An Efficient Packetization Scheme for Bluetooth Video Transmission

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The Bluetooth wireless link is likely to be the last hop in the delivery of an encoded streamed video clip. This paper shows that it is preferable to optimally map arriving IP packets onto Bluetooth packets than preserve the stream's internal synchronization structure. Video quality improves and latency reduces, even when there is cross traffic on the piconet.

Introduction: For efficient transport across an IEEE 802.15.1 (Bluetooth) wireless link [1], the slice structure of an MPEG-2 encoded video stream must be mapped onto the Bluetooth (B/T) packet structure. In the widely-deployed MPEG-2 codec, a slice consists of up to one row of macroblocks but unlike an MPEG-1 slice should not extend beyond one row. The main reason for defining slices is to prevent channel error propagation by means of synchronization markers. Assuming a slice arrives at a B/T base station encapsulated in an IP packet then it must be formed into a B/T packet, the maximum sizes of which are quantized by the B/T channel time-slot structure. This Letter demonstrates that allowing a slice to be split between two B/T packets, dynamic packetization, brings significant advantages when the receiver's buffer size is limited. The advantages occur in terms of reduced overall delay and packet loss through buffer overflow, and improved peak signal-to-noise ratio (PSNR). The dynamic packetization scheme achieved higher received video quality, despite the potential loss of synchronization at the decoder due to the arrival of packets bearing partial slices. Only in conditions of very low SNR will dynamic packetization possibly lose its attraction, in which case static slice allocation schemes may be considered. The results have implications for other codecs.

Methodology: A B/T data frame in asymmetric mode across an Asynchronous Connection-Less (ACL) link consists of a packet from the master occupying one, three or five time slots and at least a single slot reply by a slave. In Table 1, the maximum user data rates are defined for a B/T v. 2.0's Extended Data Rate (EDR) ACL link at a gross air-rate of 3.0 Mb/s. In this Letter, the assumed B/T controller behaviour is that, given a maximal B/T packetization scheme, for example 3-DH5 or 3-DH3, then packets up to the maximum user payload will be formed. However, if the arriving packets do not justify the pre-set maximal scheme then a reduced scheme is applied. For example, the controller swaps from 3-DH5 down to 3-DH3 or even 3-DH1.

The experiments assume a per link buffer size of about 100 KB, equivalent to fifty packets. Reduced

receiver buffer sizes are likely on low-cost mobile devices [2] and these must match sender buffer sizes to avoid further overflows. In [3]. it was concluded for B/T v. 1.2 basic rate, 732.2 Mb/s, that, in an Additive White Gaussian Noise (AWGN) channel, if packets are fully-filled then DH5 packets, not DH3 or DH1, are optimal for $E_s/N_0 > 13.52$ dB. For B/T v. 2.0, under the same set-up as [3], simulation revealed that a maximal 3-DH5 packet scheme is preferable for an AWGN when $E_s/N_0 > 15.10$ dB, as well as when packet loss only occurs through buffer overflow, as reported below. In conditions of low SNR, then one of B/T v. 2.0's lower gross air-rates is to be preferred rather than change the packet time-slot structure.

In simulations, a European-formatted Standard Definition (SD) MPEG-2 encoded video clip, with group of picture structure of N=12, M=3 for duration of 40 s, generated data at an average rate of 1.77 Mb/s. The clip contained moderate motion and, hence, a moderate bitrate for the given quality and size. IP packets were formed on a per-slice basis, each slice consisting of a row of macro-blocks. At 18 slices per frame, the IP packet arrival rate at the B/T master was 450 packet/s.

This research employed the University of Cincinatti Bluetooth (UCB/T) extension to the well-known ns-2 network simulator (v. 2.28 used). The UCB/T extension has the advantage that it supports B/T EDR but is also built on the air models of previous B/T extensions such as BlueHoc from IBM and Blueware.

Results: Fig. 1 is a graph of the loss rate versus packet size for selected input rate of constant-bit rate (CBR) traffic arriving at an error-free 3.0 Mb/s EDR ACL link. It becomes clear that choice of packet length has a significant effect on the goodput. For example, at 1.7 Mb/s input rate there are very low packet loss rates at a packet size starting around 875 B and extending just beyond 1000 B or again at around 1450 B, corresponding respectively to selection of a single 5-slot packet or one 5-slot packet and one 3-slot packet.

The distribution of slice sizes (equivalently arriving IP packet sizes) for the sample video clip in the simulations is given in Fig. 2. The majority of the packet sizes fall within the range 50 to 850 bytes. This implies an inefficient B/T packetization scheme in terms of the output data rate, as the B/T controller will select one or three slot packets for most of the packets. Sending any packets with a slightly larger size than the maximum of the defined packet sizes in Table 1 is inefficient as well. The controller will send a full packet for the first portion of the data but the remaining part will be sent in a partially filled single slot.

A simple measure of burstiness was calculated by dividing the peak by the average instantaneous packet throughput and various allocations of slices to packets. Table 2 demonstrates that if the arriving IP burstiness is 3.459 then a simple single slice per packet scheme results in a bursty input at the receiver and a relatively low average bitrate, principally as a result of inefficient packetization. Double-

slice allocation brings some improvement but most gain comes from dynamic packetization.

If slices are able to be aggregated and/or split between packets, so that the payload closely matches a maximum B/T 3-DH5 packet then the bitrate is restored to its input value (Table 2) and there is a reduction in per-slice delay and per-packet jitter, as recorded in Table 2 at the B/T slave receiver. As no packet loss occurs due to sender/receiver buffer overflow, the bitrate across the B/T ACL link is the same as the IP input. Equally, the risk of temporal error propagation is curtailed if there is no packet loss.

As Fig. 3 illustrates, the dynamic scheme rarely required a buffer-size over ten packets in size. The single-slice scheme quickly completely occupied the buffer, resulting in packet loss, as subsequent packets arrive. For a two-slice scheme there was a slower climb to steady state. However in steady state, the two-slice scheme buffer occupancy was generally just below saturation, with reduced packet loss, due to a higher output bitrate than the one-slice scheme.

Finally, in Table 3, slave-to-slave cross-traffic temporarily occupies the B/T shared channel while the master communicates to the other two slaves. For zero and 50 Kb/s cross traffic, no packet loss occurs in the dynamic packetization case, whereas the single and double slice per packet schemes PSNR degrades. However, when packet loss does occur for the dynamic packetization scheme, because of the slower service rate of the link buffer, even with the possibility that a single slice and its resynchronization markers are split between two B/T packets, the received video PSNR is still superior for dynamic packetization.

Conclusion: Dynamic packetization is not only advisable when relaying MPEG-2 encoded video clips across a Bluetooth link but it may also be necessary for MPEG-4 encoded video clips. Unless cross-layer communication occurs, built-in optimal slices sizes, in MPEG-4's flexible scheme, will be sub-optimal if the chosen Bluetooth packet size is not optimal due to radio interference.

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References

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2. M. Yokotsuka, 'Memory motivates cell-phone growth', *Electronic Design*, April, 2004.
3. M. C. Valenti, M. Robert, and J. H. Reed, 'On the throughput of Bluetooth data transmissions', IEEE Wireless Comms. & Networking Conf., pp. 119-123, 2002.

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Table captions:

Table 1: Packet types showing user payload and bitrates for B/T v. 2.0 EDR.

Length and master to slave bitrates, for a single ACL master-slave logical link,
DH = Data High rate, 3- indicates a gross air rate of 3.0 Mb/s

Table 2: Various packetization schemes: bitrate, burstiness, delay and jitter.

Table 3: Received video quality (PSNR) with varying cross traffic.

Figure captions:

Fig. 1: Average throughput of B/T ACL packet types in AWGN for differing B/T modulation modes.

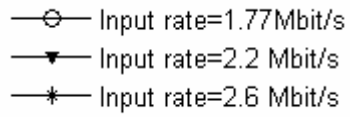


Fig. 2: Distribution of slice sizes for an SD MPEG-2 encoded video clip.

Fig. 3: Link buffer fullness for different B/T packetization schemes

Table 1

Packet type	*User payload in bytes*	*Asymmetric max. rate in kb/s*
3-DH1	0-83	531.2
3-DH3	0-552	1776.4
3-DH5	0-1021	2178.1

Table 2:

	B/T slice to packet allocation scheme		
	Single-slice	Double-slice	Dynamic
Bitrate (Mb/s)	1.33	1.62	1.77
Burstiness	1.508	1.289	1.089
Mean slice delay (s)	0.158	0.116	0.008
Per packet jitter(10^{-4} s)	1.14	2.97	0.74

Table 3:

Cross-traffic (Kb/s)	*Single Slice/ Packet (dB)*	*Double Slice/ Packet (dB)*	*Dynamic Packetization (dB)*
0	29.91	33.11	44.92
50	29.45	32.26	44.92
100	26.75	29.58	36.38
150	24.26	28.69	32.01
200	21.52	26.49	30.97

Figure 1:

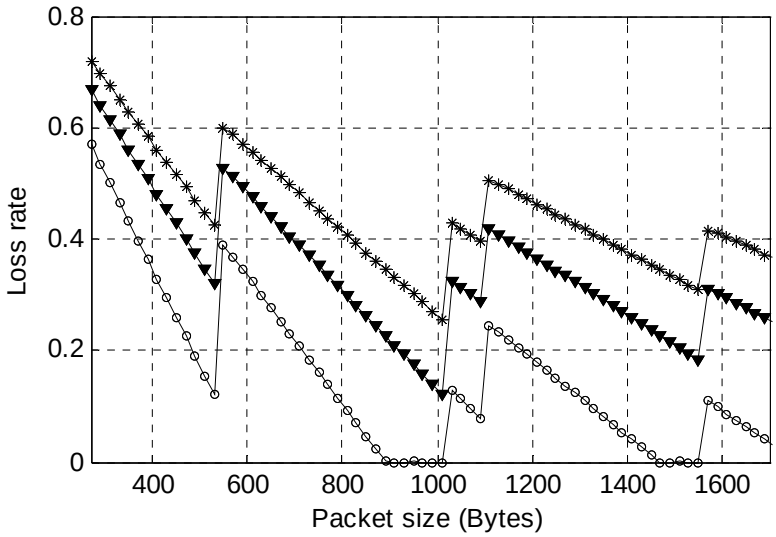

0.8
0.6
0.4
0.2
0
Loss rate
400
600
800
1000
1200
1400
1600
Packet size (Bytes)

Figure 2:

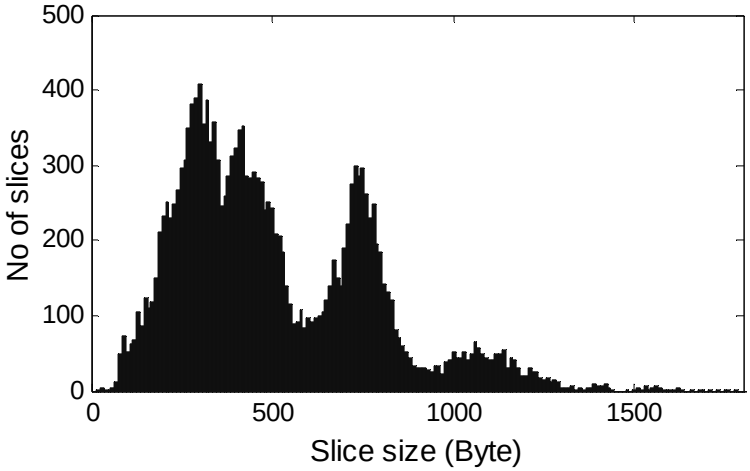
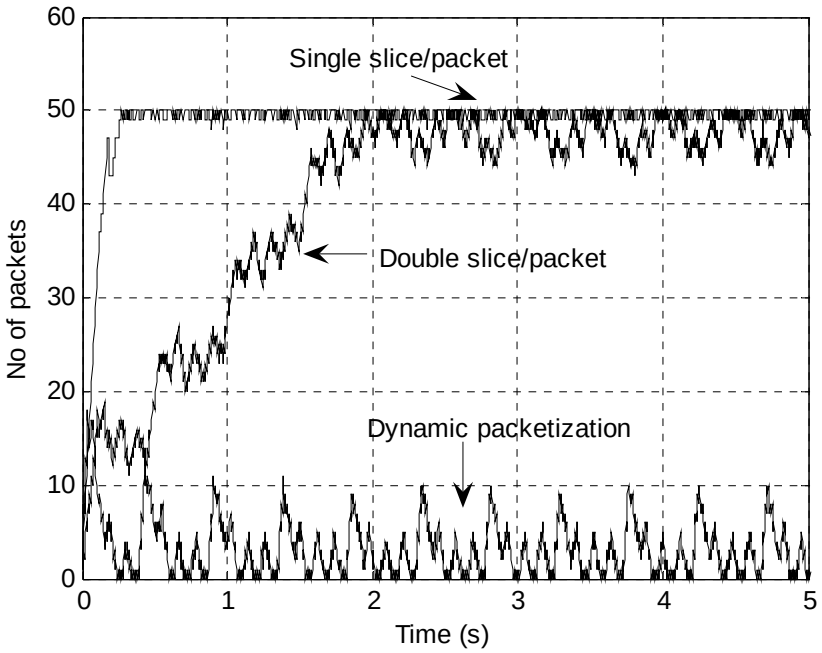

500
400
300
200
100
0
No of slices
0
500
1000
1500
Slice size (Byte)

Figure 3:


Single slice/packet
Double slice/packet
Dynamic packetization
No of packets
Time (s)
0
10
20
30
40
50
60
0
1
2
3
4
5