Buffer Size Resilience for Bluetooth Video Streams from Adaptive ARQ with Active Discard

R. Razavi, M. Fleury and M. Ghanbari.

ARQ in various forms is an important defense against RF error bursts but needs to be adaptive when delay sensitive encoded video is transmitted. This Letter demonstrates that adaptive ARQ itself is sensitive to mobile device buffer size and should be combined with an active discard policy based on picture type. For some Bluetooth send buffer sizes, this leads to up to 10 dB improvement in delivered video quality over adaptive ARQ alone.

Introduction: The IEEE 802.15.1, Bluetooth (B/T), wireless interconnect [1] is subject to error bursts, which have a severe impact on delay-sensitive services such as video streaming. There exist two deadline types for encoded video: 1) a display deadline, effectively set by the playout buffer size at the receiver; and 2) a decode deadline relative to the duration of a Group of Pictures (GOP). Packets forming an anchor frame (I- and P-picture) in the GOP are still of value in retroactive decoding of subsequent P- or B-pictures [2]. If interference is prolonged retained packets contribute to increasing buffer fullness, which may lead to missed deadlines and, in severe cases, to send buffer overflow. This Letter advocates a deadline-aware buffer (DAB) at the sender, which, in the face of disruption, actively discards expired packets according to deadlines determined by their picture type (i.e. content importance). Picture type is established at the data-link layer by inspection of packet headers, without source encoder intervention. As stop-and-wait Automatic Repeat reQuest (ARQ) in B/T comes for free by virtue of slave polling, this Letter stipulates that it too should be picture-type adaptive.

On mobile devices, memory is an important contributor to the battery power budget [3] and consequently buffers should be relatively small. The main contribution of this Letter is to show that default B/T ARQ is inadequate, adaptive ARQ *without* a DAB is very sensitive to buffer size, when these sizes are relatively small, and that only adaptive ARQ with a DAB is resilient to buffer size if higher quality video is desired. In response to send buffer fullness, adaptive ARQ changes the number of retransmissions, graded by picture type. A DAB allows adaptive ARQ to concentrate on still relevant packets, reducing the delay of remaining queued packets. The policy is directly applicable to IEEE 802.11's Point Coordination Function, as this is centrally controlled, and indirectly applicable to its widely deployed Distributed Coordination Function.

Methodology: The experiments assume B/T version 2.0 with Enhanced Data Rate (EDR), which has gross air rates of 2.0 Mbps and 3.0 Mbps, compared to the version 1 basic rate of 1.0 Mbps. For B/T v.

2.0 the research employed the University of Cincinatti B/T (UCBT) extension[1] to the well-known ns-2 network simulator (v. 2.28 used). Links were set at the maximum EDR 3.0 Mbps gross air rate, with a video stream sent directly from master to slave. Simulation runs were each repeated twenty times and the results averaged to produce summary statistics.

The default value of the ARQ retransmission timeout (RTO) in most B/T chipsets is set to infinity. In our experiments, the ARQ RTO is adaptively selected in terms of number of retransmissions allowed, to avoid further delay after the packet enters the tail of a B/T FIFO send buffer. A threshold is set that is the maximum number of retransmissions allowed when the buffer is empty. The maximum number of retransmissions is subsequently changed by a factor depending on the buffer fullness reported by the B/T module. The formula employed is summarized as

$$N = round\left(\frac{m.(c-f)}{c}\right), \qquad (1)$$

where *N* is the maximum number of retransmissions allowed -- the RTO, *m* is the maximum number of retransmissions allowed when the buffer is empty, *f* is the number of packets buffered in the send buffer (buffer fullness), and *c* is the buffer capacity. The operator *round* returns the nearest integer.

According to (1), the maximum number of retransmissions allowed is a function of buffer fullness. Figure 1 plots this function when m = 1, 3, and 5, and c = 50 packets. When the buffer is empty, f = 0, then the maximum number of retransmissions occurs, whereas when the buffer approaches full occupation no retransmissions may occur. The smaller the value of *m* the sooner this latter event occurs. The value of *m* is adapted to the type of picture being transmitted. If the picture is of I-type, upon which all other pictures in the GOP depend, then *m* is set to five. Similarly for P- and B-pictures, *m* is respectively set to three and one. In fact, P-frames are not uniform, as they may contain intra-coded macro-blocks (ones not formed predictively) and inter-coded macro-blocks. A significant number of intra-coded macro-blocks may indicate a scene change, revealed objects, a camera zoom/pan, or high motion but is encoder dependent. For simplicity of result presentation, in this Letter, the picture type priority scheme is not extended in this way.

The display deadline at the DAB, dependent on the B/T playout buffer size, was set at 0.2 s. In addition to the display deadline, all I-picture packets have a decode deadline, which is the display time remaining until the end of the GOP. For a 12-frame GOP, this is the time to display 11 frames, i.e. 0.44 s at 25 frame/s. For P-picture packets, the time varies depending on the number of frames to the end of the GOP. For B-pictures the decode deadline is set to zero. The decode deadline is added to the display deadline and a packet is discarded from the DAB after its total deadline expires. By storing the GOP end time, an implementation performs one subtraction to find each decode deadline. Account has

[1] A download is available from `http://www.ececs.uc.edu/~cdmc/ucbt`

been taken of I- B- P-picture reordering (to ensure reference pictures arrive before B-pictures), which has an effect on send buffer fullness.

A Gilbert-Elliot [4] two-state, discrete-time, ergodic Markov chain modelled the wireless channel error characteristics between a B/T master and slave node. By adopting this model it was possible to simulate non-independent burst errors of the kind that cause problems to an ARQ mechanism. The mean duration of a good state, T_g, was set at 2 s and in a bad state, T_b, was set to 0.5 s. In units of the B/T time slot duration (625 μs), T_g= 3200 and T_b= 800, which implies from:

$$T_g = \frac{1}{1 - Pgg}, T_b = \frac{1}{1 - Pbb} \qquad (1)$$

that, given the current state is good (g), Pgg, the probability that the next state is also g , is 0.9996875 and Pbb, given the current state is bad (b), the probability that the next state is also b, is 0.99875. At 3.0 Mbps, the Bit Error Rate (BER) during a good state is set to 10^{-5} and in a bad state to 10^{-4}.

The simulations were carried out with input from an MPEG-2 encoded bit-stream for a 30 s video clip with moderate motion. The display rate was 25 frame/s; 750 frames sent in all. The source video was Common Intermediate Format (CIF)-sized (366$\times$288 pixels) with a standard GOP structure of N = 12, and M = 3. To avoid consideration of a variety of decoder options, error concealment was confined to simple, previous frame substitution [2], which is a common assumption. A data frame across a B/T link in asymmetric mode consists of an Asynchronous Connection-Less packet occupying one, three or five time slots. Unfortunately, if packetization takes place on a single MPEG-2 slice per B/T packet the result is partially filled packets as well as many 1- or 3-slot packets, with a consequent drop in throughput. Therefore, in [5] fully filled B/T packets were formed, regardless of slice boundaries. While this results in some loss in error resilience, as each MPEG-2 slice contains a decoder synchronization marker, in [5] it is shown that the overall video performance is superior. In the experiments, the video B/T packet type was set to 3DH5, which corresponds to a five time slot packet. The 3DH5 user payload is 1021 B with an asymmetric maximum bit rate of 2.1781 Mbps.

Results: Table 1 reports tests on ‘no ARQ’, two different ARQ, and adaptive ARQ with DAB policies with three different send buffer sizes: 50, 100 and 150 packets. For no ARQ, the buffer size has no impact but RF channel packet loss inevitably occurs, resulting in lower mean Peak Signal-to-Noise Ratio (PSNR). When the default B/T ARQ policy is adopted, the delay in sending packets results in buffer overflow (congestion loss) even with the larger buffer sizes. There are also some missed display deadlines, a result of a conservative discard policy. Higher delay is traded against no channel losses. Adaptive ARQ succeeds in avoiding congestion loss even for the smallest buffer size tested but, though reduced in number, late packet arrivals are still a problem. Combining adaptive ARQ with DAB further reduces loss from late arrival and congestion loss to a very low level. Though active discard of expired packets takes place, it is graded, based on which packets have least impact, and the level of discard is such that total packet loss is more than halved by using the DAB, causing the video quality to be significantly and consistently above that of the other policies, regardless of the buffer sizes.

Figure 2 shows the effect on delay over time when a 150 packet send buffer was employed. When channel conditions cause approaching 1 s delay for infinite retransmission, and, while adaptive ARQ can reduce the delay level to around 0.4 s, it is the DAB that causes delay to fall below the 0.2 s display deadline, increasing the video quality as a result. The duration of periods of severe packet delay is also more prolonged if a DAB is not in place and a relatively large buffer is employed. For infinite ARQ, during bad channel conditions, some packets are lost anyway (without active discard) through overflow from a smaller buffer, but, with a larger buffer, once good conditions are restored, needlessly retained packets contribute to a slower return to normality.

Conclusion: ARQ policies can have a varying effect on received video quality depending on buffer size. In this Letter, we combine adaptive ARQ with active discard results resulting in relative immunity to buffer size in the small size range considered. As buffer sizes are not normally tuned to specific videos, our policy results in a lower memory power budget and better received video quality that can be 10 dB up on adaptive ARQ used on its own if the buffer size is just 150 packets.

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References

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Table captions:

Table 1: Packet loss statistics, video quality, and mean delay for a 30 s video clip according to ARQ scheme.

Figure captions:

Fig. 1: Maximum number of retransmissions, RTO, versus send buffer fullness.

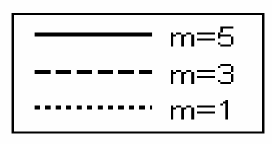

Fig. 2: Packet delay for various ARQ schemes during transmission of a 30 s video clip with buffer size of 150 packets.

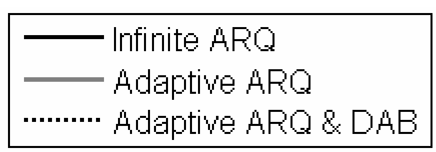

Table 1:

ARQ Policy	*Total Loss (%)*	*RF loss (%)*	*Congestion Loss (%)*	*Late Arrival Loss (%)*	*Active Discard (%)*	*Mean Delay (s)*	*Mean PSNR (dB)*
Buffer size = 50 packets							
No Retransmission	18.26	18.26	----	----	------	0.0056	25.83
Infinite ARQ	14.26	---	8.14	6.12	------	0.0955	26.91
Adaptive ARQ	8.31	6.29	----	2.02	------	0.0506	37.83
Adaptive ARQ&DAB	**7.54**	**4.30**	**----**	**0.60**	**2.64**	**0.0352**	**38.34**
Buffer size = 100 packets							
No Retransmission	18.26	18.26	----	----	------	0.0056	25.83
Infinite ARQ	20.57	---	3.06	17.51	---	0.1321	25.13
Adaptive ARQ	13.03	4.17	-----	8.86	----	0.0941	29.79
Adaptive ARQ&DAB	**7.35**	**2.75**	**---**	**0.84**	**3.76**	**0.0415**	**38.36**
Buffer size = 150 packets							
No Retransmission	18.26	18.26	----	----	------	0.0056	25.83
Infinite ARQ	25.89	---	0.24	25.65	------	0.1644	23.25
Adaptive ARQ	16.33	2.65	-----	13.68	-----	0.1278	28.07
Adaptive ARQ&DAB	**7.29**	**1.88**	**-----**	**1.06**	**4.35**	**0.0437**	**38.37**

Figure 1:

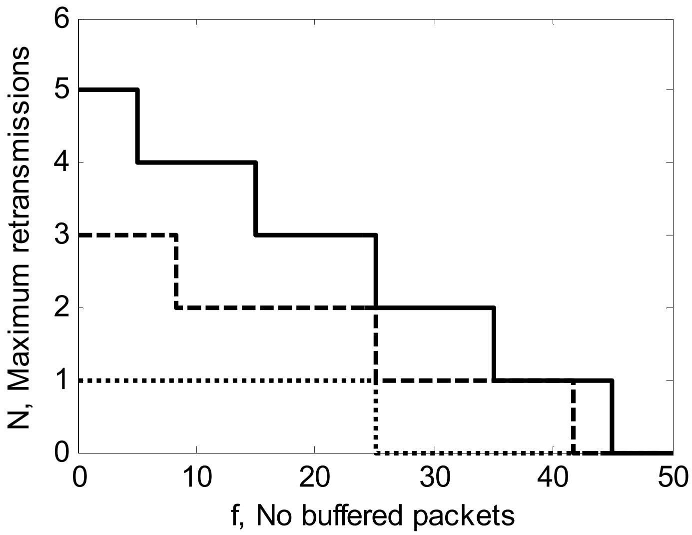

Figure 2: