Bluetooth Datarate Considerations for Combination of ACL (A2DP) and SCO/eSCO link

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This document describes some theoretical analysis regarding the packet usage in a multi-profile Bluetooth application. The usability of the results in actual implementations strongly depends on the capabilities of the utilized Bluetooth radio!

Requirements:

- Simultaneous high-speed data connection over ACL link and voice connection over SCO/eSCO link
Note: This scenario refers to the scenario of simultaneous connection of an in-car Bluetooth system and other device(s) using the A2DP and Hands Free/Headset Bluetooth profile. Considering current Bt 1.2 radios, it is recommended to reduce the system to these requirements. Having 2 A2DP links or an A2DP link and a simultaneous high-data link (e.g. OBEX transfer of large files, Internet access) might impose great influence on the data rate and therefore the service quality.

- A2DP audio quality requirements
Sampling rate: 32 kHz or higher (standard higher levels are 44.1 kHz and 48 kHz)
Bitpool values – variable (not specified)
Resolution: 16 bits/sample
Channels: 2

Bluetooth Packet Types & Bandwidth

The tables below show the maximum data rate that can be obtained for each Bluetooth packet type (see Bluetooth spec 1.2, page 274).

Type	Payload Header (bytes)	Payload (bytes)	FEC	CRC	Symmetric Max. Rate (kb/s)	Asymmetric Max. Rate (kb/s)	
						Forward	Reverse
DM1	1	0-17	2/3	yes	108.8	108.8	108.8
DH1	1	0-27	no	yes	172.8	172.8	172.8
DM3	2	0-121	2/3	yes	258.1	387.2	54.4
DH3	2	0-183	no	yes	390.4	585.6	86.4
DM5	2	0-224	2/3	yes	286.7	477.8	36.3
DH5	2	0-339	no	yes	433.9	723.2	57.6
AUX1	1	0-29	no	no	185.6	185.6	185.6

Table 6.9: ACL packets

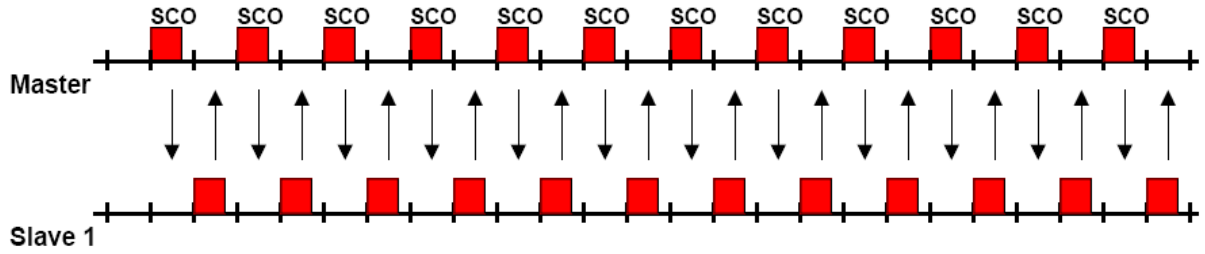
Type	Payload Header (bytes)	Payload (bytes)	FEC	CRC	Symmetric Max. Rate (kb/s)
HV1	na	10	1/3	no	64.0
HV2	na	20	2/3	no	64.0
HV3	na	30	no	no	64.0
DV[1]	1 D	10+(0-9) D	2/3 D	yes D	64.0+57.6 D
EV3	na	1-30	No	Yes	96
EV4	na	1-120	2/3	Yes	192
EV5	na	1-180	No	Yes	288

Table 6.10: Synchronous packets

SCO/eSCO packet types

HV1 packets

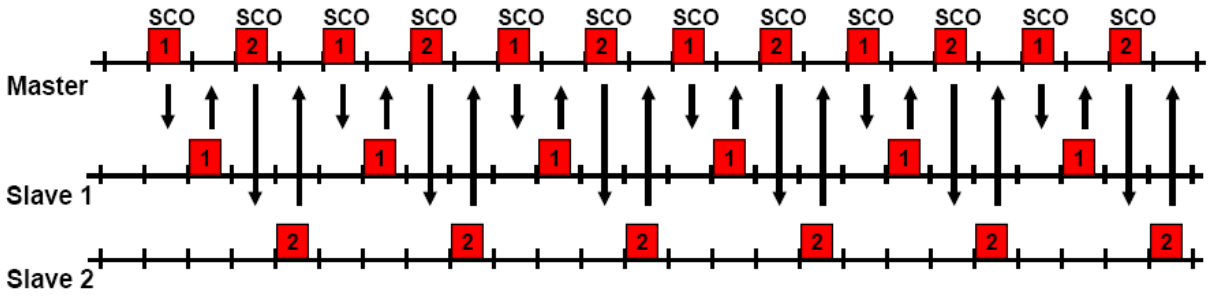
HV1 packets occupy 1 time slot and are transmitted every 2 time lots. That results in a voice data rate of max. 64 kbps.
Voice data is transmitted with a sampling rate of 8 kHz, 8 bits per sample.

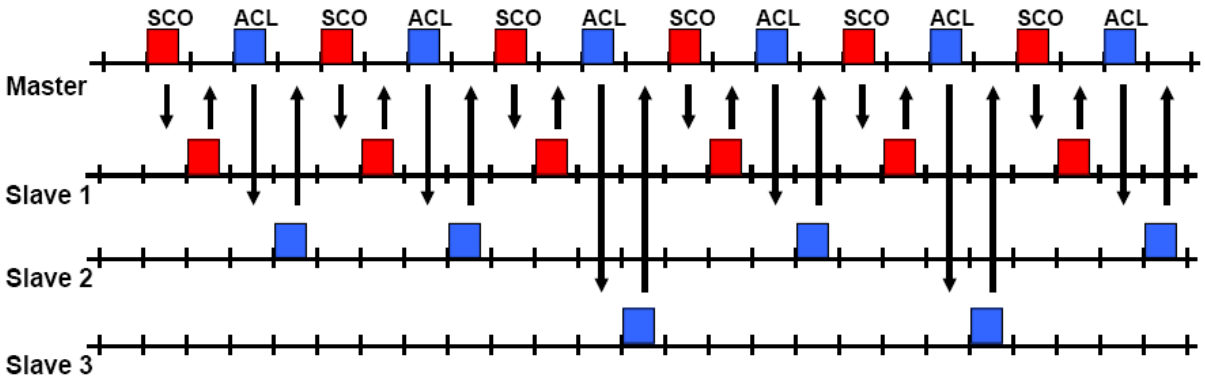


HV1 packets not applicable here, since there is no possibility for simultaneous ACL packets!

HV2 packets

HV2 packets occupy 1 time slot and are transmitted every 4 time lots. That results in a voice data rate of max. 64 kbps.
Voice data is transmitted with a sampling rate of 8 kHz, 8 bits per sample.
The following figure shows 2 SCO Links in one piconet using HV2 packets.

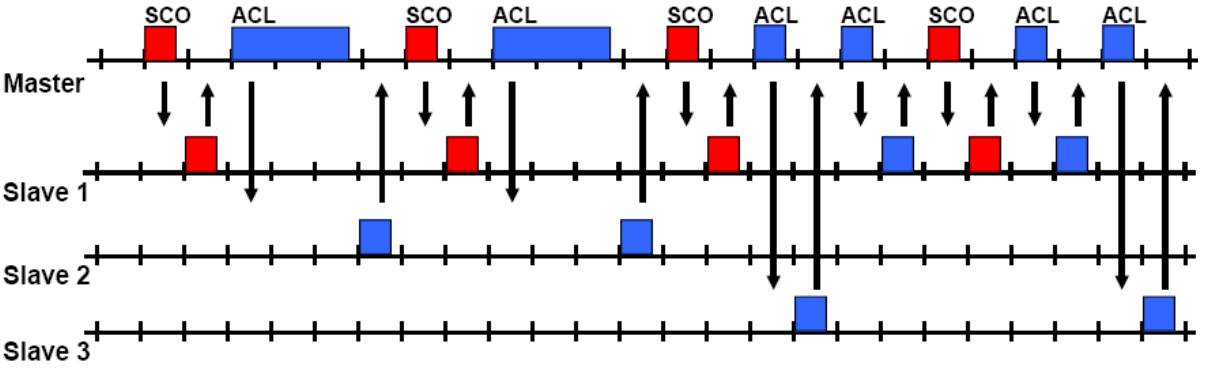




HV3 packets

HV3 packets occupy 1 time slot and are transmitted every 6 time lots. That results in a voice data rate of max. 64 kbps.
Voice data is transmitted with a sampling rate of 8 kHz, 8 bits per sample.

This leaves 5 slots available for ACL transmission. I.e. ACL packet must be no longer than 4 slots.



EV3 packets

EV3 packets occupy 1 time slot and are transmitted every 4 time slots. That results in a voice data rate of max. 96kbps.
Voice data is transmitted with a sampling rate of 12 kHz, 8 bits per sample.
This leaves 3 slots available for ACL transmission. I.e. ACL packet must be no more than 2 slots.

EV4 packets

EV4 packets occupy 3 time slots and are transmitted every 8 time slots. That results in a voice data rate of max. 192kbps.

Voice data is transmitted with a sampling rate of 24 kHz, 8 bits per sample
This leaves 5 slots available for ACL transmission. I.e. ACL packet must be no more than 4 slots.

EV4 will meet the initial requirements and also uses FEC to secure data transmission.

EV5 packets

EV5 packets occupy 5 time slots and are transmitted every 8 time slots. That results in a voice data rate of max. 288kbps.

Voice data is transmitted with a sampling rate of 36 kHz, 8 bits per sample.
This leaves 2 slots available for ACL transmission i.e. ACL packet must be no more than 1 slot.

Conclusion: It appears that HV3 or EV4 packets will leave the most bandwidth available for ACL transmission.

ACL packet types

Considering the usage of the SCO/eSCO packet types of either HV3 or EV4, 4 slots can be used for ACL transmission (and at least 1 slot for response).

This implies that ACL packet types that can be used are restricted to:
– DM3: max. 387kbps data rate, uses FEC
– DH3: max. 585kbps data rate, no FEC
– DM1: max. 108kbps data rate uses FEC
– DH1: max. 172kbps data rate, no FEC

Higher data rates are achievable if FEC is not used. However, this would result in a less robust transmission and a higher percentage of transmissions in an area of higher radio interference.
Thus, it is recommended to use transmissions employing FEC, for a more robust implementation, and only drop to no FEC if necessary.
With this assumption, The DM3 packet type would be best fitted for ACL data.

Combination of voice and data packet types

Resulting from the analysis above, the following combinations of voice and data packet types would be possible for the requirements:

– DM3 ACL packet + EV4 eSCO Packet
SCO data rate is 192kbps (Mono, 24 kHz sampling rate, 8 bits/sample). 4 slots are available for ACL packets, allowing for one DM1 response packet to be received for every DM3 packet sent out. Thus, a DM3 packet can only be sent once every 8 slots. Maximum ACL data rate possible with this combination is 193,600 bps.

- DM3 ACL packet + HV3 SCO Packet
SCO data rate is 64kbps (Mono, 8 kHz sampling rate, 8 bits/sample). 4 slots are available for ACL packets, allowing for one DM1 response packet to be received for every DM3 packet sent out. Thus, a DM3 packet can only be sent once every 6 slots. Maximum ACL data rate possible with this combination is 258,133 bps.

A2DP Audio Quality Parameters

We now need to establish which of the combinations above provides appropriate A2DP audio quality for SBC codec.

A2DP ACL bandwidth is dependent on a number of factors. In general, the bit rate (in kb/s) is calculated by the following formula (see A2DP spec 1.0, chapter 12.9):

$$\mathbf{bit\_rate} = 8 * \mathbf{frame\_length} * f_s / \mathbf{nrof\_subbands} / \mathbf{nrof\_blocks}$$

Here, f_s, *nrof_subbands* and *nrof_blocks* denote sampling frequency, number of sub bands and number of blocks, respectively.
The frame length (*frame_length*) is expressed in bytes and can be calculated for MONO and DUAL_CHANNEL channel modes by:

$$\mathbf{frame\_length} = 4 + (4 * \mathbf{nrof\_subbands} * \mathbf{nrof\_channels}) / 8 + \lceil \mathbf{nrof\_blocks} * \mathbf{nrof\_channels} * \mathbf{bitpool} / 8 \rceil$$

and for the STEREO and JOINT_ STEREO channel modes by:

$$\mathbf{frame\_length} = 4 + (4 * \mathbf{nrof\_subbands} * \mathbf{nrof\_channels}) / 8 + \lceil (\mathbf{join} * \mathbf{nrof\_subbands} + \mathbf{nrof\_blocks} * \mathbf{bitpool}) / 8 \rceil$$

Here, *nrof_channels* and *bitpool* denote number of channels and bit pool value, respectively. When joint stereo is used, *join* = 1, otherwise 0.

The A2DP specification also defines some recommended sets of SBC parameters (see A2DP spec 1.0, chapter 4.3.2.6):

	Middle Quality				High Quality			
SBC encoder settings*	**Mono**		**Joint Stereo**		**Mono**		**Joint Stereo**	
Sampling frequency (kHz)	44.1	48	44.1	48	44.1	48	44.1	48
Bitpool value	19	18	35	33	31	29	53	51
Resulting frame length (bytes)	46	44	83	79	70	66	119	115
Resulting bit rate (kb/s)	127	132	229	237	193	198	328	345
*Other settings: Block length = 16, Allocation method = Loudness, Subbands = 8								

*Table 4.7: Recommended sets of SBC parameters in the **SRC** device*

According this table, the following parameters are assumed fixed for A2DP and SBC:
– Channels: 2 (Joint Stereo mode)
– Resolution: 16 bits/sample/channel
– Block Length: 16
– Sub-bands: 8

The following parameters are assumed variable or selectable:
– Sampling Frequency: Possibilities are 32 kHz, 44.1 kHz and 48 kHz
– Bit pool Value: This is a value that can “empirically” adjust audio quality

Based on these parameters, the resulting data rate can be calculated. The following table provides an idea of the bit rates for a selection of parametric values. Areas shaded yellow can be met only by DM3+HV3 combination (max ACL is below 258,133bps), areas shaded blue can be met by DM3+EV4 combination and DM3+HV3 (max ACL is below 193,600bps):

Sampling frequency (Hz)	Bitpool value	Bit rate (bps)	Quality
48000	51	345,000	High
48000	40	279,000	
48000	37	261,000	
48000	35	249,000	
48000	33	237,000	Middle
48000	30	219,000	
48000	28	207,000	
48000	27	201,000	
44100	37	239,794	
44100	35	228,769	Middle
44100	33	217,744	
44100	30	201,206	
32000	43	198,000	
32000	*41*	*190,000*	
32000	*39*	*182,000*	
32000	*37*	*174,000*	

Summary and Trade-offs

- DM3 ACL packet + EV4 eSCO Packet combination

Does not support mandatory requirements for A2DP compatibility (48 kHz and 44.1 kHz sampling rate are mandatory according to Bt SIG specification). Audio quality is lower than for the other combination, due to lower bit pool values.
The voice link quality is higher than for the other combination and EV4 packets are less vulnerable than HV3 in higher interference surroundings (due to FEC).

- DM3 ACL packet + HV3 SCO Packet combination

Meets the requirements for A2DP profile compatibility (48 kHz and 44.1 kHz sampling rate are mandatory) and provides average audio quality. The voice link quality corresponds to the used 8 kHz sampling rate with 8 bits/sample.

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