UTILITY-DRIVEN DISTRIBUTED TRANSMISSION COORDINATION FOR VIDEO COMMUNICATIONS OVER AD HOC WIRELESS NETWORK

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ABSTRACT

Video is becoming the dominant traffic over the wireless networks. Given the limited wireless resources, supporting multi-user video streaming with good video playback quality-of-service (QoS) is very challenging. The key difficulties involve providing good playback quality while also satisfying the stringent video packet delay bounds. The allocation of wireless resources need to be efficient and coordination of mobile video users should have a distributed fashion. In this paper we present a distributed framework for multi-user video streaming over an ad-hoc 802.11 like networks. The proposed algorithm is based on a utility-driven scheme that adjusts the video users' sending rates according to APP layer video buffer status. Simulation results demonstrate that the proposed scheme is quite efficient on radio resource while have better QoS than content blind 802.11 DCF scheme.

Index Terms— Cross-Layer Optimization, Video Streaming, Video QoS

1. INTRODUCTION

With the fast development of wireless technologies and the increasing popularity of multimedia capable mobile devices, mobile video applications are becoming popular and are now account for half of the total global mobile data [13]. There are many open problems for the QoS provision of mobile video applications, one of which is to support efficient video streaming over wireless ad-hoc networks [8][9].

One major issue underlying the video transmission is the freezing problems, i.e., the playback buffer at the receiver does not have enough content to play at a particular moment. This problem is especially challenging to deal with in wireless networks due to limited and time varying network resource. One promising yet under-explored approach in this context is to exploit the heterogeneity of video streaming sessions' rate-distortion characteristics, and achieve a good balance within the whole system. For example, we can allocate less resource to relatively static video sequences and more resources to busier sequences. We have developed such a scheme in [3] for the wireless multi-access network.

In addition, it is desirable to have a distributed coordination scheme among multiple video transmissions over the same wireless network. In wireless local area network (LANs Lawns)[5], the Distributed Coordination Function (DCF) scheme of IEEE 802.11 standard coordinates the transmissions of different users via the adaptive backoff window control. This approach ensures certain fairness among the wireless users, but does not take the application layer video QoS requirements into consideration. A busy video session will not get any priority in the 802.11 standard and will more likely to incur the freezing problem due to limited receiver buffer.

In this paper, we propose a new Utility Coordination Function (UCF) based scheme that can improve the system performance in the current DCF of the 802.11 standard.

The paper is organized as follows. In Section 2, we review the related work of wireless video transmissions and the DCF mechanisms. In Section 3, we introduce the network model and users' utility functions, and then develop the distributed UCF algorithm. Numerical examples and comparison between the DCF and UCF solution are presented in Section 4. Finally we summarize our results and discuss the future work in Section 5.

2. RELATED BACKGROUND WORK

2.1. Wireless Video Communications

Multimedia transmission over wireless is becoming a key research field in video coding and networking. Researchers have proposed various joint source and coding schemes based on information theory to address the challenges in wireless communications. These efforts have strongly influenced the H.264 video coding standard [6]. On the other hand, there does not yet exist a unified framework of addressing the QoS problem of multi-user multimedia communications in wireless networks [2].

Recent results demonstrated that it is feasible to support both high data-rates and low delays of multimedia over wireless network [8][9]. For ad-hoc communications, however, research on video streaming is still at the beginning period, especially a cross-layer optimization design. Recently people have stated to look at a cross-layer design approach of video streaming over wireless ad-hoc networks.

Most recent research focused only on joint optimization. It is proposed in [8] to jointly look at path diversity and video coding. In another cross-layer proposal [9], the source, channel coding, and MAC layer retransmissions are jointly and optimally designed. Power and flow are allocated through convex optimization in [12]. MAC layer scheduling combine the above proposed in [11]. Much research still to be proposed along these directions to identify and exploit optimization and cross-layer interactions in real-time video streaming over ad-hoc wireless networks.

2.2. 802.11 DCF Algorithm

The DCF is a distributed random access scheme based on the Carrier Sense Multiple Access with Collision Avoidance (CAMS/CA) protocol. The basic operational mode in DCF is known as the two-way handshaking. A transmission station first senses the channel for at least a Distributed Inter Frame Space (DIFS) time. If there is no other node transmitting during this time, the station will transmit the Request to Send (RTS) and wait for a Short Inter Frame Space (SIFS) time. If the corresponding receiver station successfully receives a packet, it will send out a Clear to Send (CTS) to the transmission station.

In DCF mechanism, each user needs to wait a random selected back-off time after DIFS, before attempting to transmit. Each station competes to access to the medium by selecting a random number from their own contention window (CW). The resource will be allocated to the user whose random number is smallest among all the users. In this situation, all the users are treated equally.

The DCF may not work well when users have a different QoS requirement. For example, a user with a higher video streaming rate (playback rate) will have a smaller remaining buffer time, as the time passes by under the DCF scheme, and thus is likely to freeze [10].[1] One way to resolve this issue is to allocate resources to users based on their remaining playback time. This motives our utility driven algorithm in the next section.

3. UTILITY-BASED SCHEDULING ALGORITHM

3.1. User's utility functions

Consider a wireless network with n video sessions (users). Each video session consists of a transmitter and receiver pair. Session k's buffer state at its receiver can be characterized as follow,

[1]Here the remaining time is calculated by the remaining bits in the playback buffer divided by the playback rate.

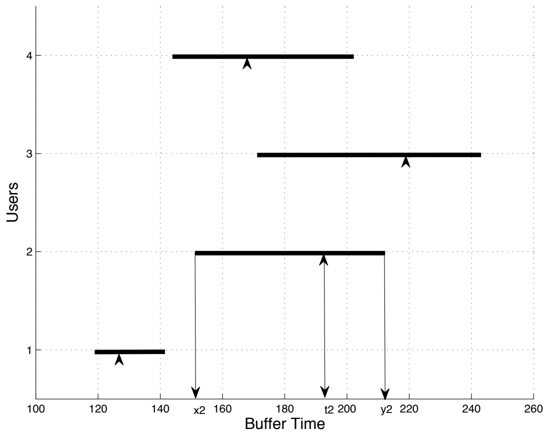

Fig. 1. Four video users buffer states

$$M_k = \{x_k, t_k, y_k\} \quad (1)$$

where x_k is the buffer content starting time stamp, y_k is ending time stamp, and t_k is the current playback time stamp. The remaining buffer time τ_k is calculated as $\tau_k = y_k - t_k$. Figure 1 shows the video buffer playback states for four users, where we mark the corresponding values for user 2 as well as the current playback segment t_k for each user.

Each user has a utility function which is increasing and concave in the remaining playback time t_k. In this problem, we will maximize an increasing function of the remaining playback time for each user k, the remaining time t_k of all users, which will lead to the same remaining playback time for all users,

$$\tau_k = S_k/\beta_k \quad (2)$$

where S_k and β_k are the remaining bits of user k's buffer and video rate of user k, respectively. Our goal is to maximize the total utility of all users.

Intuitively, a user with a smaller τ_k should be allocated more resources, since it has a higher urgency in preventing buffer underflow (freezing). To achieve this goal, we propose to use the a-fair utility function [7] to represent the performance of each user k,

$$U_k(\tau_k) = \frac{\tau_k^{1-\alpha}}{1-\alpha}, 0 < \alpha < 1. \quad (3)$$

Several utility curves with different value of α are plotted in Fig. 2. From the figure we can see that the utility curve is concave when $0 < \alpha < 1$. The gradient of utility is decreasing in τ_k, i.e., a higher utility indicates a smaller τ_k and thus a higher priority. Based on this, we develop a distributed backoff window based coordinating scheme that reflects the gradient by the backoff window size.

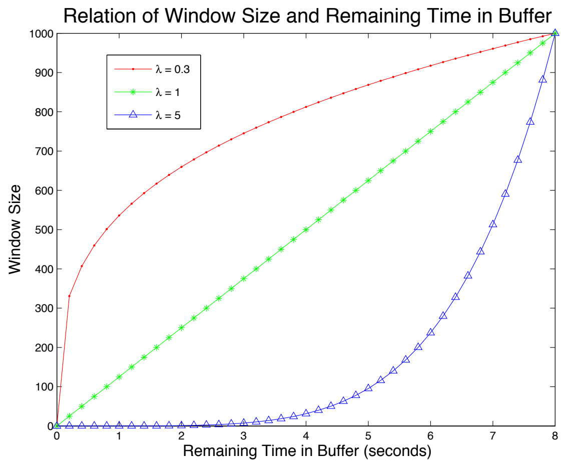

Fig. 2. Back off window size as function of buffer time

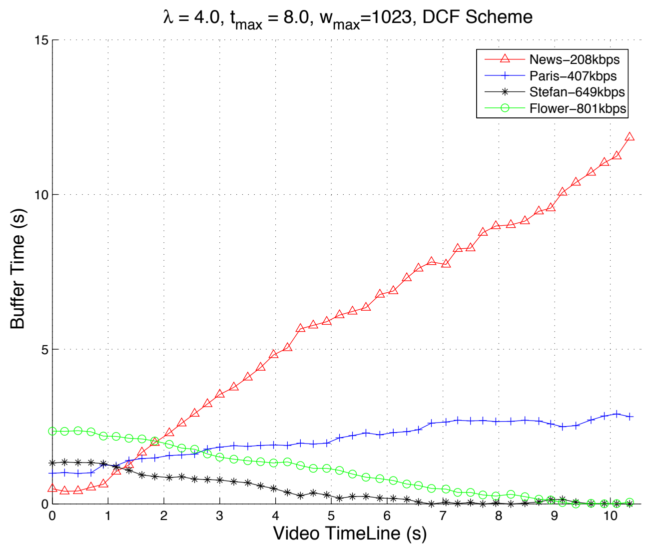

Fig. 3. Four users simulation for DCF mechanisms

3.2. Gradient-based Distributed Scheduling

The gradient of user k's utility is given by,

$$U_k'(\tau_k) = \frac{\partial U_k(\tau_k)}{\partial \tau_k} = \tau_k^{-\alpha}, 0 < \alpha < 1 \quad (4)$$

In the gradient-based scheduling algorithm, we will allocate the transmission rates proportional to the utility gradient, i.e.,

$$R_k = \beta R_0 \tau_k^{-\alpha}, \beta = \sum_k R_k / R_0 \quad (5)$$

Here R_k is the sending rate for user k, R_0 is the WiFi system raw data rate, β is the normalizing factor. Based on the value of R_0, there are two different cases in this problem: normal case and under serve. The system will be in a normal case when the raw data rate is equal or larger than the total consumption by all the users in the network, and there will be no freezing problem in this situation. When the raw data rate is less than the users' total consumption rate, we call it under serve and every user will finally freeze.

The backoff buffer window size can be calculated based on user's transmission rate by a negative exponential transformation as Eq. (6):

$$W_k = (R_k)^{-\theta}, \theta > 0 \quad (6)$$

By replacing the R_k with Eq. (5) and introducing a scaling factor, the backoff window size for video flow k is given as

$$W_k = (\beta R_0)^{-\theta} \tau_k^{\alpha\theta} = (\beta R_0)^{-\theta} \tau_k^{\lambda} \quad (7)$$

where the exponent $\lambda = \alpha\theta$. We call name this rate allocation scheme as the Utility Coordination Function (UCF) scheme.

Compared with the content-blind DCF scheme, our proposed UCF scheme allocates the resource by taking heterogeneous video contents into consideration.

The parameters of the UCF scheme are chosen similar to the DCF scheme as shown in Table. 1. The only difference is in terms of the computation of the backoff window size as in Eq. (7).

The mapping of the buffer time to the backoff window size need to be normalized in the actual implementation to reflect the system parameters, i.e., the maximum backoff window size and the system rates for the video.

The UCF scheme works as follows. First, the backoff window size for each video source k is chosen according to Eq. (7). Then a user k will choose a random integer backoff counter from the interval [1,W_k] with a uniform distribution. Different users choose their backoff counters independently. All users will perform countdown simultaneously (i.e., decrease by value one in each mini-slot [1]) until one of the users reaches zero in the counter. If user k reaches zero first and when the channel is sensed idle, it obtains the transmission opportunity and starts to send data packets. After a successful transmission, the buffer of the user who gets the transmitted data increases and buffer size for the others reduces during the transmission time. Noted that the amount of this increment and decreasing may not be equal with each other. All users will update their buffer states and recompute the utility gradients as in Eq. (4). According to Eq. (7), a higher utility gradient leads to a smaller W_k and thus a larger transmission probability. In this way, the most urgent user will have the highest probability of successfully accessing the channel.

The collision resolution is another issue in practice in this

Table 1. MAC Layer Timing Parameters

Parameters	Value
Slot Time(μs)	9
SIFS(μs)	16
DIFS(μs)	34
CW_{min}	15
CW_{max}	1023
ACK(μs)	44
R_0(Mbit/s)	2

Table 2. Initial Information of Four Sessions

User ID	Video	Rates	Buffer(s)
1	NewsCIF@15Hz	208kbps	0.5
2	ParisCIF@15Hz	407kbps	1
3	StefanCIF@15Hz	649kbps	1.25
4	FlowerCIF@15Hz	801kbps	2.1

problem. It is possible that more than one user reach zero simultaneously and then cause collision. DCF scheme resolves this issue by doubling the contention window for all users involved in the collision. We will adopt a similar approach in the proposed UCF scheme. If theres a collision, the size of the contention window of each user involved in the contention will be doubled in the next time slot. Let us denote the current window size of user k as W_k, then the new window size is

$$W'_k = min(2(W_k - 1) + 1, CW_{max}) \tag{8}$$

We also use m to denote the maximum backoff stage, which can be obtained by solving the following equation,

$$CW_{max} = 2^m \times (CW_{min} + 1) - 1 \tag{9}$$

After each successful transmission, W_k is reset by Eq. (7) for the new transmission attempt.

4. SIMULATION RESULTS

4.1. Simulation Set-up

In this section, we demonstrate the effectiveness the proposed UCF scheme. TWe choose the system parameters as in Table 1.

By taking into consideration of some background traffics and overhead, we are having total rates of R_0 for the four video sessions in Table. 1. The four users are running 4 different video sequences with different rate-distortion characteristics simultaneously over the same 802.11 air interface at the same time. Video parameters are shown in Table 2.

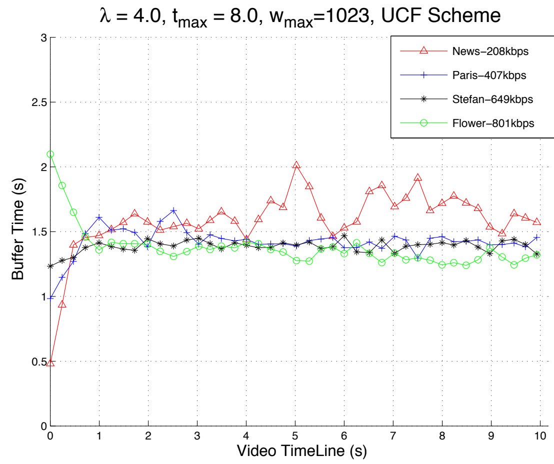

Fig. 4. Four users simulation for UCF mechanisms

Table 3. Transmission Results for DCF Mechanisms

User ID	Video	τ_k (s)	Freeze Time(s)
1	NewsCIF@15Hz	11.81	0
2	ParisCIF@15Hz	2.94	0
3	StefanCIF@15Hz	0	6.77
4	FlowerCIF@15Hz	0	9.37

4.2. Results and PSNR Comparison

We first simulate the performance of the four video sessions using the DCF scheme, as shown in Fig. 3. The total simulation time is 10 seconds.

The corresponding buffer content status evolutions are shown in Table 3. The DCF scheme is content-blind and therefore the rates allocated over time are approximately equal to all users. Due to different video rates for the four sessions, the ”stefan” video goes into freeze after 6.77 seconds and the ”flower” sequence goes into freeze at 9.37 seconds. Meanwhile, the ”news” video user obtains more resource than needed, and thus the video content buffered increases rapidly. This does not further improve its streaming quality but leads to a waste of the system resource and potential buffer overflow.

For comparison, we simulate the same video sessions with the proposed UCF scheme. The resulting video buffer states evolutions are plotted in Fig. 4. The UCF scheme updates the backoff window size every 20ms, and the resulting window size leads to a sending rate allocation that reflects the urgency in playback buffer status. Notice that in this case, the playback buffer converges within 2 seconds, and the lower bit rate sequence news’s buffer time kept at a much smaller value than the one under DCF in Fig. 3, while high bit rate sequences such as the flower’s receive enough resource allo-

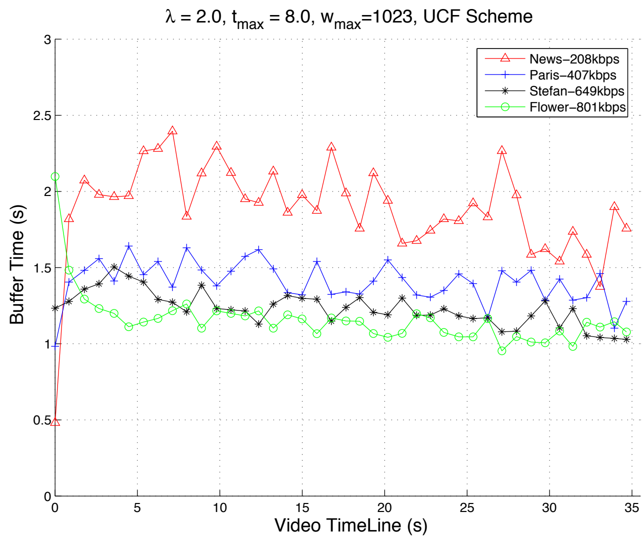

Fig. 5. Four users simulation for under-served Situation by DCF

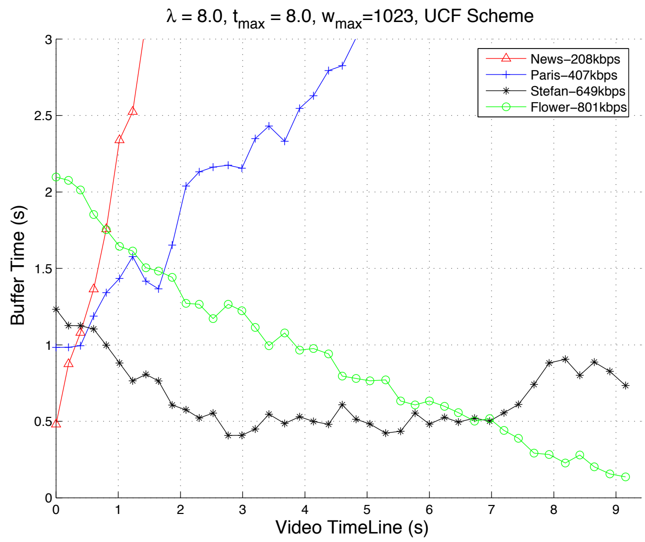

Fig. 6. Four users simulation for under-served Situation by UCF

cation and do not incur repeatedly underflow. It is clear that the proposed UCF scheme works well with 4 video sessions. The proposed backoff window control also works fine with exponent $\lambda = 4.0$ and max buffered video content size of $t_{max} = 8$ seconds. The value of λ is also tested in our simulation. Figure 5 and 6 give an example of selecting too small and too large λ. When the value is too small, the convergence will not be that good, compared with proper λ. There will be no convergence if the λ is too large since the utility is too sensitive to the buffer content.

Next we study the under-serve case, where the system raw data rate is below the total video rates. In this case, all users will eventually freeze no matter which scheduling algorithm to use. Figures 7 and 8 illustrate the performance under the DCF and UCF schemes, respectively. The UCF achieves a better performance as it incurs buffer underflow as a later time.

UCF scheme provides a smaller time scale distributed wireless resource allocation among video sessions, without the need to exchange information among video users or to a centralized coordinator. At a larger time scale, some limited exchange of information on the rate-distortion characteristics among video sessions can lead to much better rate-distortion performance than totally content blind DCF as well. This is illustrated in the Table 4. Without the exchange of information, DCF only allocates approximately the same rates among the video users, this can only achieve certain video PSNR quality which is suboptimal. Given the fact that the rate-distortion (R-D) characteristics are known, a resource pricing scheme [3] that searches on the slope of the R-D functions, can actually leads to an optimal rate allocation among video users.

Table 4. UCF and DCF PSNR Comparison

User	Video	$PSNR_U$(dB)	$PSNR_D$(dB)
1	NewsCIF@15Hz	39.84	36.86
2	ParisCIF@15Hz	36.22	36.17
3	StefanCIF@15Hz	35.71	33.94
4	FlowerCIF@15Hz	36.06	32.57

This serves as the session initialization set up and coupled with UCF, we can achieve better PSNR qualities w.r.t to the DCF schemes as well, in addition to avoiding buffer underflow.

In TABLE 4, the first two video sequences achieve the similar PSNR in both schemes. In fact, both sequences obtain more resources under the DCF scheme, but the streaming quality can not be further improved with the excessive resource allocation. Users 3 and 4 achieve significant performance increase in the proposed UCF scheme due to content-aware utility driven resource allocation. The PSNR improvements compared with the DCF case are 1.75 dB and 1.49dB, respectively.

5. CONCLUSION AND FURTHER WORK

In this paper, We proposed a content aware distributed wireless resource allocation scheme called UCF for supporting video streaming applications over the popular 802.11 networks. The solution is computationally efficient and can be easily extended from the existing DCF schemes. It provides better QoS guarantee on buffer underflow and coupled with an

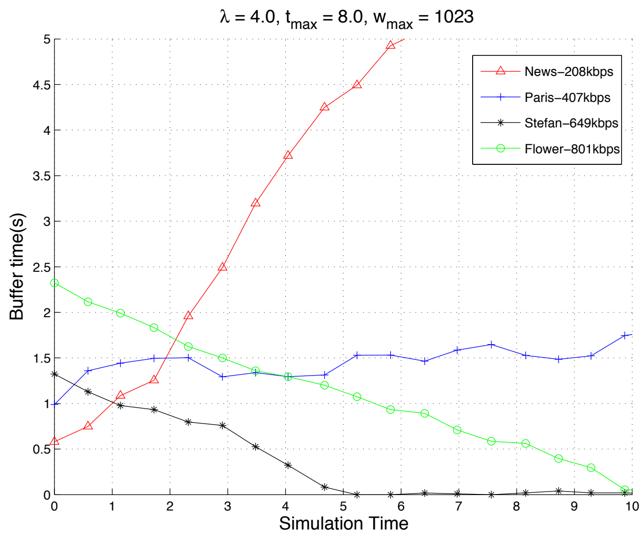

Fig. 7. Four users simulation for under-served Situation by DCF

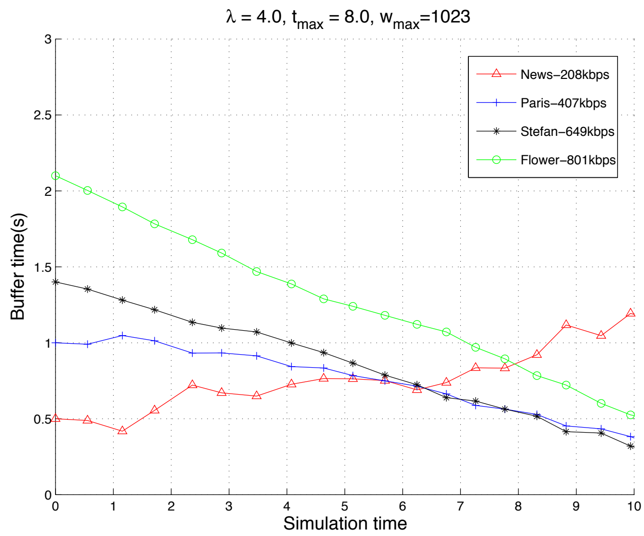

Fig. 8. Four users simulation for under-served Situation by UCF

outer loop R-D optimization control, can also achieve better total PSNR quality for video sessions.

In the future, we will investigate limited coordination schemes at larger timescale that works with UCF to have better convergence and QoS guarantees in both buffer status and PSNR quality, and explore network coding options that exploits the overhearing and opportunistic relay options among users.

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