Adaptive Packetization for Video Streams for Bluetooth v. 2.0 Data Rates

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

Bluetooth v. 2.0 interconnects employ multiple data rates and packet types. This Letter proposes monitoring the arriving IP packet sizes of an encoded video stream along with the RF background, leading to a scheme with adaptive packetization and changing data rates over time. Received video quality significantly improves over fixed or semi-adaptive schemes.

Introduction: A Bluetooth (B/T) wireless link [1] may be the last hop over an IP network in the delivery of an encoded video clip. B/T v.2.0's Extended Data Rate (EDR), with multiple B/T packet sizes and two data rates according to modulation scheme, makes it difficult for a video codec source to anticipate the optimal slice sizes to suite channel conditions. Slices are defined for error resilience purposes, to prevent channel error propagation by means of synchronization markers. A single slice/packet packetization may not efficiently use the predefined capacity of the B/T packets. One solution is dynamic packetization (DP) [2], whereby slice boundaries are not preserved in outgoing B/T packets. For higher input data rates, DP maximizes throughput, regardless of content. However, radio frequency (RF) noise may result in an increased loss of synchronization at the decoder if packets bearing partial slices are lost. Alternatively, an integral number of slices, up to some maximum, may be placed in a B/T packet, which we call integral slice packetization (ISP). At lower input data rates, DP may be unnecessary, while smaller ISPs, for example one slice per B/T packet, maximize RF noise immunity. This Letter proposes monitoring by a B/T master access point of both the incoming IP packet-size and the Carrier-to-Noise Ratio (CNR) of the B/T link, making it possible: firstly, to adapt to channel conditions by swapping between B/T EDR's two modulation schemes and, subsequently, to adapt the B/T slice packetization method to the incoming data rate. The result of this Letter's scheme is a worthwhile improvement in received Peak Signal-to-Noise Ratio (PSNR), observed for a typical MPEG-2 encoded video clip. This outcome has implications for other codecs employed within the IP Multimedia Subsytem (IMS).

Methodology: A B/T data frame in asymmetric mode across an Asynchronous Connection-Less (ACL) link contains a variably-sized 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 EDR ACL link at gross air-rates of 2.0 and 3.0 Mb/s (resulting respectively from $\pi/4$-DQPSK and 8DPSK modulation). Our experiments assume: a per B/T link buffer size of about 100 KB, equivalent to fifty packets; and B/T Automatic Repeat Request (ARQ) turned off.

As input, a European-formatted SIF-sized MPEG-2 video clip at 25 frame/s, with group of picture (GOP) structure of N=12, M=3 for duration of 40 s, was encoded at an average rate of 1.25 Mb/s. The clip contained moderate motion and, hence, a moderate bit rate for the given quality and size. Arriving IP packets at the B/T master are assumed to contain a single slice, each slice consisting of a row of 22 macro-blocks, with 18 slices per MPEG-2 picture. Likewise, RFC 2429 recommends one slice per IP packet (for H.263+). H.263 has a similar slice structure to MPEG-2, when a slice is mapped onto a group of blocks and, though H.264 has variable slice sizes, the optimal size for a particular B/T link cannot be known in advance. IP and UDP headers of 40 Bytes were encapsulated in the B/T payload in support of IMS.

To determine which data rate is appropriate in a subsequent interval, the B/T master monitors the channel CNR over the preceding interval, assuming an Additive White Gaussian noise (AWGN) channel. If packets are fully filled regardless of slice structure, Fig. 1 shows, according to a model previously established for B/T v. 1.0 basic rate in [3], the optimal B/T packet sizes based on the monitored E_s/N_0. For example, at a point around 15 dB and above, 3-DH5 packets give better throughput than all other schemes. The model of Fig. 1 or similar converted to tabular format allows the maximal packet type (as well as data rate) to be selected according to the CNR range.

The B/T master also monitors the input packets to establish the slice sizes and the average arrival data rate (AADR) over the preceding interval, again to anticipate the appropriate packetization scheme over the following interval. The B/T master notes the maximum send rate (MSR) achievable by DP. In general, the MSR is calculated for an error-free channel and a single B/T interconnect and, therefore, for DP, given the maximal packet type, the MSR is available from Table 1. If the DP MSR is less than the average arrival data rate then DP is always chosen, as DP represents the MSR of any packetization scheme. Otherwise, the master, having decided on the maximal packet type, calculates different ISP MSR with one slice per packet, then two slices per packet, and so on, stopping if the average integral number of slices (after truncation of the number) from DP MSR is reached. ISP MSRs are calculated by categorizing arriving slices according to the necessary packet slot size (1, 3, or 5) (column 2 of Table 1) for the given slice packing density, from which the aggregate send rate is found using the known send rates (column 3 Table 1). For example, the mean number of slices per 3-DH5 packet for DP with the input video clip is 3.42 slices, resulting in a limit of three slices by ISP. The first ISP MSR type to exceed the AADR is then selected as the packetization scheme, as that ISP will give the optimal potential noise immunity, while accommodating the input data rate.

Table 2, column 3, shows the distribution of slices to B/T packets for each of the ISP schemes and adaptation scheme. For a single slice/packet and 3 Mb/s data rate, only 20% of the slices justify 3-DH5 packets and the used ratio of the packets' capacity is only 59%. Though there is an increased utilization of packet capacity for increased ISP, this must be offset against a potential decrease in RF noise immunity. DP will give the maximum capacity but equally the least immunity. (The other results of Table 2 are discussed later.)

The B/T specification requires an CNR value between 0 and 255 to be returned from a call across the B/T Host-Computer-Interface (HCI). In the widely deployed B/T Cambridge Silicon Radio chipset, it is reported [4] that there is an almost linear relationship between returned link quality and BER. However, this Letter assumes an ideal stable value over the given monitoring interval, though oscillations may occur in practice.

A Gilbert-Elliot two state, discrete-time, ergodic Markov chain modeled the wireless channel error characteristics between a B/T master and slave node. The mean duration of a good state, T_g, was set at 2 s and in a bad state, T_b, was set to 0.25 s. In units of 625 μs (the B/T time-slot duration), T_g= 3200 and T_b= 400, which implies from:

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

that, given the current state is g, the transition probability of remaining in a good state, Pgg, is 0.9996875 and the transition probability of remaining in a bad state, Pbb, is 0.9975. At 3 Mb/s, the Bit Error Rate (BER) during a good state was set to 10^{-5} and during a bad state to 10^{-3}. The transition probabilities, as well as the BER, are approximately similar to those in [5], but the mean state durations are adapted to B/T. The two states result in CNRs of respectively 15.97 and 13.02 dB. These CNRs correspond to the approximate middle of the CNR ranges when either 3-DH5 or 2-DH5 packets are optimal from Fig. 1.

This research employed the University of Cincinatti Bluetooth (UCB/T) extension[1] to the well-known ns-2 network simulator (v. 2.28 used).

Results: Fig. 2 shows, for both EDR datarates, the MSRs according to ISP type predicted by picture interval monitoring. In Fig. 2 (a), 20-picture interval monitoring is shown to give a smoother prediction than that arising from 5- or 10-picture intervals, thus, avoiding any ambiguity in MSR choice. From Fig. 2 (a), at a gross air rate of 3.0 Mb/s, 1 ISP is below the required datarate of 1.25 Mb/s and is rejected as a prediction, while 2 ISP is selected and 3 ISP is rejected, as there is an increased risk of packet loss compared to 2 ISP, due to packet corruption by RF noise. In Fig. 3 (b), at a selected gross air rate of 2.0 Mb/s, all plotted ISPs fall below the desired input rate, therefore, the predicted scheme at 2.0 Mb/s is DP. As DP has a mean 2.66 slices per packet, 3 ISP would anyway be rejected.

Table 2 shows packet loss rates and resulting mean PSNRs (averaged over time) for the MPEG-2 video clip, from an average of ten simulations runs. In Table 2, PSNR does not always follow loss rates, as it is the pattern of losses that is important. Congestion loss occurs owing to buffer overflow when the B/T is unable to meet the external IP packet arrival rate. Considering fixed packetization schemes, congestion loss increases the smaller the ISP but loss due to RF noise decreases. Clearly, losses due to RF noise increase at the higher gross air rate. When rate change is applied for a fixed ISP or DP, according to the CNR state, then Table 2 shows that the selected packetization schemes according to the methodology, 2 ISP for 3.0 Mb/s and DP for 2.0 Mb/s, benefit more from lack of congestion than the increase in loss from RF noise, resulting in optimal video quality (PSNR). However, semi-adaptive rate changing is not better than simply opting for DP at 2.0 Mb/s throughout.

Finally, in the proposed adaptive scheme of Table 2, when rate changing is combined with selecting DP at 2.0 Mb/s and 2 ISP at 3.0 Mb/s, there is a reduction of the loss rate to an optimal level of 0.0515. Furthermore, when PSNRs were taken the video quality improved from 37.92 dB (DP at 2.0 Mb/s) to 38.79 dB. Therefore, a fully adaptive scheme should be selected to gain almost one dB in quality.

Conclusion: Monitoring of the input video stream and the channel CNR level is feasible and will improve received video quality over B/T EDR interconnects by means of the cross-layer control algorithm given in the Letter. Simply switching the B/T data rate in noisy conditions is not sufficient for encoded video input, as the matching, content-dependent packetization scheme must also be chosen.

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References

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[1] Downloadable from `http://www.ececs.uc.edu/~cdmc/ucB/T/`.

Table captions:

Table 1: Packet types showing user payload and data rates (1 Mb = 2^{20} bits) for B/T v. 2.0 EDR, according to number of B/T time slots for a single master-slave ACL logical link.

DH = Data High rate, 2-, 3- indicates a gross air rate of 2.0, 3.0 Mb/s (metric units).

Table 2: Slice to packet allocation capacities, with resulting packet loss rates (packets lost/total packets sent) and received video quality for a 40 s encoded video clip.

Figure captions:

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

Fig. 2: B/T MSR predictions for MSRs with various ISPs for gross air-rates of (a) 3.0 Mb/s (with 5, 10, 20 picture interval sampling) (b) 2.0 Mb/s (with 20 picture interval sampling) (Predictions with 1 Mb = 2^{20} bits).

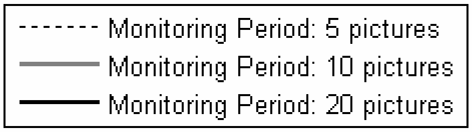


Table 1:

Packet type	*User payload in bytes*	*Asymmetric max. rate in Mb/s*
2-DH1	0-54	0.3290
2-DH3	0-367	1.1200
2-DH5	0-679	1.3814
3-DH1	0-83	0.5066
3-DH3	0-552	1.6941
3-DH5	0-1021	2.0772

Table 2:

	Scheme	*Channel rate (Mb/s)*	*Used capacity ratio*	*Total loss rate*	*RF channel loss*	*Conge-stion loss*	*Average PNSR (dB)*
Fixed Schemes	1 ISP	2	0.7219	0.3438	6.11E-4	0.3431	25.53
	2 ISP	2	0.8241	0.1571	0.0016	0.1555	31.02
	3 ISP	2	0.8812	0.0870	0.0025	0.0845	37.18
	DP	2	1.0	0.0696	0.0099	0.0596	37.92
	1 ISP	3	0.5862	0.3136	0.1042	0.2093	26.83
	2 ISP	3	0.7776	0.1684	0.1684	----	30.36
	3 ISP	3	0.8264	0.1984	0.1984	----	29.94
	DP	3	1.0	0.2103	0.2103	----	29.71
Rate-change	1 ISP	2/3	0.6016	0.2443	0.0217	0.2225	28.07
	2 ISP	2/3	0.7829	0.0969	0.0618	0.0351	36.32
	3 ISP	2/3	0.8336	0.0960	0.0945	0.0015	36.27
	DP	2/3	1	0.0825	0.0825	----	37.74
	Adaptive Scheme	2/3	0.8029	0.0515	0.0515	----	38.79

Figure 1:

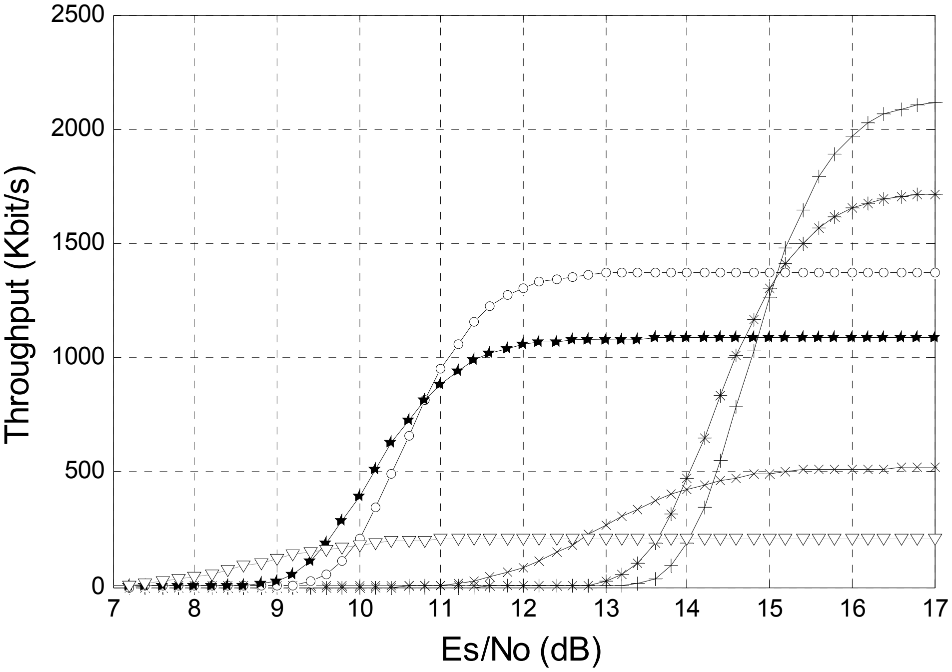
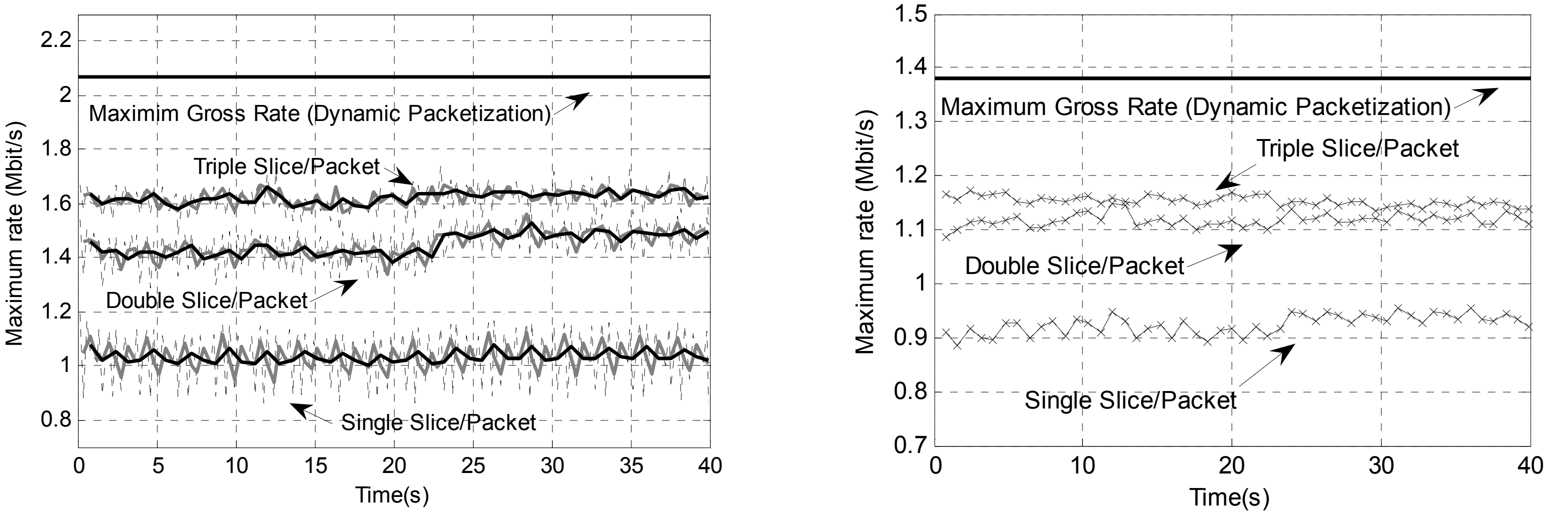

2500
2000
1500
1000
500
0
Throughput (Kbit/s)
7
8
9
10
11
12
13
14
15
16
17
Es/No (dB)

Figure 2:


Maximim Gross Rate (Dynamic Packetization)
Triple Slice/Packet
Double Slice/Packet
Single Slice/Packet
Maximum rate (Mbit/s)
Time(s)
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0
5
10
15
20
25
30
35
40
Maximum Gross Rate (Dynamic Packetization)
Triple Slice/Packet
Double Slice/Packet
Single Slice/Packet
Maximum rate (Mbit/s)
Time(s)
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0
10
20
30
40

(a)

(b)