VIDEO STREAMING OVER 802.11 WLAN WITH CONTENT-AWARE ADAPTIVE RETRY

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ABSTRACT

Robust video streaming over error-prone wireless LANs (WLANs) poses many challenges. In this paper, we propose a timestamp-based content-aware adaptive retry (CAR) mechanism for MPEG video streaming over 802.11 WLANs, where the MAC dynamically determines whether to send or discard a packet based on its retransmission deadline. The retransmission deadline is assigned to each packet according to its temporal relationship and error propagation characteristics with respect to other video packets in the same GOP. The proposed scheme avoids late packets by eliminating the impact of random backoff deference and co-channel interference with proper initial delay introduced at the receiver. Simulation results show CAR significantly improves video quality and saves channel bandwidth.

1. INTRODUCTION

With the wide adoption of 802.11 WLANs, wireless video streaming has gained a lot of attention. However, due to the error prone nature of WLANs, wireless video streaming also poses many challenges. Examples of existing solutions to combat the variation of the wireless medium conditions include rate adaptation [1], packet size optimization [2], dynamic rate shaping [3], and applying FEC, ARQ, or Hybrid ARQ in the application layer [4].

For inter-coded video sequences, the delay and loss of each video packet have different impact on the video quality, and thus different type of packets should be differentially handled. For example, packets belonging to intra-coded frames (I frames) have more impact on video quality than packets of predicted frames (P frames), which have more impact than packets in bidirectionally-predicted frames (B frames). In [5], a selective dropping mechanism is proposed. B frames are intentionally discarded at the VoD server when network condition degrades so as to prioritize I and P frames. Another mechanism is to schedule video packets in a different order from the original playback order to obtain unequal loss ratios is presented in [6] and [7].

The above mechanisms improve video streaming. However, such mechanisms are implemented solely in the application layer. To find a more efficient way in wireless video streaming, joint consideration of two or more layers is desirable [8]. In [9], a cross-layer technique with real-time adaptive retry for layered video with priority queues is presented. The retry limit is periodically adapted by considering sending buffer occupancy. However, [9] does not consider the playback schedule of each retrying packet, which may lead to late arrivals and hence degrade the visual quality.

In this paper, we propose a timestamp-based content-aware adaptive retry (CAR) mechanism to improve video streaming over 802.11 WLANs. Instead of adopting a static count-based retry limit for each packet in a uniform way, a CAR-aided MAC dynamically determines whether to send or discard a packet based on its retransmission deadline, which is assigned to each packet according to its temporal relationship and error propagation characteristics with respect to other video packets within the same GOP. Because retry decisions are made after the completion of the immediately previous transmission, the impact of IEEE random backoff deference and co-channel interference[1] that can cause late packets are considered and can be eliminated. This property holds when one GOP period initial delay (equivalent to one GOP receiver buffer) is introduced at the receiver.

The rest of this paper is organized as follows: Section 2 introduces the proposed CAR algorithm where an initial delay of one GOP period is sufficient. Section 3 analyzes the initial delay for a more flexible retry strategy where the retransmission deadline is extended beyond the GOP boundary in order to accommodate more retries in highly variable network conditions. Section 4 shows the simulation results. Section 5 concludes this paper.

2. CONTENT-AWARE ADAPTIVE RETRY (CAR)

When video frames are encoded with equal importance, the maximal retry limit for each video packet is assigned independently. However, since video frames are typically inter-coded, resulting in that reflects their different error propagation characteristics, video packets should be protected with retry strategies that reflect their contribution to the visual quality. One solution is to increase the retry of an important packet, at the expense of losing less important ones (as long as the receiver can

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[1] Co-channel interference happens when one or more contending stations inject traffic during the backoff time.

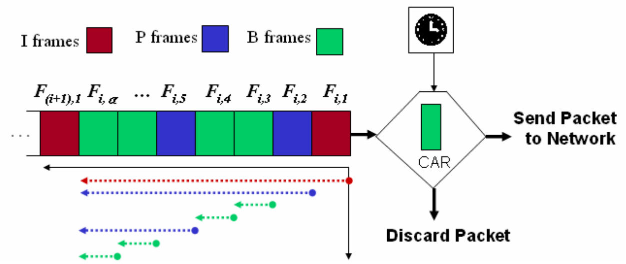

Figure 1: Content-aware adaptive retry (CAR) architecture

accommodate this extra retry latency). Consider a video sequence with GOP size α and inter frame interval λ. For simplicity, we assume α and λ are fixed and known *a priori*. As shown in Figure 1, the video sequence is expressed by

$$S = \{F_{1,1}\, F_{1,2}\, F_{1,3} \ldots F_{1,\alpha}\, F_{2,1} \ldots F_{i,j} \ldots\}$$

where $F_{i,j}$ denotes the j-th frame within the i-th GOP. Frame $F_{i,j}$ is composed of video packets with $P_{i,j}^{(k)}$ denoting the k-th video packet in $F_{i,j}$. For each $P_{i,j}^{(k)}$, We define the following *retransmission extension period* in seconds

$$R(P_{i,j}^{(k)}) = \lambda(M(F_{i,j}) + 1) \qquad (1)$$

$M(F_{i,j})$ is the number of frames inter-coded with respect to $F_{i,j}$. For simplicity, all video packets corresponding to the same frame are assign an equal $R(\cdot)$, which is shown as the dashed lines in Figure 1. For example, for the first P-frame, we assign 6λ as its retransmission extension period because 5 frames are inter-coded with respect to it and one frame accounts for itself. For the first B frame, we assign λ as its retransmission extension period because no frames are inter-coded with respect to it. By associating a reference frame (and all its composing video packets) with a larger $R(\cdot)$, we provide an unequal protection to frames with different error propagation capabilities.

Given the *retransmission extension period* defined in (1), the *retransmission deadline*, i.e. the time instant when retry stops and the packet is discarded, can be calculated and retry decisions can be made accordingly. Suppose video is played strictly following the original temporal relationship at the receiver (no stretching or shrinking of the total display time). We formulate the *retransmission deadline* $D(P_{i,j}^{(k)})$ for video packet $P_{i,j}^{(k)}$ as:

$$D(P_{i.j}^{(k)}) = ((i-1)\alpha + (j-1))\lambda + R(P_{i.k}^{(k)}) \qquad (2)$$

The adaptive retry technique works as follows: Whenever there is a packet $P_{i,j}^{(k)}$ to be sent, the MAC compares the current time with $D(P_{i,j}^{(k)})$. If the current time is less than $D(P_{i,j}^{(k)})$, an initial transmission or a retransmission is issued. Otherwise this packet is dropped, a new packet is de-queued, and the process is repeated. Figure 2 illustrates an example of this operation. A packet is retransmitted over and over until a retransmission succeeds or it reaches its retransmission deadline. In addition, with a larger deadline assigned, a packet can achieve more retries (Fig. 2a), or it may achieve fewer retries (Fig. 2b) if it has been assigned a shorter deadline.

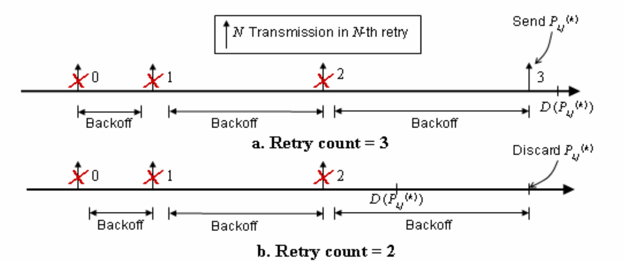

Figure 2: Example of the CAR process

Equation (2) is derived assuming that an initial delay of one GOP period ($\alpha\lambda$), equivalent to one GOP size receiver buffer, is sufficient. We assume an external signaling protocol (for example, RTCP) to negotiate this information between the sender and the receiver. In the next section, we generalize this assumption to achieve a more flexible solution.

3. ANALYSIS OF RECEIVER INITIAL DELAY

In a highly variable channel condition, it can be more effective to extend the retransmission deadline to accommodate more retries in bad conditions. We call this strategy a "deadline-extended retransmission". Based on this idea, (2) is rewritten to:

$$D'(P_{i.j}^{(k)}) = \Delta + ((i-1)\alpha + (j-1))\lambda + R(P_{i.k}^{(k)}) \qquad (2)'$$

Δ is a user-defined parameter, used to deal with transient channel errors that cannot be handled by the original retransmission deadline. $D'(P_{i,j}^{(k)})$ increases the initial delay requirement from ($\alpha\lambda$) to ($\Delta+\alpha\lambda$), but does not change the retransmission behavior in the steady state. Therefore, there is no accumulation of delay.

Intuitively, the larger Δ is selected, the more retries the sender can issue, but the more buffer space the receiver requires. Therefore, one question of interest is how large Δ it requires to accomplish one "deadline-extended retransmission". To solve this problem, we need to consider the random backoff deference and co-channel interference taking place in a retransmission. In this section, we first introduce the random backoff process defined in 802.11. We then develop a statistical analysis to approximate Δ required to support a specific number of "deadline-extended retransmissions".

3.1. 802.11 random backoff process

The IEEE Distribution Coordination Function (DCF) mode [10] is a contention-based medium access scheme. Before transmission, a station first senses the wireless channel to detect if the channel is busy. If the channel is idle, it transmits immediately; otherwise it backs off for a randomly selected time slots based on the current contention window. At that point, the station holds transmission until the channel is detected idle for a distributed inter frame space (DIFS) interval.

The backoff time counter is decremented as long as the channel is sensed idle, "frozen" when a transmission is detected on the channel, and reactivated when the channel is sensed idle again for more than a DIFS. The station transmits when the backoff counter reaches zero. Because the station has to stop decrementing the counter whenever the channel is in use, the actual deference period is usually longer than the selected backoff slot. This property affects the time taken in a retransmission.

3.2. Analysis for the receiver initial delay in one "deadline-extended retransmission"

To support one "deadline-extended retransmission", Δ has to be set large enough to accommodate the time taken in that retransmission. However, due to the dynamic nature of 802.11 random backoff process and time-varying co-channel interference, a determined Δ cannot be obtained. Next, we try to solve this problem on a statistical basis by adopting the Markov chain model in [11]. This work extends the throughput analysis in [12] to model freezing of the backoff counter when the medium is busy.

Due to limited space, we only summarize the mathematical results from [11] and apply those results directly. Interested readers can refer to [11] for detailed derivations.

As in [11], we define the following system parameters. Their values are either known *a priori*, or can be easily computed from other known parameters. Let:

- *n = number of contention stations*
- *T_s = time spent in a successful transmission*
- *T_c = time spent in a collision*
- *$W = CW_{min}$, $CW_{man} = 2^m CW_{min}$, and tSlotTime are defined in IEEE 802.11 specifications*

We also define the following unknown variables. Let:

- *P_{tr} = probability that there is at least one transmission in a slot*
- *P_s = probability that a transmission is successful*
- *τ = probability that the station transmits a packet in a given slot time*
- *p = probability of detection the channel busy*

We assume a case of saturated stations, i.e. stations always have packets to transmit. The following equations summarize the analysis in [11]:

$$P_{tr} = 1-(1-\tau)^{n-1}$$

$$P_s = n\tau(1-\tau)^{n-1}$$

$$\tau = \frac{2(1-2p)(1-p)}{(1-2p)(W+1)+pW(1-(2p)^m)}$$

$$p = 1-(1-\tau)^n \qquad (3)$$

Now we define the metrics of interest for our analysis of receiver initial delay:

- *$\delta(w,k)$ = time duration of finishing w backoff slots within k slot times(k≥w)*
- *P(w,k) = the probability of finishing w backoff slots within k slot times(k≥w)*

Borrowing the model from [11], we can obtain

$$\delta(w,k) = w \cdot tSlotTime + (k-w) \cdot [T_S \cdot P(P_s \mid P_{tr}) + T_C \cdot P(P_{tr} - P_s \mid P_{tr})] \qquad (4)$$

$$P(w,k) = \sum_{i=w}^{k} C_{i-w}^{i-1} P_{tr}^{\,i-w}(1-P_{tr}) \qquad (5)$$

With all the quantities in hand, we can calculate the time to complete one "deadline-extended retransmission" in a case of *w* backoff slots within *k* slot time, which corresponds to $\delta(w,k)+T_s$ in a successful retransmission or $\delta(w,k)+T_c$ in a failed retransmission. For example, assume an 802.11a WLAN with 10 contending stations injecting traffic in a 6Mbps base rate. If the packet size is fixed to 1024 octets, by substituting the result in (3) into (5), we can calculate the probability of finishing 512 backoff slots within 900 slot time:

$$P(512,900) = 0.973$$

Then by solving equation (3) and (4), we get

$$\delta(512,900) + T_s \approx \delta(512,900) + T_c \approx 180ms$$

That is to say, under such network condition, setting Δ=180ms can accommodate one additional "deadline-extended retransmission" with probability 0.973. Based on this model, one can calculate various Δ's with different statistical properties.

We can repeat this process to obtain the statistical initial delay required for more "deadline-extended retransmissions". The final Δ is the sum of these results.

4. PERFORMANCE EVALUATION

For performance evaluation, we create an 802.11a independent basic service set (IBSS) with 6 stations. Station 0 (video sender) transmits an MPEG-4 video stream to Station 1 (video receiver) continuously. The test video sequence is "foreman" encoded in CIF format with quantization step 4, 30 frames per second, and 15 frames per GOP with 4 P frames between I frames and 2 B frames between P frames. Six sequences are concatenated to represent a 60-second video stream. The video sequence is fragmented into 1024-octet MAC frames with inter arrival time equal to 5 ms. Station 2 and Station 4 serve as competing data sources, injecting data traffic in 6 Mbps to Station 3 and Station 5, respectively. The initial delay is set to 500 ms (a GOP period) to accommodate the latency introduced by retransmissions as described in section 2. In addition, we include a Rayleign fading

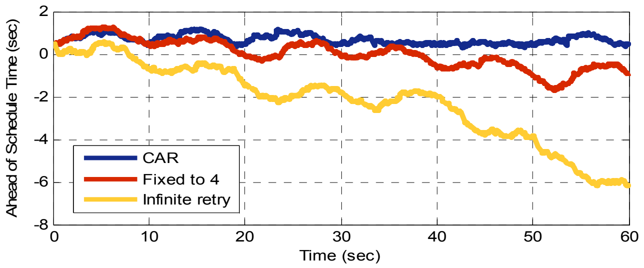

Figure 3: Ahead of Schedule Time

envelope presented in [13] to simulate a small-scale fading channel.

Figure 3 shows the time difference between arrival and playback (ahead of schedule time) of all the video packets in, (a) the proposed CAR mechanism, (b) a fixed retry limit = 4, (c) an infinite retry limit. A negative value of ahead of schedule time means an outdated packet which will be discarded by the receiver. The simulation result shows that CAR outperforms the other two in terms of on-schedule packets. With a 500 ms initial delay, all the packets arrive on schedule in the CAR scenario. Without retry limit adaptation, accumulated delay is observed in (b) and (c), which leads to serious quality distortion.

Table 1 lists packet drop rate at the network, by the video sender[2], and by the video receiver, for the three scenarios. As expected, CAR suffers the least total packet lost. Moreover, since important packets are assigned longer retransmission extension periods, I frame packet loss is less than P-frame packet loss. Likewise, P-frame packet loss is less than B-frame packet loss. Because outdated packets are intentionally dropped at the sender, channel bandwidth is saved from sending useless packets that will inevitably be discarded at the receiver.

Figure 4 shows the Mean Square Error (MSE) of the Y component in the received video. The figure shows that CAR can maintain a relatively low MSE throughout the whole simulation period.

5. CONCLUSION

In this paper, we presented a timestamp-based content-aware adaptive retry (CAR) mechanism for video streaming over 802.11 WLANs. CAR exploits the temporal relationship and error propagation characteristics of different video frames to maximize video quality at the receiver. It considers the impact of IEEE random backoff deference and co-channel interference to avoid outdated packets and to save channel bandwidth. A statistical analysis of extra retries beyond the retransmission deadline is also proposed to adopt in variable channel conditions. Simulation results show that CAR outperforms the conventional persistent retry and fixed retry limit mechanism significantly in terms of packet loss, channel utilization, and user-perceived visual quality.

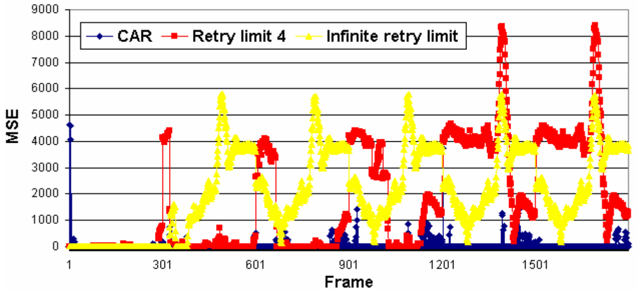

Figure 4: MSE of the Y component

Table 1: The comparison of packet drop rate

Dropped Location	Retry Limit	I-Frame Packets	P-Frame Packets	B-Frame Packets
Sender	CAR adapted	0	0.30%	13.87%
	Fixed at 4	-	-	-
	Infinite	-	-	-
Network	CAR adapted	0	0	0.71%
	Fixed at 4	0.56%	0.47%	0.53%
	Infinite	0	0	0
Receiver	CAR adapted	0	0	0
	Fixed at 4	49.81%	48.81%	50.00%
	Infinite	89.32%	88.78%	89.76%

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[2] This represents a case that the deadline of a packet is smaller than the current time at its initial transmission. Therefore, the sender drops the packet directly.