all the video frames. In this case, the video scheduling algorithm is expect-

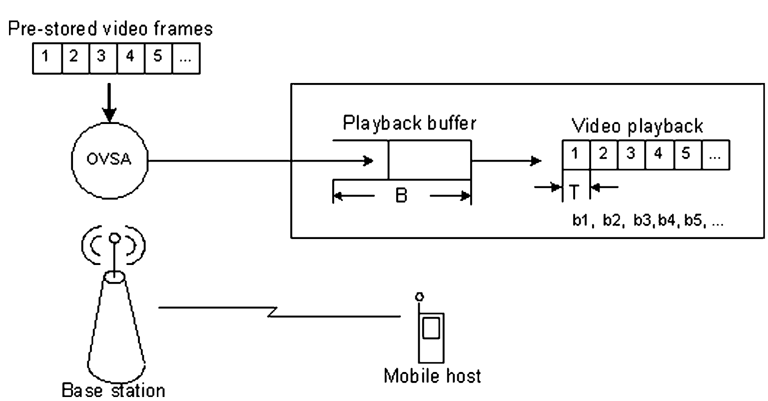


Fig. 1. Video buffering and playback at the mobile host.