Efficient Packetization for Bluetooth Video Transmission

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Abstract

The arrival of Enhanced Data Rate makes a Bluetooth home entertainment network more likely. However, if arriving IP packets do not account for the Bluetooth packet structure, poor performance will result. A dynamic IP packetization scheme is advocated and shown to overcome Bluetooth's packet length dependencies. The research is relevant to converged IP networks which use Bluetooth as the wireless link.

1 Introduction

Bluetooth (Bt) is a low-cost (< 5 USD), short-range (< 10 m for Class 2 devices), radio frequency (RF) interconnect (in the unlicensed 2.4 GHz Industrial, Scientific and Medical (ISM) band). Bt [1] was originally conceived by Ericsson Mobile Communications in 1994 as an alternative to IrDA serial cable replacement, without IrDA's line-of-sight restriction. It received much publicity at its introduction to the marketplace in 1998, and, in 2002, formed IEEE 802.15.1 standard. Perhaps due to bandwidth limitations, Bt has received comparatively limited investigation as a form of home entertainment network [2], exceptions being [3][4][5]. With the enhanced data rates (EDR) offered by Bt version 2.0 [6], this restriction has eased. This paper investigates EDR Bt packetization schemes for MPEG-2 video, given performance appears to be strongly dependent on packet length. Since the bandwidth limitation (even in the EDR version) is the main constraint in multimedia transmission over Bt, an efficient packetization scheme is required to maximize the achievable data rate. This paper proposes dynamic IP packetization at a video stream source, based on the target Bluetooth packet structure.

The EDR, gross air rate of 2.0 or 3.0 Mbps depending on modulation (Section 2), has made much more viable a range of multimedia services, as v.2 devices emerged in 2005, especially those enabled for category 2 EDR with multiple time slot packets. In particular, it now seems possible to form an all-wireless Bt entertainment network within the home. A Bt piconet has a star topology, with a master at the hub of the star and slaves at the spokes. A master controls access to a piconet wireless channel using a polling and reservation scheme. This paper confines its attention to a single master-slave link within a piconet and is not concerned with the extension of a piconet to a scatternet, which seems unlikely in the context of a home entertainment network.

The experiments in the paper assume the widely-deployed MPEG-2 codec, with a video clip streamed from a remote server across an IP network. To isolate the behavior at the Bt link, the IP input packet stream is assumed to be have a packet loss-free passage across an intervening IP network. In 'best-effort' Internet delivery, this is an unlikely scenario. However, recent progression towards converged IP networks, in which the IP network is a switched Clos network with low-blocking probability, have brought the experimental scenario nearer to reality. In fact, one of the main planks of British Telecom's proposed replacement IP converged telephony network (CTN) [7], the 21C Network (21CN), is the "Bluephone", which, equipped with a Bluetooth module, allows roaming from home to cellular network with automatic re-connection to maintain call continuity.

2 Bluetooth characteristics

Bt uses packet-switching with an FHSS (Frequency Hopping Spread Spectrum) approach. The hop frequency is 1600 hops per second, with the frequency spectrum maximally divided up into 79 hops of 1 MHz bandwidth each. FHSS is combined with ARQ, CRC, and FEC error control. When the Federal Communications Commission changed its rules, version 1.2 addressed the issue of narrowband interference on the unlicensed 2.4 GHz Industrial, Scientific and Medical (ISM) band, by means of adaptive frequency hopping. Then, in late 2004, the specification for version 2.0 (v.2) [6], added Phase Shift Keying (PSK) to Gaussian Frequency-Shift Keying (GFSK)[1] modulation, increasing the maximum gross user payload (mgup) data rate from 0.7232 Mbps to 2.1781 Mbps.[2]Depending on the wireless environment a gross air rate of 2.0 Mbps (mgup of 1.4485 Mbps) or 3.0 Mbps using respectively $\frac{\pi}{4}-$DQPSK or 8DPSK but retaining the same symbol rate, 1 Ms/s, throughout.

A Bt wireless channel in a piconet between a master and up to seven active slaves, avoids access contention by time division multiplexing under the control of the master. A Bt data frame in asymmetric mode consists of a packet from the master occupying one, three or five time slots *and* a single slot reply by a slave.[3] Bt's data-bearing Asynchronous Connectionless

[1]GFSK is retained in v.2 for packet headers to help ensure their integrity and is also retained as a basic rate for backward compatibility.

[2]The quoted data rates are without the Bt payload header or Cyclic Redundancy Check and without the Bt packet header. The sustainable mgup data rate also depends on noise conditions and, hence, whether data-link layer Forward Error Correction (FEC) has been turned on.

[3]Further increase in the packet size is restricted and regulated by the need to avoid over occupation of any one ISM frequency.

(ACL) physical link has proved more attractive than a similar predecessor, DECT and its ISM band relative, WDCT's data service. When an IP packet arrives at a Bt master, after removal of UDP/IP headers, it is encapsulated by adding a four-byte Logical Link and Control Adaptation Protocol (L2CAP) header and sent via a Host Computer Interface (HCI) to the appropriate local transmission queue, which acts as a FIFO queue. It is possible to directly pass arriving packets from the HCI to a Bt wireless module [5], without passing through L2CAP to reduce header overhead, but that raises compatibility issues. In general, apart from Bt packet headers, the packet payload is of variable length, up to a slot limit. The Bt packet sizes become especially significant and their affect on user payload are summarized in Table 1 for a single master-slave ACL link. For comparison, the Table includes rates for the earlier Bt version 1.2, to show the gain from employing EDR.

The assumed Bt controller behavior is that, given a maximal Bt packetization scheme, for example 3-DH3 or 3-DH5, 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 used. For example, the controller swaps from 3-DH5 down to 3-DH3 or even 3-DH1. Through noise detection, the controller may also revert to DMI packets, though this possibility does not arise in this study.

This research employed the University of Cincinatti Bluetooth (UCBT) extension[4] to the ns-2 network simulator (v. 2.28 used). The UCBT extension has the advantage that it supports Bt EDR but is also built on the air models of previous Bt extensions such as BlueHoc from IBM and Blueware. Unlike earlier models, the UCBT extension also takes account of clock drift.

[4]Download available from
`http://www.ececs.uc.edu/ cdmc/ucbt/`.

Packet type	User payload (B) v.2 (v.1.2)	Asymmetric max. rate (kbps) v.2 (v.1.2)
DMI	0-17	108.8
DM3	0-121	387.2
DM5	0-224	477.8
2-DH1	0-54(27)	345.6(172.8)
2-DH3	0-367(183)	1174.4(390.4)
2-DH5	0-679(339)	1448.5(433.9)
3-DH1	0-83(27)	531.2(172.8)
3-DH3	0-552(183)	1776.4(390.4)
3-DH5	0-1021(339)	2178.1(723.2)

Table 1: Packet types showing user payload: length and master to slave data rates, for a single ACL master-slave logical link, with DM = Data Medium Rate (no EDR) and DH = Data High Rate, 2-DH3 is 2.0 Mbps modulation three time-slot packet.

3 Results

3.1 Effect of packet length

Fig. 1 shows the 3D graph of the loss rate versus packet size and input rate for constant bit rate traffic arriving at a 3 Mbps EDR ACL link. The transmitter and sender buffers were set at 50 packets, and a 5-slot packet scheme selected. As the physical channel is assumed to be error free, loss occurs through buffer overflow at the sender. There are troughs in the packet loss rate, which deepen as the data rate is increased. It becomes clear that choice of packet length has a significant effect on the goodput.

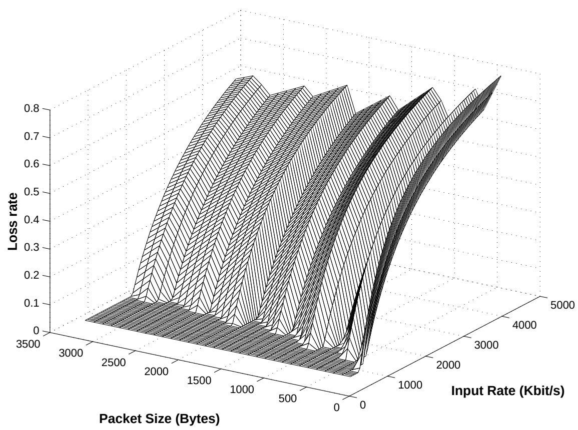

Figure 1: Packet loss versus the input rate and packet length for a 3 Mbps ACL link.

3.2 Video communication

A CIF-sized MPEG-2 encoded video clip, Table 2, was transmitted over an error-free 3-DH5 ACL link. The clip's subject was a newscaster figure at a desk, with a shifting background, displaying events in the news report. 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 Bt master is 450 packet/s. Fig. 2 shows the distribution of slice sizes (equivalently packet sizes)

Feature	Value
Size	352×288 pixel
Color depth	24-bit
Number of frames	18000
Frame rate	25 f/s
Duration	720 s
Input date rate	1.770 Mbps
GOP structure	n=12,m=3

Table 2: MPEG-2 video clip characteristics

for the sample video clip in the simulations. The majority of the packet sizes fall within the range 50 to 850 bytes. This implies an inefficient Bt packetization scheme in terms of the output data rate, as the Bt controller will select one or three slot packets (rather than five-slot packets) for most of the packets. We should also note that any packets with a slightly larger size than the maximum of the defined package sizes in Table 1 (e.g. 3-DH5 packets with user user payload just greater than 1021 B) are inefficient as well. (The controller will sent a full packet for the first portion of the data but the remaining part will be sent in a partially-filled single slot.)

Apart from slice length, the burstiness of the input IP packet stream has a role to play, as this will affect buffer occupancy and, hence, packet loss. 50-packet send/receive buffers were used in these experiments. The maximum slice size from Fig. 2 implies 100 KB receive buffers to gain the same result. Packets arrive at the master for transmission every 2 ms, which assumes no intervening packet dispersion were, for example, the input to be transmitted from a remote server. A simple measure of burstiness was calculated by dividing the peak by the average instantaneous packet throughput over the 3000 packets for the input and single-slice per packet scheme (and two other schemes considered next). Table 3 shows that a single slice scheme results in a bursty input at the receiver and a relatively low average bitrate, principally as a result of inefficient packetization, with some contribution from packet loss, owing to Bt master buffer overflow.

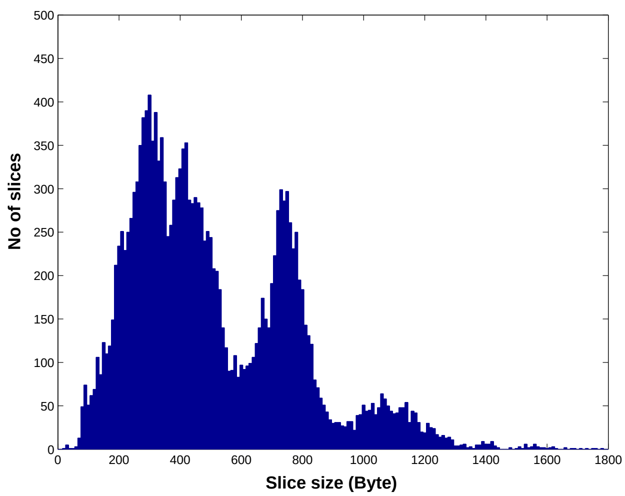

Figure 2: Distribution of slice sizes for a CIF-sized MPEG-2 encoded video clip.

Scheme	Burstiness	Bitrate (Mbps)
Input single-slice IP	3.459	1.77
Single-slice Bt	1.508	1.33
Double-slice Bt	1.289	1.62
Dynamic IP/Bt	1.092	1.77

Table 3: Burstiness against bitrate for various packetization schemes.

3.3 Double slice scheme

It is also possible to group two slices per IP packet, with the distribution in Fig. 3. Fig. 3 is an ideal scenario, in the sense that possible IP packet fragmentation is not accounted for. There is now a shift in arrival packet size to larger sizes, compared to Fig. 2. This does allow the Bt controller to select the larger and more efficient 3-DH3 and 3-DH5 Bt packets. However, there are still packets above the maximum user payload of both those packet types (depending on which was set as the maximum size). There is also packet loss at the Bt sender buffer. However, there is an overall increase in bitrate (compared to the single slice scheme) and a reduction in burstiness, Table 3.

3.4 Dynamic packetization

If slices are split between packets so that each IP packet is fixed in size and exactly matches a Bt 3-DH5 packet then the bitrate is restored to its input value, with a reduction in burstiness (recorded in Table 3 at the Bt slave receiver). As no packet loss occurs, the bitrate across the Bt ACL link is the same as the IP input. The UCBT simulator does not support more than one logical link across one ACL physical link, but a second logical link can be modelled by a second ACL physical link to a second slave. As the Bt channel is shared, the effect is equivalent. Fig. 4 compares the packet loss rate for increasing cross-traffic bit-rate, when the dynamic scheme is self-evidently superior. Note also that only the dynamic scheme has no loss at zero cross-traffic. As Fig. 5 shows, the dynamic scheme rarely requires a buffer-size over

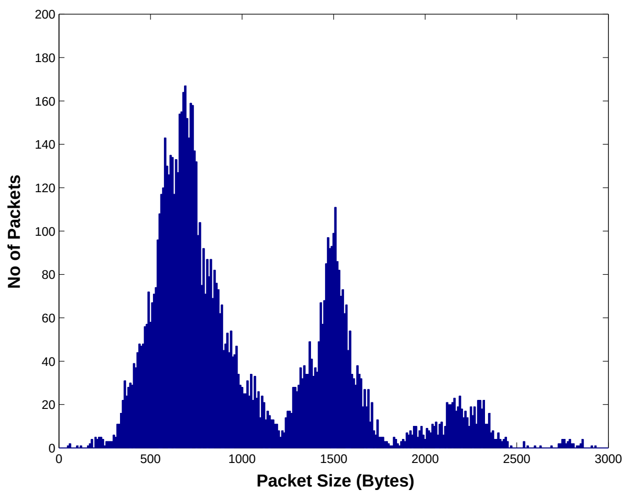

Figure 3: Distribution of packet sizes with each packet consisting of two slices per packet, for a CIF-sized MPEG-2 encoded video clip.

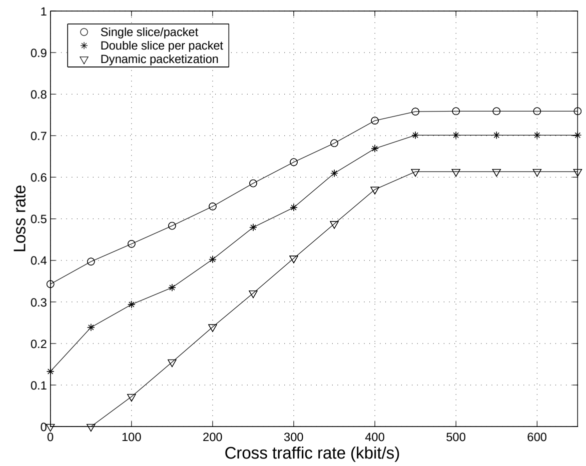

Figure 4: Packet loss rate for different Bt packetization schemes with varying cross-traffic.

Scheme	Mean packet delay (s)	Jitter (variance) $\times 10^{-4}$ (s)
Single-slice Bt	0.158	1.14
Double-slice Bt	0.232	2.97
Dynamic IP/Bt	0.013	0.74

Table 4: Per Bt packet delay for various packetization schemes, with a 50-packet buffer.

ten packets in size. The single-slice scheme quickly completely occupies the buffer, resulting in packet loss as subsequent packets arrive. The only reason why packet loss is less for the two-slice scheme is that there is a slow climb to full occupancy of the buffer (not shown in the Figure).

Delay in the master's buffer will determine the start-up time before the first frame is delivered, whereas jitter may influence the size of the playout buffer at the slave device. Table 4 summarizes the delay, when again a significant improvement arises from the advocated dynamic packetization scheme.

3.5 Slicing issues

In practice, splitting a slice between two packets is not strictly necessary in MPEG-2, as a slice can may take in a fraction of a row of macroblocks. (Unlike MPEG-1, in MPEG-2 a slice cannot extend over more than one row of macroblocks, whereas in MPEG-4 there is a high degree of flexibility, including partial macroblocks.) For an 18-slice scheme, the 32-bit slice overhead at 25 frame/s amounts to 14.4 kbps. On the other hand, because it provides re-synchronization points, the slice structure offers a degree of immunity to channel errors. An ideal scheme would use short slices for macroblocks with significant energy (such as Intra-macroblocks) and long slices for less significant ones (e.g. macroblocks in B-pictures).

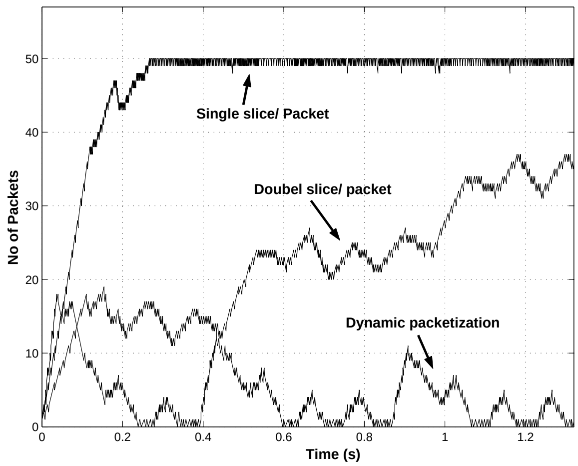

Figure 5: Buffer fullness for different Bt packetization schemes with max. buffer size 50 packets.

4 Conclusion

The packetization scheme vitally effects the received video streams bitrate and loss rate. This is because both these metrics relate to Bluetooth packet length. This paper has shown through a case study that a significant advantage arises from dynamic packetization, increasing the received bitrate, decreasing the delay, and the packet loss rate, with and without congestion. The implication is that remote video servers should be Bluetooth-aware, if streamed video is to be part of such a home entertainment network.

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