Core System Package [Controller volume]
Part B

# BASEBAND SPECIFICATION

***This document describes the specification of the Bluetooth link controller which carries out the baseband protocols and other low-level link routines.***

# CONTENTS

# 1 GENERAL DESCRIPTION

This part specifies the normal operation of a Bluetooth baseband.

The Bluetooth system provides a point-to-point connection or a point-to-multipoint connection, see (a) and (b) in Figure 1.1 on page 63. In a point-to-point connection the physical channel is shared between two Bluetooth devices. In a point-to-multipoint connection, the physical channel is shared among several Bluetooth devices. Two or more devices sharing the same physical channel form a *piconet*. One Bluetooth device acts as the master of the piconet, whereas the other device(s) act as slave(s). Up to seven slaves can be active in the piconet. Additionally, many more slaves can remain connected in a parked state. These parked slaves are not active on the channel, but remain synchronized to the master and can become active without using the connection establishment procedure. Both for active and parked slaves, the channel access is controlled by the master.

Piconets that have common devices are called a *scatternet,* see (c) in Figure 1.1 on page 63. Each piconet only has a single master, however, slaves can participate in different piconets on a time-division multiplex basis. In addition, a master in one piconet can be a slave in other piconets. Piconets shall not be frequency synchronized and each piconet has its own hopping sequence.

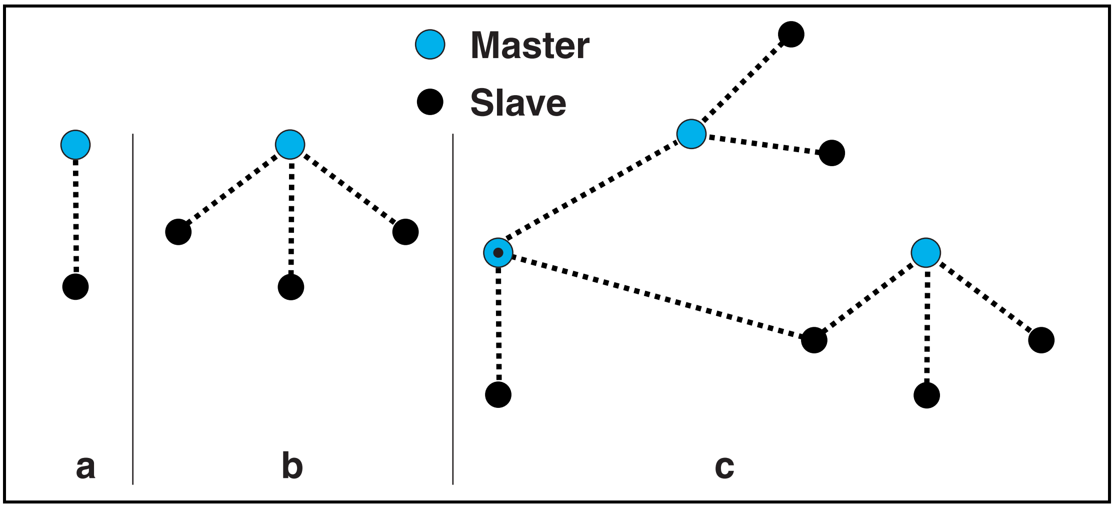


*Figure 1.1: Piconets with a single slave operation (a), a multi-slave operation (b) and a scatternet operation (c).*

Data is transmitted over the air in packets. Two modulation modes are defined: a mandatory mode called Basic Rate and an optional mode called Enhanced Data Rate. The symbol rate for all modulation schemes is 1 Ms/s. The gross air data rate is 1 Mbps for Basic Rate. Enhanced Data Rate has a primary modulation mode that provides a gross air data rate of 2 Mbps, and a secondary modulation mode that provides a gross air data rate of 3 Mbps.

The general Basic Rate packet format is shown in Figure 1.2. Each packet consists of 3 entities: the access code, the header, and the payload.

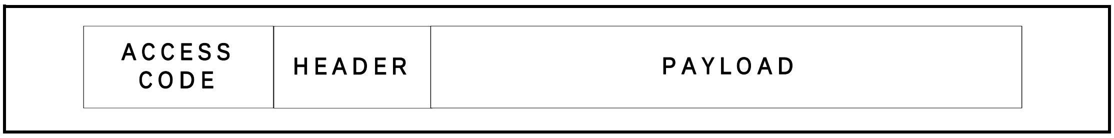


*Figure 1.2: Standard Basic Rate packet format.*

The general Enhanced Data Rate packet format is shown in Standard Enhanced Data Rate packet format. Each packet consists of 6 entities: the access code, the header, the guard period, the synchronization sequence, the Enhanced Data Rate payload and the trailer. The access code and header use the same modulation scheme as for Basic Rate packets while the synchronization sequence, the Enhanced Data Rate payload and the trailer use the Enhanced Data Rate modulation scheme. The guard time allows for the transition between the modulation schemes.

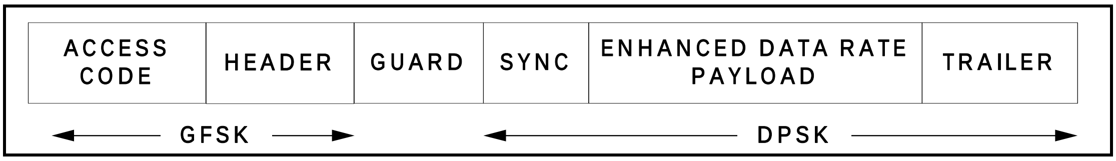


*Figure 1.3: Standard Enhanced Data Rate packet format*

## 1.1 BLUETOOTH CLOCK

Every Bluetooth device shall have a native clock that shall be derived from a free running system clock. For synchronization with other devices, offsets are used that, when added to the native clock, provide temporary Bluetooth clocks that are mutually synchronized. It should be noted that the Bluetooth clock has no relation to the time of day; it may therefore be initialized to any value. The clock has a cycle of about a day. If the clock is implemented with a counter, a 28-bit counter is required that shall wrap around at $2^{28}$-1. The least significant bit (LSB) shall tick in units of 312.5 µs (i.e. half a time slot), giving a clock rate of 3.2 kHz.

The clock determines critical periods and triggers the events in the device. Four periods are important in the Bluetooth system: 312.5 µs, 625 µs, 1.25 ms, and 1.28 s; these periods correspond to the timer bits $CLK_0$, $CLK_1$, $CLK_2$, and $CLK_{12}$, respectively, see Figure 1.4 on page 65.

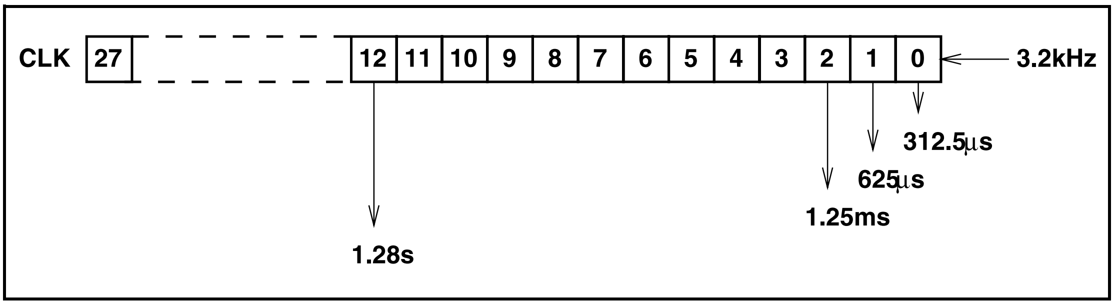


*Figure 1.4: Bluetooth clock.*

In the different modes and states a device can reside in, the clock has different appearances:

- CLKN native clock
- CLKE estimated clock
- CLK master clock

CLKN is the native clock and shall be the reference to all other clock appearances. In STANDBY and in Park, Hold and Sniff mode the native clock may be driven by a low power oscillator (LPO) with worst case accuracy (+/-250ppm). Otherwise, the native clock shall be driven by the reference crystal oscillator with worst case accuracy of +/-20ppm.

See Section 2.2.4 on page 72 for the definition of CLK and Section 2.4.1 on page 76 for the definition of CLKE.

The master shall never adjust its native clock during the existence of the piconet.

## 1.2 BLUETOOTH DEVICE ADDRESSING

Each Bluetooth device shall be allocated a unique 48-bit Bluetooth device address (BD_ADDR). This address shall be obtained from the IEEE Registration Authority. The address is divided into the following three fields:

- LAP field: lower address part consisting of 24 bits
- UAP field: upper address part consisting of 8 bits
- NAP field: non-significant address part consisting of 16 bits

The LAP and UAP form the significant part of the BD_ADDR. The bit pattern in Figure 1.5 is an example BD_ADDR.

| LSB | | | | | | | | | | | MSB |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **company_assigned** | | | | | | **company_id** | | | | | |
| **LAP** | | | | | | **UAP** | | **NAP** | | | |
| 0000 | 0001 | 0000 | 0000 | 0000 | 0000 | 0001 | 0010 | 0111 | 1011 | 0011 | 0101 |

*Figure 1.5: Format of BD_ADDR.*

The BD_ADDR may take any values except the 64 reserved LAP values for general and dedicated inquiries (see Section 1.2.1 on page 66).

### 1.2.1 Reserved addresses

A block of 64 contiguous LAPs is reserved for inquiry operations; one LAP common to all devices is reserved for general inquiry, the remaining 63 LAPs are reserved for dedicated inquiry of specific classes of devices (see Assigned Numbers on the web site[1]). The same LAP values are used regardless of the contents of UAP and NAP. Consequently, none of these LAPs can be part of a user BD_ADDR.

The reserved LAP addresses are 0x9E8B00-0x9E8B3F. The general inquiry LAP is 0x9E8B33. All addresses have the LSB at the rightmost position, hexadecimal notation. The default check initialization (DCI) is used as the UAP whenever one of the reserved LAP addresses is used. The DCI is defined to be 0x00 (hexadecimal).

1. https://www.bluetooth.org/foundry/assignnumb/document/assigned_numbers

## 1.3 ACCESS CODES

In the Bluetooth system all transmissions over the physical channel begin with an access code. Three different access codes are defined, see also Section 6.3.1 on page 111:

- device access code (DAC)
- channel access code (CAC)
- inquiry access code (IAC)

All access codes are derived from the LAP of a device address or an inquiry address. The device access code is used during **page**, **page scan** and **page response** substates and shall be derived from the paged device's BD_ADDR. The channel access code is used in the **CONNECTION** state and forms the beginning of all packets exchanged on the piconet physical channel. The channel access code shall be derived from the LAP of the master's BD_ADDR. Finally, the inquiry access code shall be used in the **inquiry** substate. There is one general IAC (GIAC) for general inquiry operations and there are 63 dedicated IACs (DIACs) for dedicated inquiry operations.

The access code also indicates to the receiver the arrival of a packet. It is used for timing synchronization and offset compensation. The receiver correlates against the entire synchronization word in the access code, providing very robust signalling.

# 2 PHYSICAL CHANNELS

The lowest architectural layer in the Bluetooth system is the physical channel. A number of types of physical channels are defined. All Bluetooth physical channels are characterized by the combination of a pseudo-random frequency hopping sequence, the specific slot timing of the transmissions, the access code and packet header encoding. These aspects, together with the range of the transmitters, define the signature of the physical channel. For the basic and adapted piconet physical channels frequency hopping is used to change frequency periodically to reduce the effects of interference and to satisfy local regulatory requirements.

Two devices that wish to communicate use a shared physical channel for this communication. To achieve this, their transceivers must be tuned to the same RF frequency at the same time, and they must be within a nominal range of each other.

Given that the number of RF carriers is limited and that many Bluetooth devices may be operating independently within the same spatial and temporal area there is a strong likelihood of two independent Bluetooth devices having their transceivers tuned to the same RF carrier, resulting in a physical channel collision. To mitigate the unwanted effects of this collision each transmission on a physical channel starts with an access code that is used as a correlation code by devices tuned to the physical channel. This channel access code is a property of the physical channel. The access code is always present at the start of every transmitted packet.

Four Bluetooth physical channels are defined. Each is optimized and used for a different purpose. Two of these physical channels (the basic piconet channel and adapted piconet channel) are used for communication between connected devices and are associated with a specific piconet. The remaining physical channels are used for discovering (the inquiry scan channel) and connecting (the page scan channel) Bluetooth devices.

A Bluetooth device can only use one of these physical channels at any given time. In order to support multiple concurrent operations the device uses time-division multiplexing between the channels. In this way a Bluetooth device can appear to operate simultaneously in several piconets, as well as being discoverable and connectable.

Whenever a Bluetooth device is synchronized to the timing, frequency and access code of a physical channel it is said to be 'connected' to this channel (whether or not it is actively involved in communications over the channel.) At a minimum, a device need only be capable of connection to one physical channel at a time, however, advanced devices may be capable of connecting simultaneously to more than one physical channel, but the specification does not assume that this is possible.

## 2.1 PHYSICAL CHANNEL DEFINITION

Physical channels are defined by a pseudo-random RF channel hopping sequence, the packet (slot) timing and an access code. The hopping sequence is determined by the UAP and LAP of a Bluetooth device address and the selected hopping sequence. The phase in the hopping sequence is determined by the Bluetooth clock. All physical channels are subdivided into time slots whose length is different depending on the physical channel. Within the physical channel, each reception or transmission event is associated with a time slot or time slots. For each reception or transmission event an RF channel is selected by the hop selection kernel (see Section 2.6 on page 82).The maximum hop rate is 1600 hops/s in the **CONNECTION** state and the maximum is 3200 hops/s in the **inquiry** and **page** substates.

The following physical channels are defined:

- basic piconet physical channel
- adapted piconet physical channel
- page scan physical channel
- inquiry scan physical channel

## 2.2 BASIC PICONET PHYSICAL CHANNEL

During the **CONNECTION** state the basic piconet physical channel is used by default. The adapted piconet physical channel may also be used. The adapted piconet physical channel is identical to the basic piconet physical channel except for the differences listed in Section 2.3 on page 75.

### 2.2.1 Master-slave definition

The basic piconet physical channel is defined by the master of the piconet. The master controls the traffic on the piconet physical channel by a polling scheme. (see Section 8.5 on page 167)

By definition, the device that initiates a connection by paging is the master. Once a piconet has been established, master-slave roles may be exchanged. This is described in Section 8.6.5 on page 175.

### 2.2.2 Hopping characteristics

The basic piconet physical channel is characterized by a pseudo-random hopping through all 79 RF channels. The frequency hopping in the piconet physical channel is determined by the Bluetooth clock and BD_ADDR of the master. When the piconet is established, the master clock is communicated to the slaves. Each slave shall add an offset to its native clock to synchronize with the master clock. Since the clocks are independent, the offsets must be updated regularly. All devices participating in the piconet are time-synchronized and hop-synchronized to the channel.

The basic piconet physical channel uses the basic channel hopping sequence and is described in Section 2.6 on page 82.

### 2.2.3 Time slots

The basic piconet physical channel is divided into time slots, each 625 µs in length. The time slots are numbered according to the most significant 27 bits of the Bluetooth clock $CLK_{28-1}$ of the piconet master. The slot numbering ranges from 0 to $2^{27}$-1 and is cyclic with a cycle length of $2^{27}$. The time slot number is denoted as k.

A TDD scheme is used where master and slave alternatively transmit, see Figure 2.1 on page 71. The packet start shall be aligned with the slot start. Packets may extend over up to five time slots.

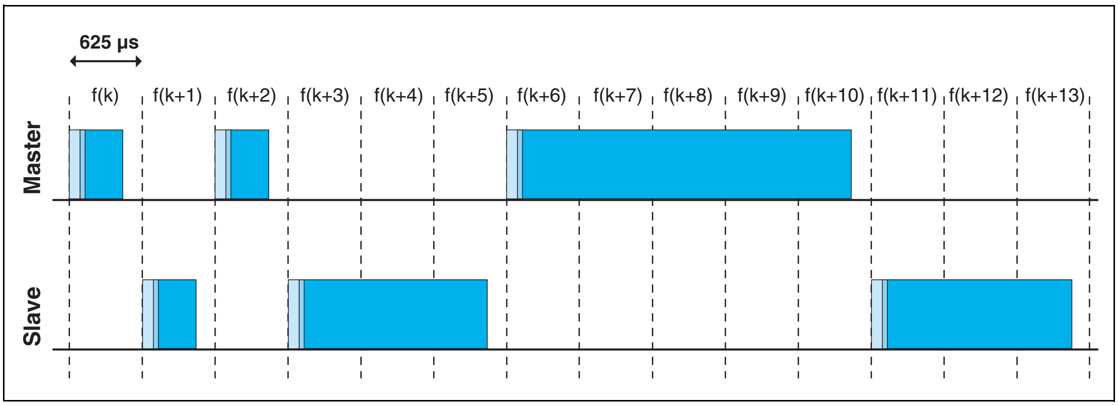


*Figure 2.1: Multi-slot packets*

The term *slot pairs* is used to indicate two adjacent time slots starting with a master-to-slave transmission slot.

### 2.2.4 Piconet clocks

CLK is the master clock of the piconet. It shall be used for all timing and scheduling activities in the piconet. All devices shall use the CLK to schedule their transmission and reception. The CLK shall be derived from the native clock CLKN (see Section 1.1 on page 64) by adding an offset, see Figure 2.2 on page 72. The offset shall be zero for the master since CLK is identical to its own native clock CLKN. Each slave shall add an appropriate offset to its CLKN such that the CLK corresponds to the CLKN of the master. Although all CLKNs in the devices run at the same nominal rate, mutual drift causes inaccuracies in CLK. Therefore, the offsets in the slaves must be regularly updated such that CLK is approximately CLKN of the master.

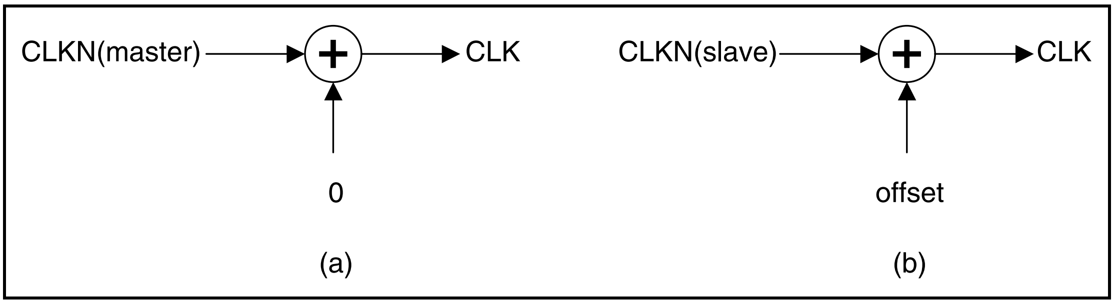


*Figure 2.2: Derivation of CLK in master (a) and in slave (b).*

### 2.2.5 Transmit/receive timing

The master transmission shall always start at even numbered time slots ($CLK_1$=0) and the slave transmission shall always start at odd numbered time slots ($CLK_1$=1). Due to packet types that cover more than a single slot, master transmission may continue in odd numbered slots and slave transmission may continue in even numbered slots, see Figure 2.1 on page 71.

All timing diagrams shown in this chapter are based on the signals as present at the antenna. The term “exact” when used to describe timing refers to an ideal transmission or reception and neglects timing jitter and clock frequency imperfections.

The average timing of packet transmission shall not drift faster than 20 ppm relative to the ideal slot timing of 625 µs. The instantaneous timing shall not deviate more than 1 µs from the average timing. Thus, the absolute packet transmission timing $t_k$ of slot boundary $k$ shall fulfill the equation:

$$t_k = \left( \sum_{i=1}^{k} (1 + d_i) T_N \right) + j_k + \text{offset}, \qquad \text{(EQ 1)}$$

where $T_N$ is the nominal slot length (625 µs), $j_k$ denotes jitter ($|j_k| \le 1$ µs) at the start of slot $k$, and, $d_k$, denotes the drift ($|d_k| \le 20$ ppm) within slot $k$. The jitter and drift may vary arbitrarily within the given limits for every slot, while *offset* is an arbitrary but fixed constant. For hold, park and sniff the drift and jitter parameters specified in Link Manager Protocol [Part C] Section 4.3.1 on page 262 apply.

### *2.2.5.1 Piconet physical channel timing*

In the figures, only single-slot packets are shown as an example.

The master TX/RX timing is shown in Figure 2.3 on page 73. In Figure 2.3 and Figure 2.4 the channel hopping frequencies are indicated by *f(k)* where k is the time slot number. After transmission, a return packet is expected N × 625 μs after the start of the TX packet where N is an odd, integer larger than 0. N depends on the type of the transmitted packet.

To allow for some time slipping, an uncertainty window is defined around the exact receive timing. During normal operation, the window length shall be 20 μs, which allows the RX packet to arrive up to 10 μs too early or 10 μs too late. It is recommended that slaves implement variable sized windows or time tracking to accommodate a master's absence of more than 250ms.

During the beginning of the RX cycle, the access correlator shall search for the correct channel access code over the uncertainty window. If an event trigger does not occur the receiver may go to sleep until the next RX event. If in the course of the search, it becomes apparent that the correlation output will never exceed the final threshold, the receiver may go to sleep earlier. If a trigger event occurs, the receiver shall remain open to receive the rest of the packet unless the packet is for another device, a non-recoverable header error is detected, or a non-recoverable payload error is detected.

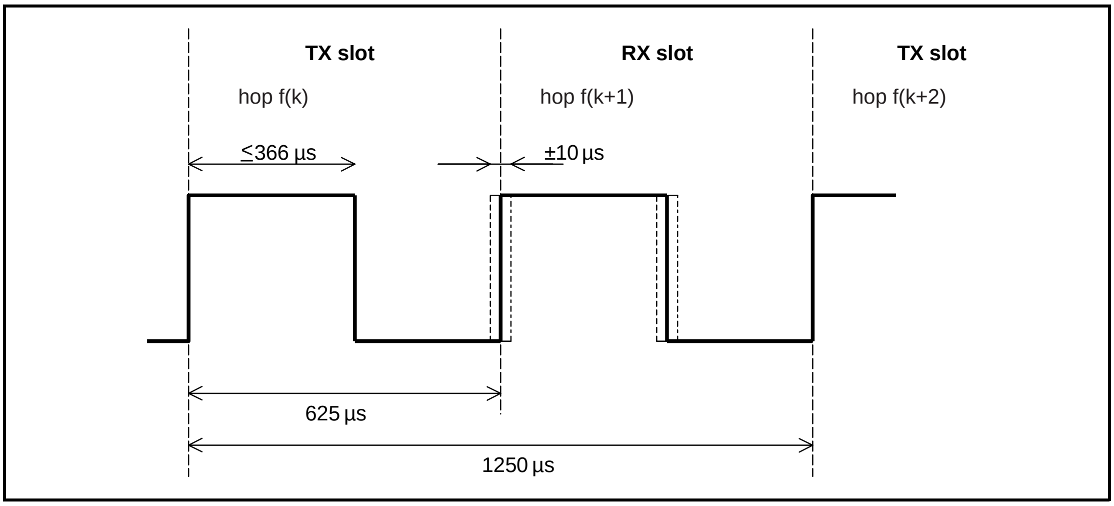


*Figure 2.3: RX/TX cycle of master transceiver in normal mode for single-slot packets.*

Each master transmission shall be derived from bit 2 of the Master's native Bluetooth clock, thus the current transmission will be scheduled Mx1250μs after the start of the previous master TX burst where M depends on the transmitted and received packet type and is an even, integer larger than 0. The master TX timing shall be derived from the master's native Bluetooth clock, and thus it will not be affected by time drifts in the slave(s).

Slaves maintain an estimate of the master's native clock by adding a timing offset to the slave's native clock (see Section 2.2.4 on page 72). This offset shall be updated each time a packet is received from the master. By comparing the exact RX timing of the received packet with the estimated RX timing, slaves shall correct the offset for any timing misalignments. Since only the channel access code is required to synchronize the slave, slave RX timing can be corrected with any packet sent in the master-to-slave transmission slot.

The slave's TX/RX timing is shown in Figure 2.4 on page 74. The slave's transmission shall be scheduled N × 625µs after the start of the slave's RX packet where N is an odd, positive integer larger than 0. If the slave's RX timing drifts, so will its TX timing. During periods when a slave is in the active mode (see Section 8.6 on page 168) and is not able to receive any valid channel access codes from the master, the slave may increase its receive uncertainty window and/or use predicted timing drift to increase the probability of receiving the master's bursts when reception resumes.

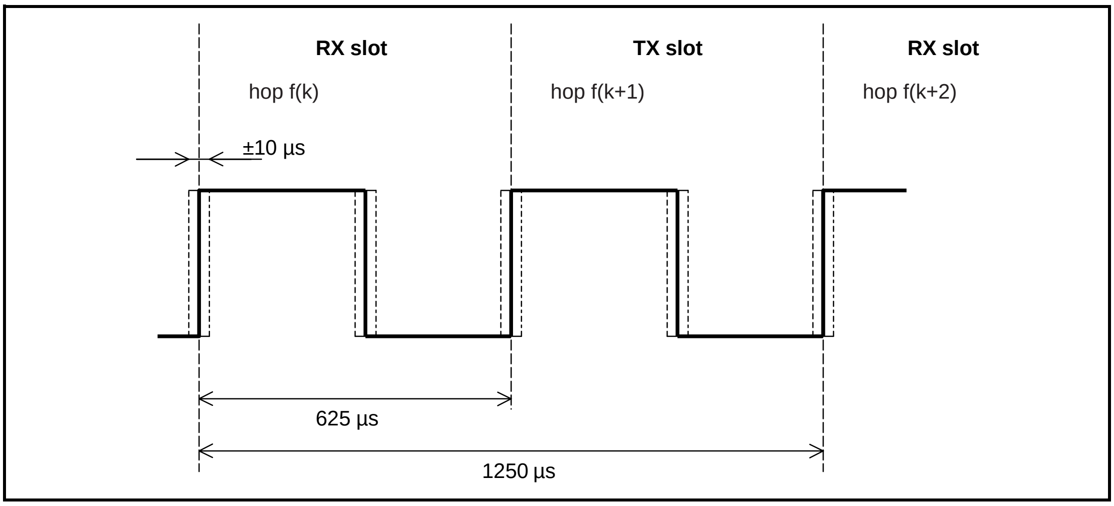


*Figure 2.4: RX/TX cycle of slave transceiver in normal mode for single-slot packets.*

### 2.2.5.2 Piconet physical channel re-synchronization

In the piconet physical channel, a slave may loose synchronization if it does not receive a packet from the master at least every 250ms (or less if the low power clock is used). This may occur in sniff, hold, park, in a scatternet or due to interference. When re-synchronizing to the piconet physical channel a slave device shall listen for the master before it may send information. In this case, the length of the search window in the slave device may be increased from 20 µs to a larger value X µs as illustrated in Figure 2.5 on page 75. Note that only RX hop frequencies are used. The hop frequency used in the master-to-slave (RX) slot shall also be used in the uncertainty window, even when it is extended into the preceding time interval normally used for the slave-to-master (TX) slot.

If the length of search window, X, exceeds 1250 µs, consecutive windows shall avoid overlapping search windows. Consecutive windows should instead be centered at *f(k), f(k+4),... f(k+4i)* (where 'i' is an integer), which gives a maximum value X=2500 µs, or even at *f(k), f(k+6),...f(k+6i)* which gives a maximum value X=3750 µs. The RX hop frequencies used shall correspond to the master-to-slave transmission slots.

It is recommended that single slot packets are transmitted by the master during slave re-synchronization.

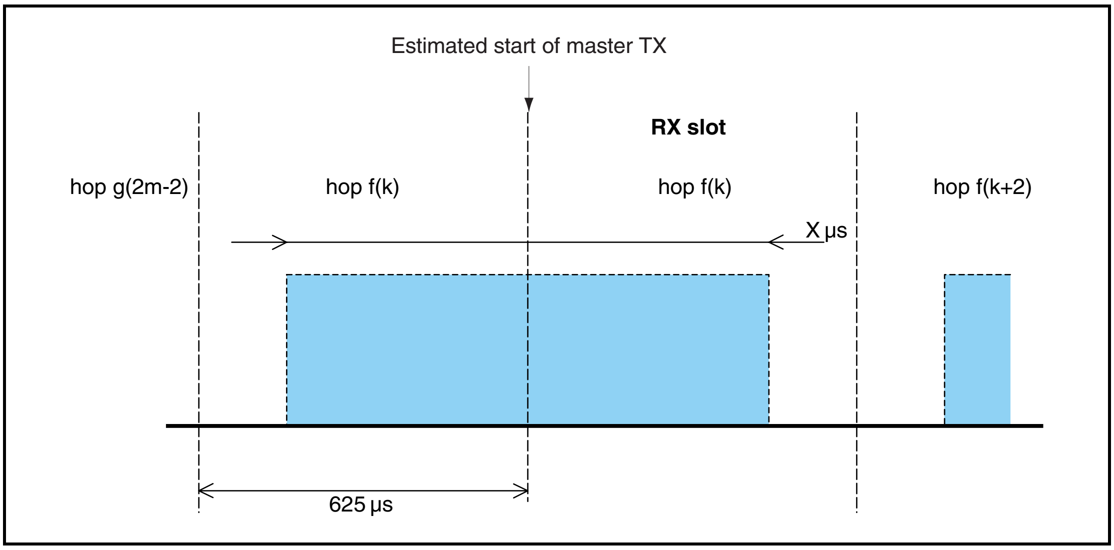


*Figure 2.5: RX timing of slave returning from hold mode.*

## 2.3 ADAPTED PICONET PHYSICAL CHANNEL

### 2.3.1 Hopping characteristics

The adapted piconet physical channel shall use at least $N_{min}$ RF channels (where $N_{min}$ is 20).

The adapted piconet physical channel uses the adapted channel hopping sequence described in Section 2.6 on page 82.

Adapted piconet physical channels can be used for connected devices that have adaptive frequency hopping (AFH) enabled. There are two distinctions between basic and adapted piconet physical channels. The first is that the same channel mechanism that makes the slave frequency the same as the preceding master transmission. The second aspect is that the adapted piconet physical channel may be based on less than the full 79 frequencies of the basic piconet physical channel.

## 2.4 PAGE SCAN PHYSICAL CHANNEL

Although master and slave roles are not defined prior to a connection, the term *master* is used for the paging device (that becomes a master in the **CONNECTION** state) and *slave* is used for the page scanning device (that becomes a slave in the **CONNECTION** state).

### 2.4.1 Clock estimate for paging

A paging device uses an estimate of the native clock of the page scanning device, CLKE; i.e. an offset shall be added to the CLKN of the pager to approximate the CLKN of the recipient, see Figure 2.6 on page 76. CLKE shall be derived from the reference CLKN by adding an offset. By using the CLKN of the recipient, the pager might be able to speed up the connection establishment.

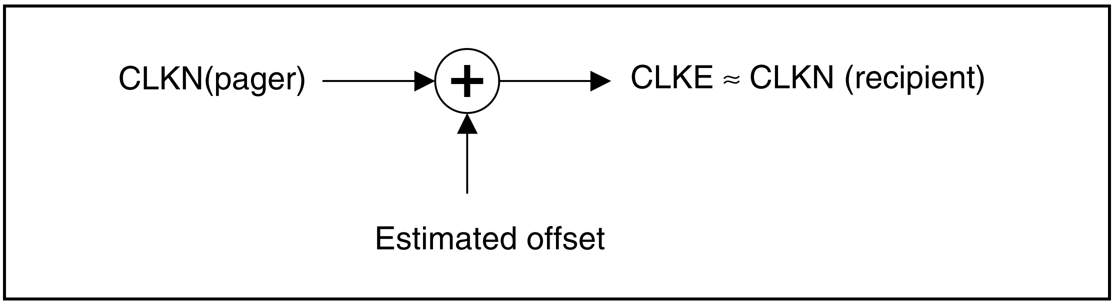


*Figure 2.6: Derivation of CLKE.*

### 2.4.2 Hopping characteristics

The page scan physical channel follows a slower hopping pattern than the basic piconet physical channel and is a short pseudo-random hopping sequence through the RF channels. The timing of the page scan channel shall be determined by the native Bluetooth clock of the scanning device. The frequency hopping sequence is determined by the Bluetooth address of the scanning device.

The page scan physical channel uses the page, master page response, slave page response, and page scan hopping sequences specified in Section 2.6 on page 82.

### 2.4.3 Paging procedure timing

During the paging procedure, the master shall transmit paging messages (see Table 8.3 on page 159) corresponding to the slave to be connected. Since the paging message is a very short packet, the hop rate is 3200 hops/s. In a single TX slot interval, the paging device shall transmit on two different hop frequencies. In Figure 2.7 through Figure 2.11, *f(k)* is used for the frequencies of the page hopping sequence and *f'(k)* denotes the corresponding page response sequence frequencies. The first transmission starts where $CLK_0 = 0$ and the second transmission starts where $CLK_0 = 1$.

In a single RX slot interval, the paging device shall listen for the slave page response message on two different hop frequencies. Similar to transmission, the nominal reception starts where $CLK_0 = 0$ and the second reception nominally starts where $CLK_0 = 1$; see Figure 2.7 on page 77. During the TX slot, the paging device shall send the paging message at the TX hop frequencies *f(k)* and *f*(*k*+1). In the RX slot, it shall listen for a response on the corresponding RX hop frequencies *f'(k)* and *f'*(*k*+1). The listening periods shall be exactly timed 625 µs after the corresponding paging packets, and shall include a ±10 µs uncertainty window.

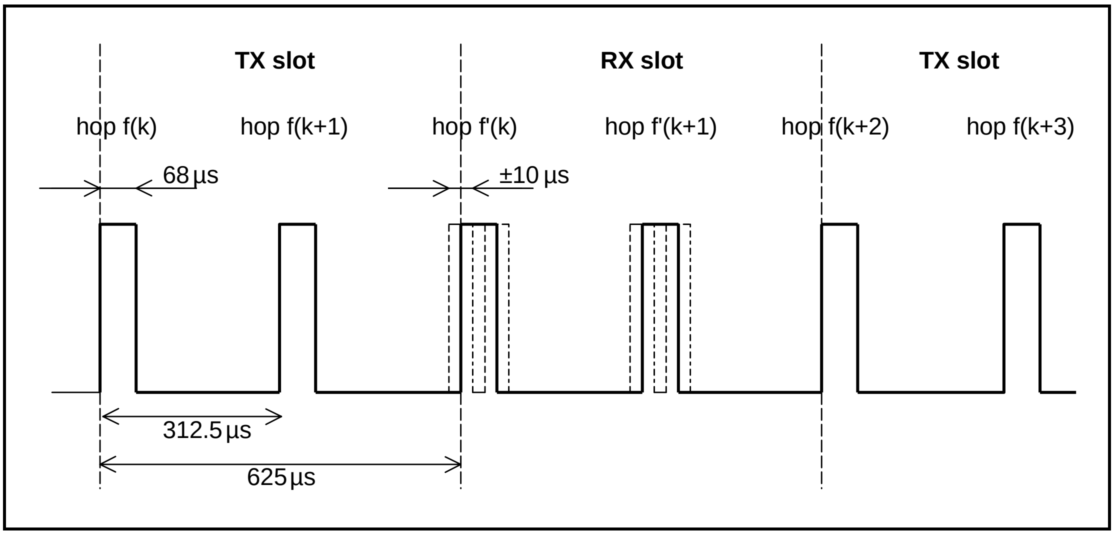


*Figure 2.7: RX/TX cycle of transceiver in PAGE mode.*

### 2.4.4 Page response timing

At connection setup a master page response packet is transmitted from the master to the slave (see Table 8.3 on page 159). This packet establishes the timing and frequency synchronization. After the slave device has received the page message, it shall return a response message that consists of the slave page response packet and shall follow 625 µs after the receipt of the page message. The master shall send the master page response packet in the TX slot following the RX slot in which it received the slave response, according to the RX/TX timing of the master. The time difference between the slave page response and master page response message will depend on the timing of the page message the slave received. In Figure 2.8 on page 78, the slave receives the paging message sent **first** in the master-to-slave slot. It then responds with a first slave page response packet in the first half of the slave-to-master slot. The timing of the master page response packet is based on the timing of the page message sent first in the preceding master-to-slave slot: there is an exact 1250 µs delay between the first page message and the master page response packet. The packet is sent at the hop frequency *f(k*+1*)* which is the hop frequency following the hop frequency *f(k)* the page message was received in.

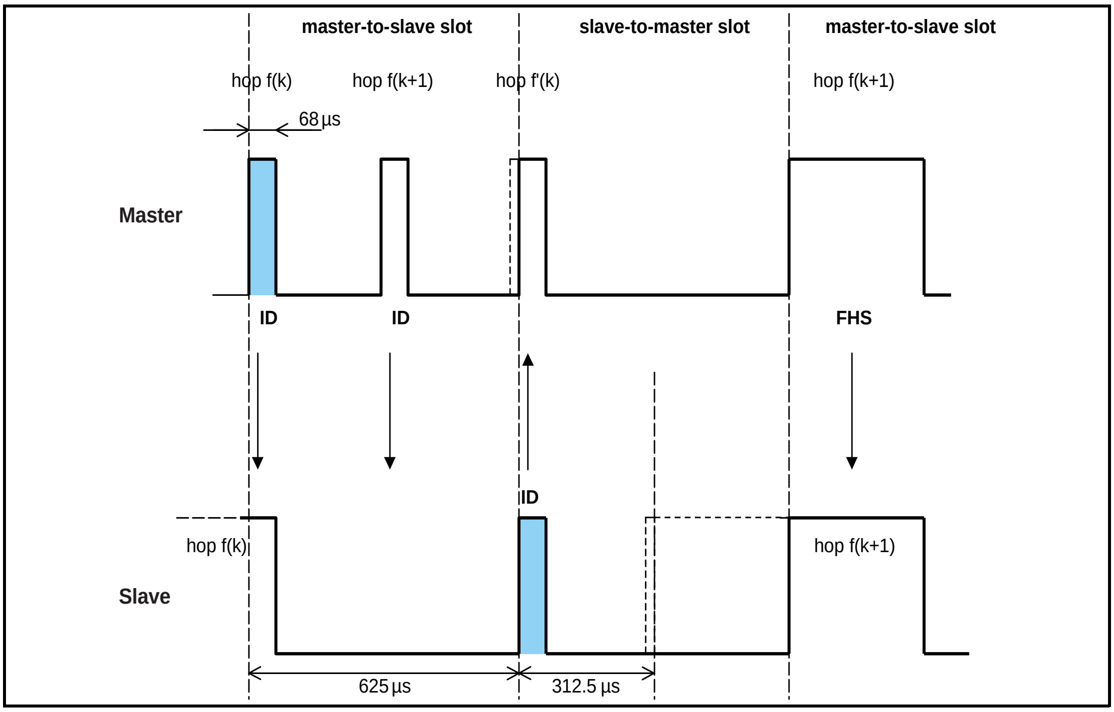


*Figure 2.8: Timing of page response packets on successful page in first half slot*

In Figure 2.9 on page 79, the slave receives the paging message sent **second** in the master-to-slave slot. It then responds with a slave page response packet in the second half of the slave-to-master slot exactly 625 µs after the receipt of the page message. The timing of the master page response packet is still based on the timing of the page message sent **first** in the preceding master-to-slave slot: there is an exact 1250 µs delay between the **first** page message and the master page response packet. The packet is sent at the hop frequency *f*(*k*+2*)* which is the hop frequency following the hop frequency *f*(*k*+1*)* the page message was received in.

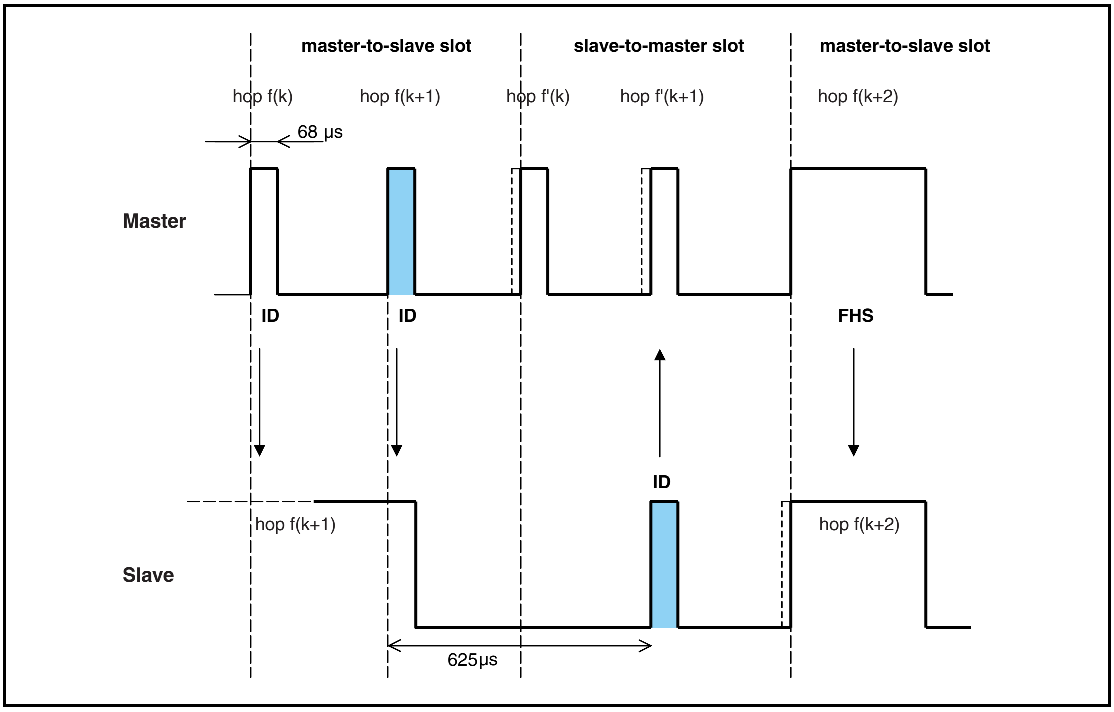


*Figure 2.9: Timing of page response packets on successful page in second half slot*

The slave shall adjust its RX/TX timing according to the reception of the master page response packet (and not according to the reception of the page message). That is, the second slave page response message that acknowledges the reception of the master page response packet shall be transmitted 625 µs after the start of the master page response packet.

## 2.5 INQUIRY SCAN PHYSICAL CHANNEL

Although master and slave roles are not defined prior to a connection, the term *master* is used for the inquiring device and *slave* is used for the inquiry scanning device.

### 2.5.1 Clock for inquiry

The clock used for inquiry and inquiry scan shall be the device's native clock.

### 2.5.2 Hopping characteristics

The inquiry scan channel follows a slower hopping pattern than the piconet physical channel and is a short pseudo-random hopping sequence through the RF channels. The timing of the inquiry scan channel is determined by the native Bluetooth clock of the scanning device while the frequency hopping sequence is determined by the general inquiry access code.

The inquiry scan physical channel uses the inquiry, inquiry response, and inquiry scan hopping sequences described in Section 2.6 on page 82.

### 2.5.3 Inquiry procedure timing

During the inquiry procedure, the master shall transmit inquiry messages with the general or dedicated inquiry access code. The timing for inquiry is the same as for paging (see Section 2.4.3 on page 77).

### 2.5.4 Inquiry response timing

An inquiry response packet is transmitted from the slave to the master after the slave has received an inquiry message (see Table 8.5 on page 167). This packet contains information necessary for the inquiring master to page the slave (see definition of the FHS packet in Section 6.5.1.4 on page 120) and follows 625μs after the receipt of the inquiry message. In Figure 2.10 and Figure 2.11, *f(k)* is used for the frequencies of the inquiry hopping sequence and f'(k) denotes the corresponding inquiry response sequence frequency. The packet is received by the master at the hop frequency *f'(k)* when the inquiry message received by the slave was first in the master-to-slave slot.

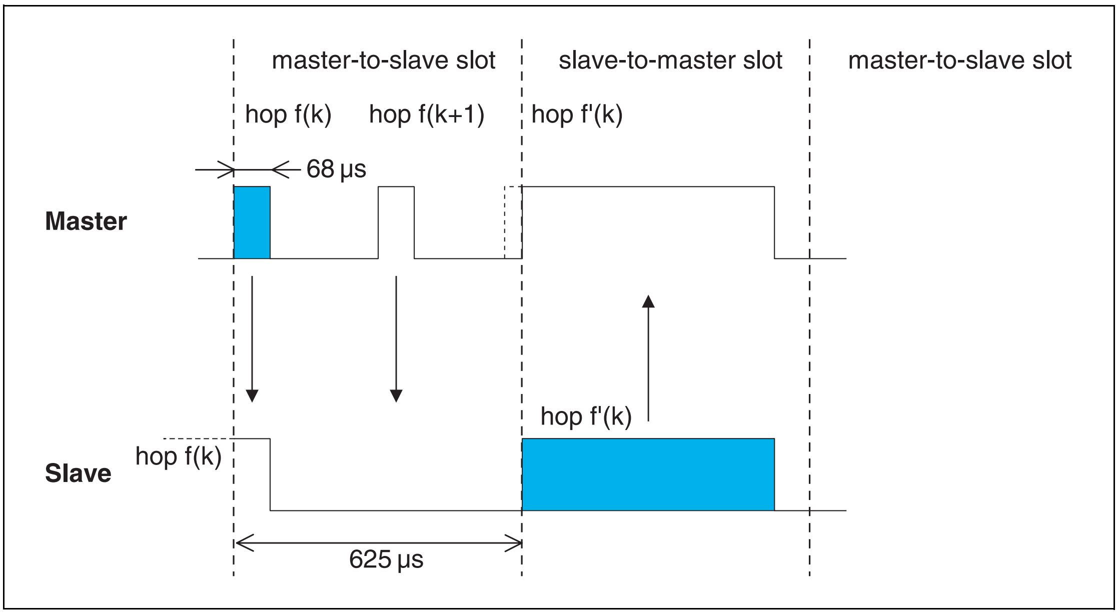


*Figure 2.10: Timing of inquiry response packet on successful inquiry in first half slot*

When the inquiry message received by the slave was the second in the master-to-slave slot the packet is received by the master at the hop frequency *f'(k+1)*.

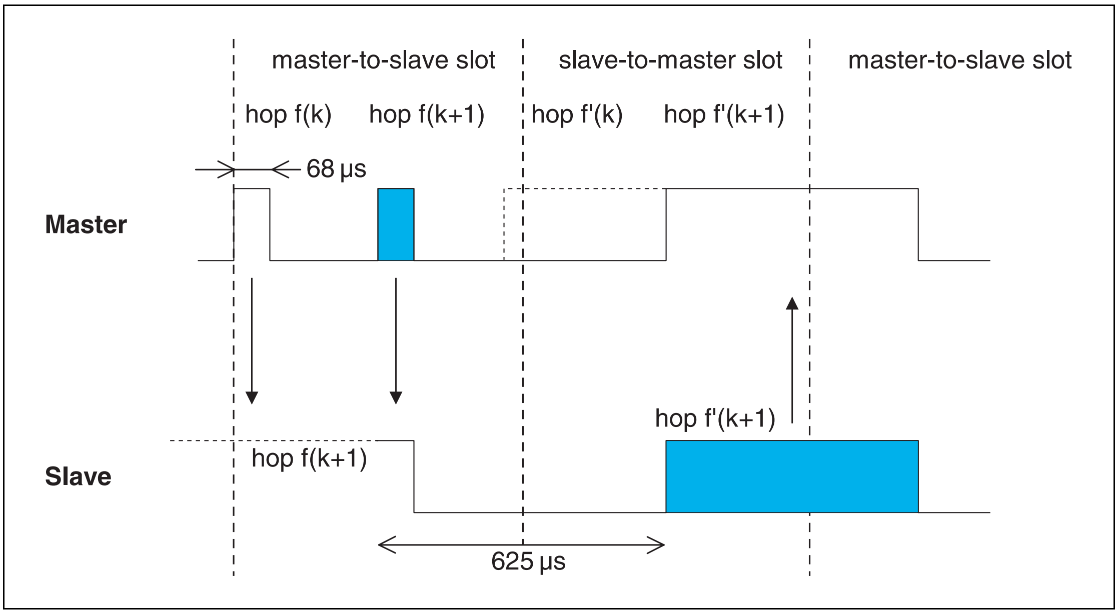


*Figure 2.11: Timing of inquiry response packet on successful inquiry in second half slot*

## 2.6 HOP SELECTION

Bluetooth devices shall use the hopping kernel as defined in the following sections.

In total, six types of hopping sequence are defined – five for the basic hop system and one for an adapted set of hop locations used by adaptive frequency hopping (AFH). These sequences are:

- A **page hopping sequence** with 32 wake-up frequencies distributed equally over the 79 MHz, with a period length of 32;
- A **page response hopping sequence** covering 32 response frequencies that are in a one-to-one correspondence to the current page hopping sequence. The master and slave use different rules to obtain the same sequence;
- An **inquiry hopping sequence** with 32 wake-up frequencies distributed equally over the 79 MHz, with a period length of 32;
- An **inquiry response hopping sequence** covering 32 response frequencies that are in a one-to-one correspondence to the current inquiry hopping sequence.
- A **basic channel hopping sequence** which has a very long period length, which does not show repetitive patterns over a short time interval, and which distributes the hop frequencies equally over the 79 MHz during a short time interval.
- An **adapted channel hopping sequence** derived from the basic channel hopping sequence which uses the same channel mechanism and may use fewer than 79 frequencies. The adapted channel hopping sequence is only used in place of the basic channel hopping sequence. All other hopping sequences are not affected by hop sequence adaptation.

### 2.6.1 General selection scheme

The selection scheme consists of two parts:

- selecting a sequence;
- mapping this sequence onto the hop frequencies;

The general block diagram of the hop selection scheme is shown in Figure 2.12 on page 83. The mapping from the input to a particular RF channel index is performed in the selection box.

The inputs to the selection box are the selected clock, frozen clock, N, $k_{offset}$, address, sequence selection and AFH_channel_map. The source of the clock input depends on the hopping sequence selected. Additionally, each hopping sequence uses different bits of the clock (see Table 2.2 on page 91). N and $k_{offset}$ are defined in Section 2.6.4 on page 90.

The *sequence selection* input can be set to the following values:

- page scan
- inquiry scan
- page
- inquiry
- master page response
- slave page response
- inquiry response
- basic channel
- adapted channel

The address input consists of 28 bits including the entire LAP and the 4 LSBs of the UAP. This is designated as the UAP/LAP. When the basic or adapted channel hopping sequence is selected, the Bluetooth device address of the master (BD_ADDR) shall be used. When the page, master page response, slave page response, or page scan hopping sequences are selected the BD_ADDR given by the Host of the paged device shall be used (see HCI Create Connection Command [Part E] Section 7.1.5 on page 406). When the inquiry, inquiry response, or inquiry scan hopping sequences are selected, the UAP/LAP corresponding to the GIAC shall be used even if it concerns a DIAC. Whenever one of the reserved BD_ADDRs (see Section 1.2.1 on page 66) is used for generating a frequency hop sequence, the UAP shall be replaced by the default check initialization (DCI, see Section 7.1 on page 138). The hopping sequence is selected by the sequence selection input to the selection box.

When the adapted channel hopping sequence is selected, the *AFH_channel_map* is an additional input to the selection box. The *AFH_channel_map* indicates which channels shall be *used* and which shall be *unused*. These terms are defined in Section 2.6.3 on page 89.

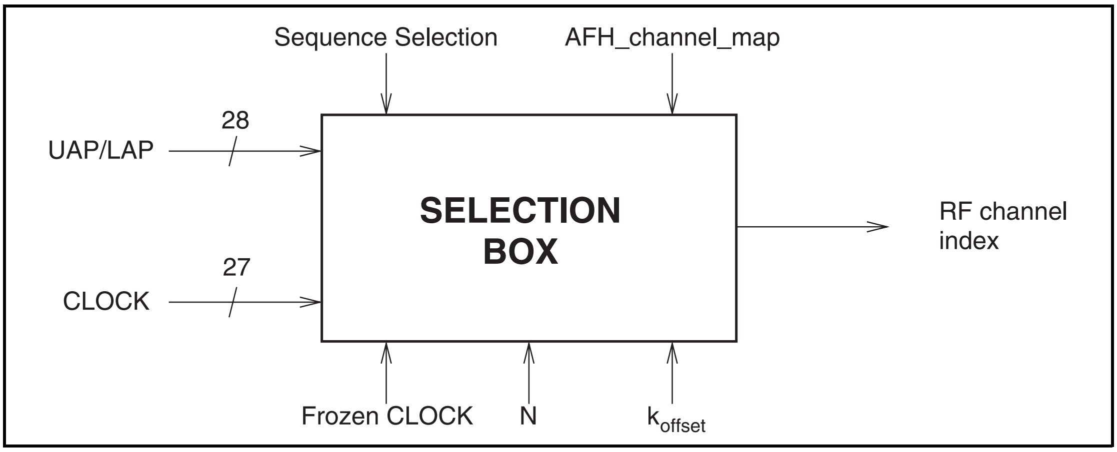


*Figure 2.12: General block diagram of hop selection scheme.*

The output, *RF channel index*, constitutes a pseudo-random sequence. The RF channel index is mapped to RF channel frequencies using the equation in Table 2.1 on page 29 in the Radio Specification.

The selection scheme chooses a segment of 32 hop frequencies spanning about 64 MHz and visits these hops in a pseudo-random order. Next, a different 32-hop segment is chosen, etc. In the page, master page response, slave page response, page scan, inquiry, inquiry response and inquiry scan hopping sequences, the same 32-hop segment is used all the time (the segment is selected by the address; different devices will have different paging segments). When the basic channel hopping sequence is selected, the output constitutes a pseudo-random sequence that slides through the 79 hops. The principle is depicted in Figure 2.13 on page 84.

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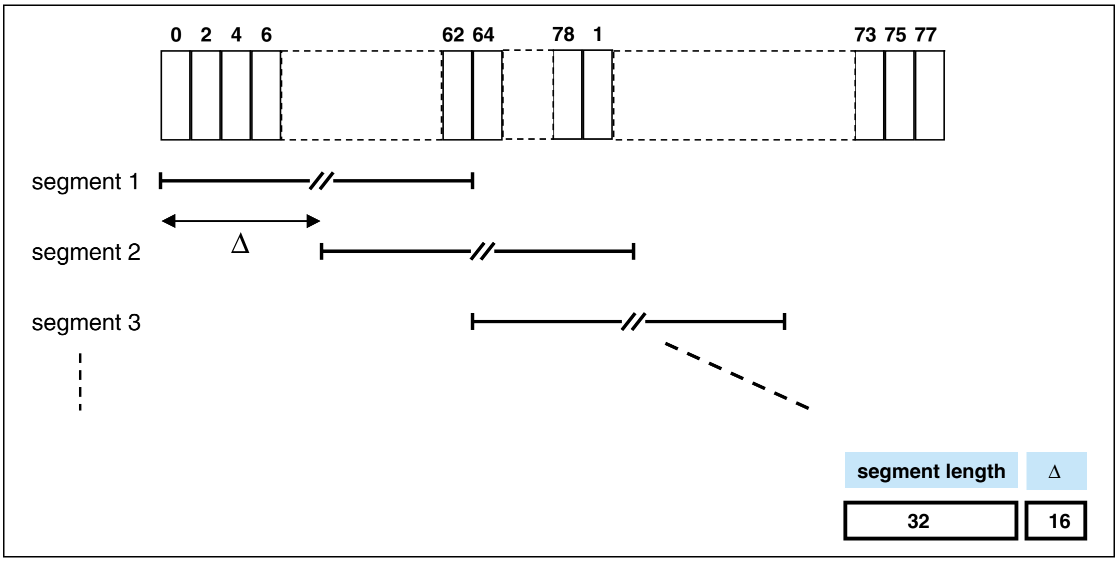


*Figure 2.13: Hop selection scheme in CONNECTION state.*

The RF frequency shall remain fixed for the duration of the packet. The RF frequency for the packet shall be derived from the Bluetooth clock value in the first slot of the packet. The RF frequency in the first slot after a multi-slot packet shall use the frequency as determined by the Bluetooth clock value for that slot. Figure 2.14 on page 85 illustrates the hop definition on single- and multi-slot packets.

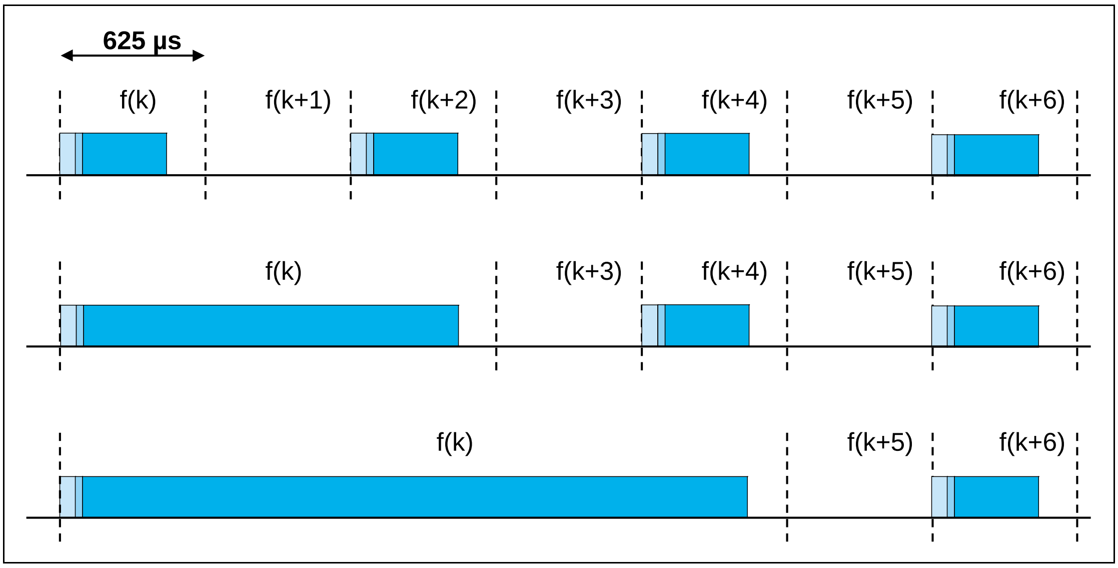


*Figure 2.14: Single- and multi-slot packets.*

When the adapted channel hopping sequence is used, the pseudo-random sequence contains only frequencies that are in the RF channel set defined by the *AFH_channel_map* input. The adapted sequence has similar statistical properties to the non-adapted hop sequence. In addition, the slave responds with its packet on the same RF channel that was used by the master to address that slave (or would have been in the case of a synchronous reserved slot without a validly received master-to-slave transmission). This is called the *same channel mechanism* of AFH. Thus, the RF channel used for the master to slave packet is also used for the immediately following slave to master packet. An example of the same channel mechanism is illustrated in Figure 2.15 on page 85. The same channel mechanism shall be used whenever the adapted channel hopping sequence is selected.

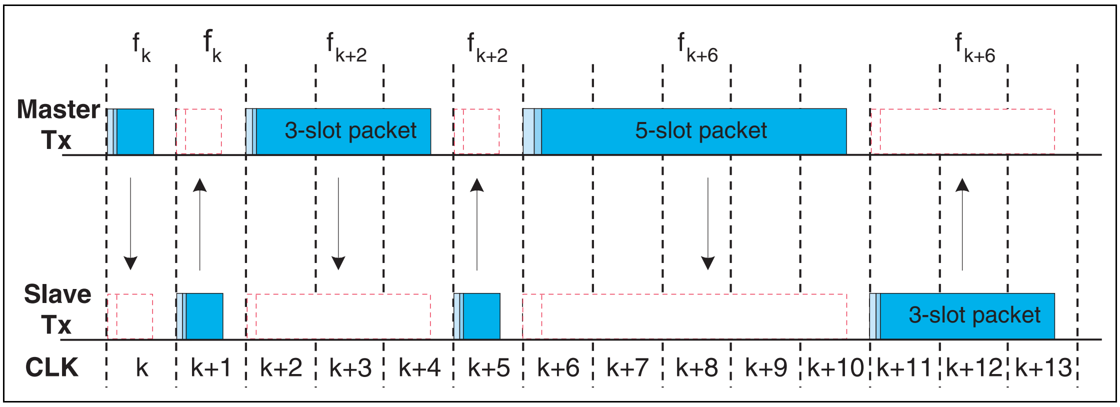


*Figure 2.15: Example of the same channel mechanism.*

### 2.6.2 Selection kernel

The basic hop selection kernel shall be as shown in Figure 2.16 on page 86 and is used for the page, page response, inquiry, inquiry response and basic channel hopping selection kernels. In these substates the AFH_channel_map input is unused. The adapted channel hopping selection kernel is described in Section 2.6.3 on page 89. The X input determines the phase in the 32-hop segment, whereas Y1 and Y2 selects between master-to-slave and slave-to-master. The inputs A to D determine the ordering within the segment, the inputs E and F determine the mapping onto the hop frequencies. The kernel addresses a register containing the RF channel indices. This list is ordered so that first all even RF channel indices are listed and then all odd hop frequencies. In this way, a 32-hop segment spans about 64 MHz.

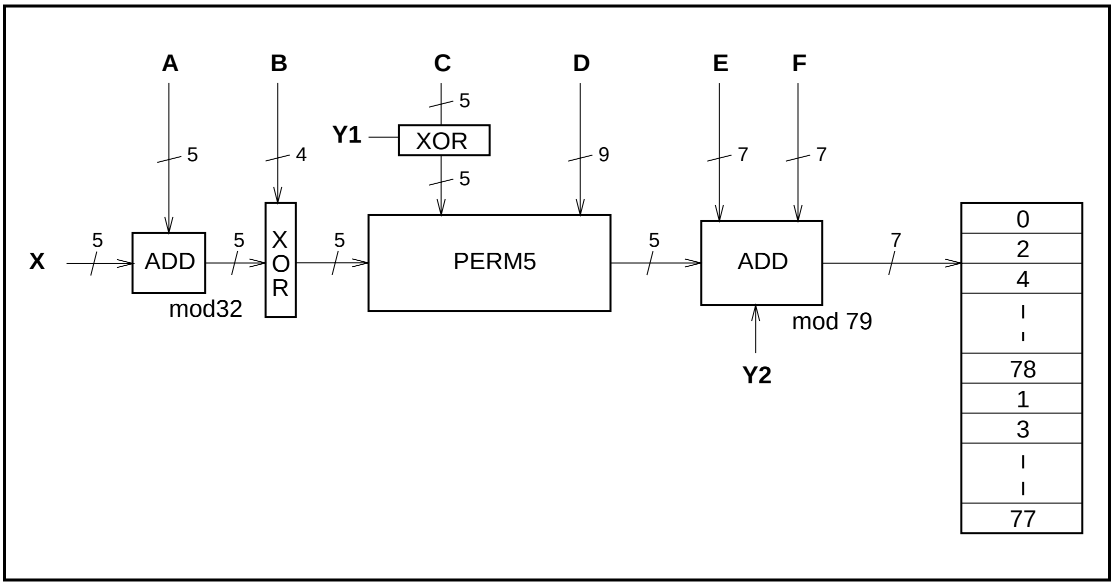


*Figure 2.16: Block diagram of the basic hop selection kernel for the hop system.*

The selection procedure consists of an addition, an XOR operation, a permutation operation, an addition, and finally a register selection. In the remainder of this chapter, the notation $A_i$ is used for bit i of the BD_ADDR.

#### *2.6.2.1 First addition operation*

The first addition operation only adds a constant to the phase and applies a modulo 32 operation. For the page hopping sequence, the first addition is redundant since it only changes the phase within the segment. However, when different segments are concatenated (as in the basic channel hopping sequence), the first addition operation will have an impact on the resulting sequence.

### 2.6.2.2 XOR operation

Let Z' denote the output of the first addition. In the XOR operation, the four LSBs of Z' are modulo-2 added to the address bits $A_{22\text{-}19}$. The operation is illustrated in Figure 2.17 on page 87.

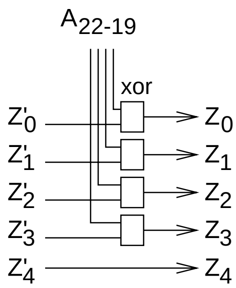


*Figure 2.17: XOR operation for the hop system.*

### 2.6.2.3 Permutation operation

The permutation operation involves the switching from 5 inputs to 5 outputs for the hop system, controlled by the control word. The permutation or switching box shall be as shown in Figure 2.18 on page 88. It consists of 7 stages of butterfly operations. The control of the butterflies by the control signals P is shown in Table 2.1. $P_{0\text{-}8}$ corresponds to $D_{0\text{-}8}$, and, $P_{i+9}$ corresponds to $C_i \oplus Y1$ for $i = 0 \ldots 4$ in Figure 2.16.

| Control signal | Butterfly | | Control signal | Butterfly |
|---|---|---|---|---|
| $P_0$ | $\{Z_0,Z_1\}$ | | $P_8$ | $\{Z_1,Z_4\}$ |
| $P_1$ | $\{Z_2,Z_3\}$ | | $P_9$ | $\{Z_0,Z_3\}$ |
| $P_2$ | $\{Z_1,Z_2\}$ | | $P_{10}$ | $\{Z_2,Z_4\}$ |
| $P_3$ | $\{Z_3,Z_4\}$ | | $P_{11}$ | $\{Z_1,Z_3\}$ |
| $P_4$ | $\{Z_0,Z_4\}$ | | $P_{12}$ | $\{Z_0,Z_3\}$ |
| $P_5$ | $\{Z_1,Z_3\}$ | | $P_{13}$ | $\{Z_1,Z_2\}$ |
| $P_6$ | $\{Z_0,Z_2\}$ | | | |
| $P_7$ | $\{Z_3,Z_4\}$ | | | |

*Table 2.1: Control of the butterflies for the hop system*

The Z input is the output of the XOR operation as described in the previous section. The butterfly operation can be implemented with multiplexers as depicted in Figure 2.19 on page 88.

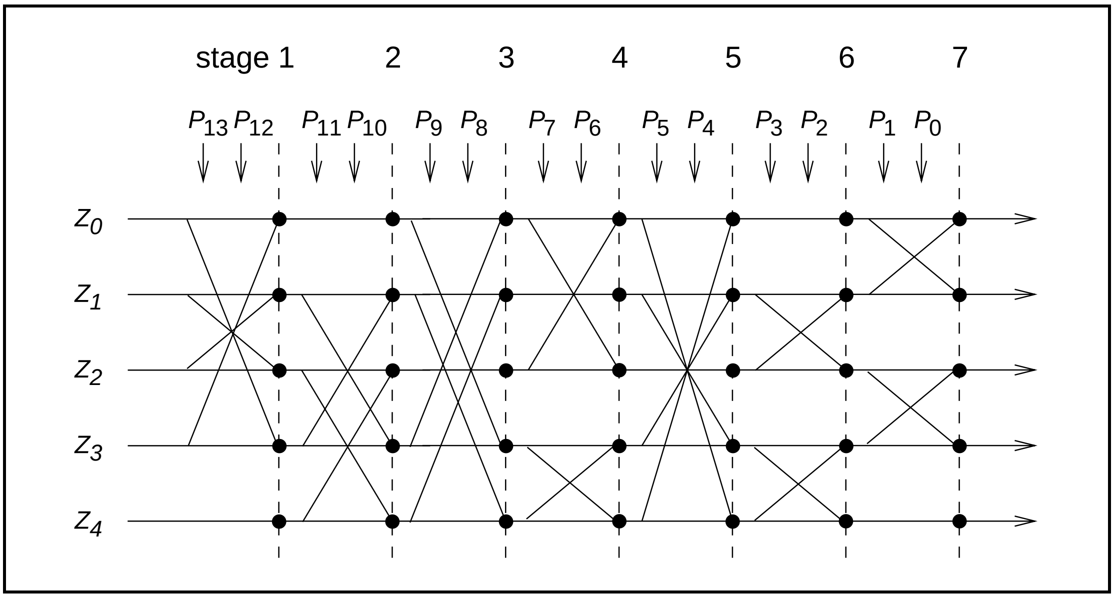


*Figure 2.18: Permutation operation for the hop system.*

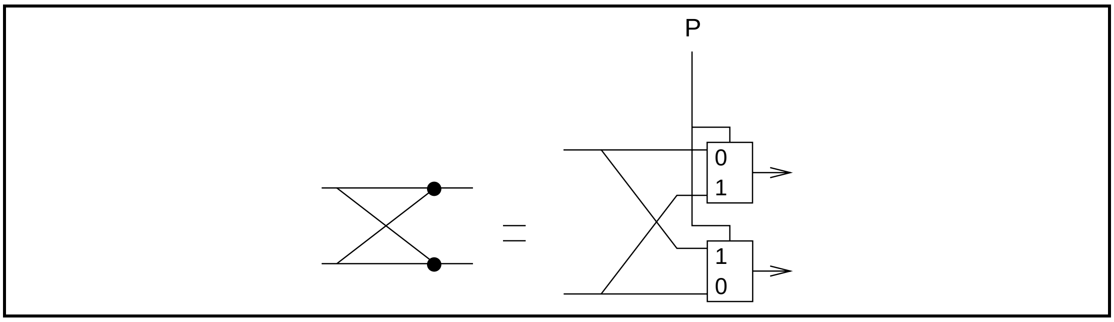


*Figure 2.19: Butterfly implementation.*

## 2.6.2.4 Second addition operation

The addition operation only adds a constant to the output of the permutation operation. The addition is applied modulo 79.

## 2.6.2.5 Register bank

The output of the adder addresses a bank of 79 registers. The registers are loaded with the synthesizer code words corresponding to the hop frequencies 0 to 78. Note that the upper half of the bank contains the even hop frequencies, whereas the lower half of the bank contains the odd hop frequencies.

### 2.6.3 Adapted hop selection kernel

The adapted hop selection kernel is based on the basic hop selection kernel defined in the preceding sections.

The inputs to the adapted hop selection kernel are the same as for the basic hop system kernel except that the input AFH_channel_map (defined in Link Manager Protocol [Part C] Section 5.2 on page 303) is used. The *AFH_channel_map* indicates which RF channels shall be *used* and which shall be *unused*. When hop sequence adaptation is enabled, the number of *used* RF channels may be reduced from 79 to some smaller value N. All devices shall be capable of operating on an adapted hop sequence (AHS) with $N_{min} \le N \le 79$, with any combination of *used* RF channels within the *AFH_channel_map* that meets this constraint. $N_{min}$ is defined in Section 2.3.1 on page 75.

Adaptation of the hopping sequence is achieved through two additions to the basic channel hopping sequence according to Figure 2.16 on page 86:

- *Unused* RF channels are re-mapped uniformly onto *used* RF channels. That is, if the hop selection kernel of the basic system generates an *unused* RF channel, an alternative RF channel out of the set of *used* RF channels is selected pseudo-randomly.
- The *used* RF channel generated for the master-to-slave packet is also used for the immediately following slave-to-master packet (see Section 2.6.1 on page 82).

#### *2.6.3.1 Channel re-mapping function*

When the adapted hop selection kernel is selected, the basic hop selection kernel according to Figure 2.16 on page 86 is initially used to determine an RF channel. If this RF channel is *unused* according to the *AFH_channel_map*, the *unused* RF channel is re-mapped by the re-mapping function to one of the *used* RF channels. If the RF channel determined by the basic hop selection kernel is already in the set of *used* RF channels, no adjustment is made. The hop sequence of the (non-adapted) basic hop equals the sequence of the adapted selection kernel on all locations where *used* RF channels are generated by the basic hop. This property facilitates non-AFH slaves remaining synchronized while other slaves in the piconet are using the adapted hopping sequence.

A block diagram of the re-mapping mechanism is shown in Figure 2.20 on page 90. The re-mapping function is a post-processing step to the selection kernel from Figure 2.16 on page 86, denoted as 'Hop selection of the basic hop'. The output $f_k$ of the basic hop selection kernel is an RF channel number that ranges between 0 and 78. This RF channel will either be in the set of *used* RF channels or in the set of *unused* RF channels.

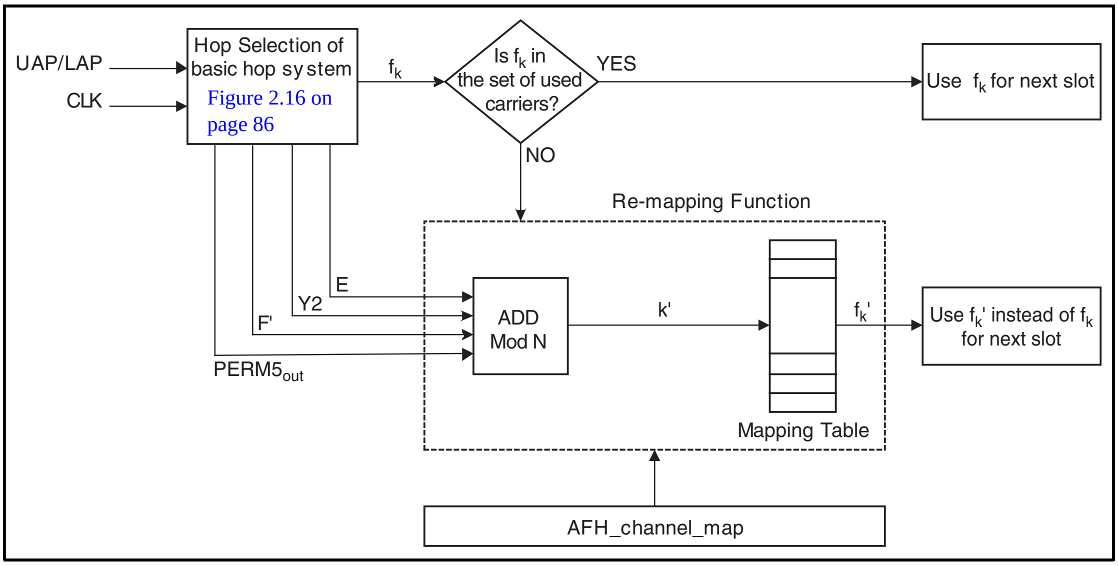


*Figure 2.20: Block diagram of adaptive hop selection mechanism*

When an unused RF channel is generated by the basic hop selection mechanism, it is re-mapped to the set of *used* RF channels as follows. A new index $k' \in \{0, 1, ..., N-1\}$ is calculated using some of the parameters from the basic hop selection kernel:

$$k' = (PERM5_{out} + E + F' + Y2) \bmod N$$

where *F'* is defined in Table 2.2 on page 91. The index *k'* is then used to select the re-mapped channel from a mapping table that contains all of the even *used* RF channels in ascending order followed by all the odd *used* RF channels in ascending order (i.e., the mapping table of Figure 2.16 on page 86 with all the *unused* RF channels removed).

### 2.6.4 Control word

In the following section $X_{j-i}$, $i<j$, will denote bits $i, i+1, ..., j$ of the bit vector X. By convention, $X_0$ is the least significant bit of the vector X.

The control word of the kernel is controlled by the overall control signals X, Y1, Y2, A to F, and F' as illustrated in Figure 2.16 on page 86 and Figure 2.20 on page 90. During paging and inquiry, the inputs A to E use the address values as given in the corresponding columns of Table 2.2 on page 91. In addition, the inputs X, Y1 and Y2 are used. The F and F' inputs are unused. The clock bits $CLK_{6-2}$ (i.e., input X) specifies the phase within the length 32 sequence. $CLK_1$ (i.e., inputs Y1 and Y2) is used to select between TX and RX. The address inputs determine the sequence order within segments. The final mapping onto the hop frequencies is determined by the register contents.

During the **CONNECTION** state (see Section 8.5 on page 167), the inputs A, C and D shall be derived from the address bits being bit-wise XORed with the clock bits as shown in the "Connection state" column of Table 2.2 on page 91 (the two most significant bits, MSBs, are XORed together, the two second MSBs are XORed together, etc.).

| | **Page scan / Interlaced Page Scan / Inquiry scan / Interlaced Inquiry Scan** | **Page/Inquiry** | **Master/Slave page response and Inquiry response** | **Connection state** |
|---|---|---|---|---|
| X | $\mathrm{CLKN}_{16-12}$/ $(\mathrm{CLKN}_{16-12}+16)mod32$/ $Xir_{4-0}$/ $Xir_{4-0}+16)mod32$ | $Xp_{4-0}/Xi_{4-0}$ | $Xprm_{4-0}$/ $Xprs_{4-0}$/ $Xir_{4-0}$ | $\mathrm{CLK}_{6-2}$ |
| Y1 | 0 | $\mathrm{CLKE}_1/\mathrm{CLKN}_1$ | $\mathrm{CLKE}_1/\mathrm{CLKN}_1/1$ | $\mathrm{CLK}_1$ |
| Y2 | 0 | $32\times\mathrm{CLKE}_1/$ $32\times\mathrm{CLKN}_1$ | $32\times\mathrm{CLKE}_1$ / $32\times\mathrm{CLKN}_1$ / $32\times1$ | $32\times\mathrm{CLK}_1$ |
| A | $A_{27-23}$ | $A_{27-23}$ | $A_{27-23}$ | $A_{27-23}\oplus\mathrm{CLK}_{25-21}$ |
| B | $A_{22-19}$ | $A_{22-19}$ | $A_{22-19}$ | $A_{22-19}$ |
| C | $A_{8,6,4,2,0}$ | $A_{8,6,4,2,0}$ | $A_{8,6,4,2,0}$ | $A_{8,6,4,2,0}\oplus\mathrm{CLK}_{20-16}$ |
| D | $A_{18-10}$ | $A_{18-10}$ | $A_{18-10}$ | $A_{18-10}\oplus\mathrm{CLK}_{15-7}$ |
| E | $A_{13,11,9,7,5,3,1}$ | $A_{13,11,9,7,5,3,1}$ | $A_{13,11,9,7,5,3,1}$ | $A_{13,11,9,7,5,3,1}$ |
| F | 0 | 0 | 0 | $16\times\mathrm{CLK}_{27-7}\bmod 79$ |
| F' | n/a | n/a | n/a | $16\times\mathrm{CLK}_{27-7}\bmod N$ |

*Table 2.2: Control for hop system.*

The five X input bits vary depending on the current state of the device. In the **page scan** and **inquiry scan** substates, the native clock (CLKN) shall be used. In **CONNECTION** state the master clock (CLK) shall be used as input. The situation is somewhat more complicated for the other states.

#### 2.6.4.1 Page scan and inquiry scan hopping sequences

When the sequence selection input is set to page scan, the Bluetooth device address of the scanning device shall be used as address input. When the sequence selection input is set to inquiry scan, the GIAC LAP and the four LSBs of the DCI (as $A_{27-24}$), shall be used as address input for the hopping sequence. For the transmitted access code and in the receiver correlator, the appropriate GIAC or DIAC shall be used. The application decides which inquiry access code to use depending on the purpose of the inquiry.

### 2.6.4.2 Page hopping sequence

When the sequence selection input is set to page, the paging device shall start using the **A**-train, i.e., $\{f(k-8), \ldots, f(k), \ldots, f(k+7)\}$ , where $f(k)$ is the source's estimate of the current receiver frequency in the paged device. The index $k$ is a function of all the inputs in Figure 2.16. There are 32 possible paging frequencies within each 1.28 second interval. Half of these frequencies belong to the **A**-train, the rest (i.e., $\{f(k+8), \ldots, f(k+15), f(k-16), \ldots, f(k-9)\}$ ) belong to the **B**-train. In order to achieve the -8 offset of the **A**-train, a constant of 24 shall be added to the clock bits (which is equivalent to -8 due to the modulo 32 operation). The **B**-train is obtained by setting the offset to 8. A cyclic shift of the order within the trains is also necessary in order to avoid a possible repetitive mismatch between the paging and scanning devices. Thus,

$$Xp = [\mathrm{CLKE}_{16-12} + k_{offset} + (\mathrm{CLKE}_{4-2,0} - \mathrm{CLKE}_{16-12}) \mod 16] \mod 32, \qquad \text{(EQ 2)}$$

where

$$k_{offset} = \begin{cases} 24 & \text{A-train,} \\ 8 & \text{B-train.} \end{cases} \qquad \text{(EQ 3)}$$

Alternatively, each switch between the **A**- and **B**-trains may be accomplished by adding 16 to the current value of $k_{offset}$ (originally initialized with 24).

### 2.6.4.3 Slave page response hopping sequence

When the sequence selection input is set to *slave page response,* in order to eliminate the possibility of losing the link due to discrepancies of the native clock CLKN and the master's clock estimate CLKE, the four bits $\mathrm{CLKN}_{16-12}$ shall be frozen at their current value. The value shall be frozen at the content it has in the slot where the recipient's access code is detected. The native clock shall *not* be stopped; it is merely the values of the bits used for creating the X-input that are kept fixed for a while. A frozen value is denoted by an asterisk (*) in the discussion below.

For each response slot the paged device shall use an X-input value one larger (modulo 32) than in the preceding response slot. However, the first response shall be made with the X-input kept at the same value as it was when the access code was recognized. Let $N$ be a counter starting at zero. Then, the X-input in the $(N+1)$-th response slot (the first response slot being the one immediately following the page slot now responding to) of the **slave response** substate is:

$$Xprs = [\mathrm{CLKN}^{*}_{16-12} + N] \mod 32, \qquad \text{(EQ 4)}$$

The counter $N$ shall be set to zero in the slot where the slave acknowledges the page (see Figure 8.3 on page 160 and Figure 8.4 on page 160). Then, the value of $N$ shall be increased by one each time $\mathrm{CLKN}_1$ is set to zero, which corresponds to the start of a master TX slot. The X-input shall be constructed this way until the first **FHS** packet is received *and* the immediately following response packet has been transmitted. After this the slave shall enter the **CONNECTION** state using the parameters received in the **FHS** packet.

### 2.6.4.4 Master page response hopping sequence

When the sequence selection input is set to *master page response*, the master shall freeze its estimated slave clock to the value that triggered a response from the paged device. It is equivalent to using the values of the clock estimate when receiving the slave response (since only $\mathrm{CLKE}_1$ will differ from the corresponding page transmission). Thus, the values are frozen when the slave **ID** packet is received. In addition to the clock bits used, the current value of $k_{offset}$ shall also be frozen. The master shall adjust its X-input in the same way the paged device does, i.e., by incrementing this value by one for each time $\mathrm{CLKE}_1$ is set to zero. The first increment shall be done before sending the **FHS** packet to the paged device. Let $N$ be a counter starting at one. The rule for forming the X-input is:

$$Xprm = [\mathrm{CLKE}^*_{16-12} + k_{offset}{}^* + (\mathrm{CLKE}^*_{4-2,0} - \mathrm{CLKE}^*_{16-12}) \bmod 16 + N] \bmod 32, \qquad \text{(EQ 5)}$$

The value of $N$ shall be increased each time $\mathrm{CLKE}_1$ is set to zero, which corresponds to the start of a master TX slot.

### 2.6.4.5 Inquiry hopping sequence

When the sequence selection input is set to *inquiry*, the X-input is similar to that used in the *page hopping sequence*. Since no particular device is addressed, the native clock CLKN of the inquirer shall be used. Moreover, which of the two train offsets to start with is of no real concern in this state. Consequently,

$$Xi = [\mathrm{CLKN}_{16-12} + k_{offset} + (\mathrm{CLKN}_{4-2,0} - \mathrm{CLKN}_{16-12}) \bmod 16] \bmod 32, \qquad \text{(EQ 6)}$$

where $k_{offset}$ is defined by (EQ 3) on page 92. The initial choice of the offset is arbitrary.

The GIAC LAP and the four LSBs of the DCI (as $A_{27-24}$) shall be used as address input for the hopping sequence generator.

### *2.6.4.6 Inquiry response hopping sequence*

The *inquiry response* hopping sequence is similar to the *slave page response* hopping sequence with respect to the X-input. The clock input shall not be frozen, thus the following equation apply:

$$Xir = [\mathrm{CLKN}_{16-12} + N] \bmod 32, \qquad \text{(EQ 7)}$$

Furthermore, the counter $N$ is increased not on $\mathrm{CLKN}_1$ basis, but rather after each **FHS** packet has been transmitted in response to the inquiry. There is no restriction on the initial value of $N$ as it is independent of the corresponding value in the inquiring unit.

The GIAC LAP and the four LSBs of the DCI (as $A_{27-24}$) shall be used as address input for the hopping sequence generator. The other input bits to the generator shall be the same as for page response.

### *2.6.4.7 Basic and adapted channel hopping sequence*

In the *basic* and *adapted channel hopping sequences*, the clock bits to use in the basic or adapted hopping sequence generation shall always be derived from the master clock, CLK. The address bits shall be derived from the Bluetooth device address of the master.

# 3 PHYSICAL LINKS

A physical link represents a baseband connection between devices. A physical link is always associated with exactly one physical channel. Physical links have common properties that apply to all logical transports on the physical link.

The common properties of physical links are:

- Power control (see Link Manager Protocol Section 4.1.3 on page 235)
- Link supervision (see Section 3.1 on page 95 and Link Manager Protocol Section 4.1.6 on page 242)
- Encryption (see Security [Part H] Section 4 on page 787 and Link Manager Protocol [Part C] Section 4.2.5 on page 257)
- Channel quality-driven data rate change (see Link Manager Protocol Section 4.1.7 on page 243)
- Multi-slot packet control (see Link Manager Protocol Section 4.1.10 on page 247)

## 3.1 LINK SUPERVISION

A connection can break down due to various reasons such as a device moving out of range, encountering severe interference or a power failure condition. Since this may happen without any prior warning, it is important to monitor the link on both the master and the slave side to avoid possible collisions when the logical transport address (see Section 4.2 on page 97) or parked member address (see Section 4.7.1 on page 105) is reassigned to another slave.

To be able to detect link loss, both the master and the slave shall use a link supervision timer, $T_{supervision}$. Upon reception of a valid packet header with one of the slave's addresses (see Section 4.2 on page 97) on the physical link, the timer shall be reset. If at any time in **CONNECTION** state, the timer reaches the *supervisionTO* value, the connection shall be considered disconnected. The same link supervision timer shall be used for SCO, eSCO, and ACL logical transports.

The timeout period, *supervisionTO*, is negotiated by the Link Manager. Its value shall be chosen so that the supervision timeout will be longer than hold and sniff periods. Link supervision of a parked slave shall be done by unparking and re-parking the slave.

# 4 LOGICAL TRANSPORTS

## 4.1 GENERAL

Between master and slave(s), different types of logical transports may be established. Five logical transports have been defined:

- Synchronous Connection-Oriented (SCO) logical transport
- Extended Synchronous Connection-Oriented (eSCO) logical transport
- Asynchronous Connection-Oriented (ACL) logical transport
- Active Slave Broadcast (ASB) logical transport
- Parked Slave Broadcast (PSB) logical transport

The synchronous logical transports are point-to-point logical transports between a master and a single slave in the piconet. The synchronous logical transports typically support time-bounded information like voice or general synchronous data. The master maintains the synchronous logical transports by using reserved slots at regular intervals. In addition to the reserved slots the eSCO logical transport may have a retransmission window after the reserved slots.

The ACL logical transport is also a point-to-point logical transport between the master and a slave. In the slots not reserved for synchronous logical transport(s), the master can establish an ACL logical transport on a per-slot basis to any slave, including the slave(s) already engaged in a synchronous logical transport.

The ASB logical transport is used by a master to communicate with active slaves. The PSB logical transport is used by a master to communicate with parked slaves.

## 4.2 LOGICAL TRANSPORT ADDRESS (LT_ADDR)

Each slave active in a piconet is assigned a primary 3-bit logical transport address (LT_ADDR). The all-zero LT_ADDR is reserved for broadcast messages. The master does not have an LT_ADDR. A master's timing relative to the slaves distinguishes it from the slaves. A secondary LT_ADDR is assigned to the slave for each eSCO logical transport in use in the piconet. Only eSCO traffic (i.e. NULL, POLL, and one of the EV packet types as negotiated at eSCO logical transport setup) may be sent on these LT_ADDRs. ACL traffic (including LMP) shall always be sent on the primary LT_ADDR. A slave shall only accept packets with matching primary or secondary LT_ADDR and broadcast packets. The LT_ADDR is carried in the packet header (see Section 6.4 on page 116). The LT_ADDR shall only be valid for as long as a slave is in the active mode. As soon as it is disconnected or parked, the slave shall lose all of its LT_ADDRs.

The primary LT_ADDR shall be assigned by the master to the slave when the slave is activated. This is either at connection establishment, at role switch, or when the slave is unparked. At connection establishment and at role switch, the primary LT_ADDR is carried in the **FHS** payload. When unparking, the primary LT_ADDR is carried in the unpark message.

## 4.3 SYNCHRONOUS LOGICAL TRANSPORTS

The first type of synchronous logical transport, the SCO logical transport is a symmetric, point-to-point link between the master and a specific slave. The SCO logical transport reserves slots and can therefore be considered as a circuit-switched connection between the master and the slave. The master may support up to three SCO links to the same slave or to different slaves. A slave may support up to three SCO links from the same master, or two SCO links if the links originate from different masters. SCO packets are never retransmitted.

The second type of synchronous logical transport, the eSCO logical transport, is a point-to-point logical transport between the master and a specific slave. eSCO logical transports may be symmetric or asymmetric. Similar to SCO, eSCO reserves slots and can therefore be considered a circuit-switched connection between the master and the slave. In addition to the reserved slots, eSCO supports a retransmission window immediately following the reserved slots. Together, the reserved slots and the retransmission window form the complete eSCO window.

## 4.4 ASYNCHRONOUS LOGICAL TRANSPORT

In the slots not reserved for synchronous logical transports, the master may exchange packets with any slave on a per-slot basis. The ACL logical transport provides a packet-switched connection between the master and all active slaves participating in the piconet. Both asynchronous and isochronous services are supported. Between a master and a slave only a single ACL logical transport shall exist. For most ACL packets, packet retransmission is applied to assure data integrity.

ACL packets not addressed to a specific slave are considered as broadcast packets and should be read by every slave. If there is no data to be sent on the ACL logical transport and no polling is required, no transmission is required.

## 4.5 TRANSMIT/RECEIVE ROUTINES

This section describes the way to use the packets as defined in Section 6 on page 109 in order to support the traffic on the ACL, SCO and eSCO logical transports. Both single-slave and multi-slave configurations are considered. In addition, the use of buffers for the TX and RX routines are described.

*The TX and RX routines described in sections 4.5.1 and 4.5.2 are informative only.*

### 4.5.1 TX Routine

The TX routine is carried out separately for each asynchronous and synchronous link. Figure 4.1 on page 99 shows the asynchronous and synchronous buffers as used in the TX routine. In this figure, only a single TX asynchronous buffer and a single TX synchronous buffer are shown. In the master, there is a separate TX asynchronous buffer for each slave. In addition there may be one or more TX synchronous buffers for each synchronous slave (different SCO or eSCO logical transports may either reuse the same TX synchronous buffer, or each have their own TX synchronous buffer). Each TX buffer consists of two FIFO registers: one **current** register which can be accessed and read by the Link Controller in order to compose the packets, and one **next** register that can be accessed by the Baseband Resource Manager to load new information. The positions of the switches S1 and S2 determine which register is current and which register is next; the switches are controlled by the Link Controller. The switches at the input and the output of the FIFO registers can never be connected to the same register simultaneously.

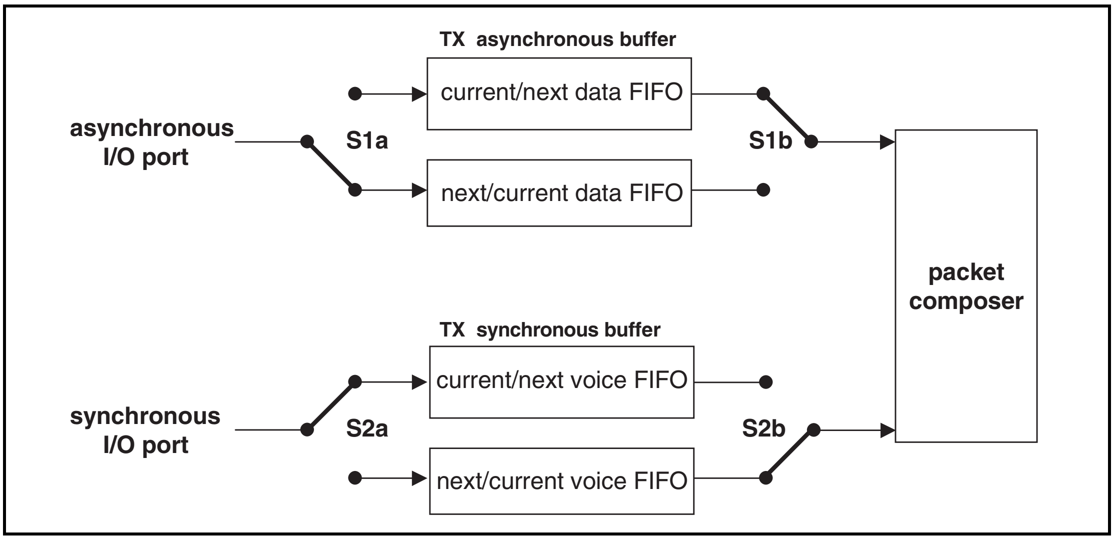


*Figure 4.1: Functional diagram of TX buffering.*

Of the packets common on the ACL and SCO logical transports (**NULL**, **POLL and DM1**) only the **DM1** packet carries a payload that is exchanged between the Link Controller and the Link Manager; this common packet makes use of the asynchronous buffer. All ACL packets make use of the asynchronous buffer. All SCO and eSCO packets make use of the synchronous buffer except for the **DV** packet where the synchronous data part is handled by the synchronous buffer and the data part is handled by the asynchronous buffer. In the next sections, the operation for ACL traffic, SCO traffic, eSCO traffic, and combined data-voice traffic on the SCO logical transport are described.

#### *4.5.1.1 ACL traffic*

In the case of asynchronous data only the TX ACL buffer in Figure 4.1 on page 99 has to be considered. In this case, only packet types **DM** or **DH** are used, and these can have different lengths. The length is indicated in the payload header. The selection of **DM** or **DH** packets should depend on the quality of the link. See [Part C] Section 4.1.7 on page 243.

The default packet type in pure data traffic is **NULL** (see Section 6.5.1.2 on page 120). This means that, if there is no data to be sent (the data traffic is asynchronous, and therefore pauses occur in which no data is available) or no slaves need to be polled, **NULL** packets are sent instead – in order to send link control information to the other device (e.g. ACK/STOP information for received data). When no link control information is available (either no need to acknowledge and/or no need to stop the RX flow) no packet is sent at all.

The TX routine works as follows. The Baseband Resource Manager loads new data information in the register to which the switch S1a points. Next, it gives a command to the Link Controller, which forces the switch S1 to change (both S1a and S1b switch synchronously). When the payload needs to be sent, the packet composer reads the current register and, depending on the packet type, builds a payload which is appended to the channel access code and the header and is subsequently transmitted. In the response packet (which arrives in the following RX slot if it concerned a master transmission, or may be postponed until some later RX slot if it concerned a slave transmission), the result of the transmission is reported back. In case of an ACK, the switch S1 changes position; if a NAK (explicit or implicit) is received instead, the switch S1 will not change position. In that case, the same payload is retransmitted at the next TX occasion.

As long as the Baseband Resource Manager keeps loading the registers with new information, the Link Controller will automatically transmit the payload; in addition, retransmissions are performed automatically in case of errors. The Link Controller will send **NULL** or nothing when no new data is loaded. If no new data has been loaded in the **next** register, during the last transmission, the packet composer will be pointing to an empty register after the last transmission has been acknowledged and the **next** register becomes the **current** register. If new data is loaded in the **next** register, a **flush** command is required to switch the S1 switch to the proper register. As long as the Baseband Resource Manager keeps loading the data and type registers before each TX slot, the data is automatically processed by the Link Controller since the S1 switch is controlled by the ACK information received in response. However, if the traffic from the Baseband Resource Manager is interrupted once and a default packet is sent instead, a **flush** command is necessary to continue the flow in the Link Controller.

The **flush** command can also be used in case of time-bounded (isochronous) data. In case of a bad link, many retransmissions are necessary. In certain applications, the data is time-bounded: if a payload is retransmitted all the time because of link errors, it may become outdated, and the system might decide to continue with more recent data instead and skip the payload that does not come through. This is accomplished by the **flush** command as well. With the **flush**, the switch S1 is forced to change and the Link Controller is forced to consider the next data payload and overrules the ACK control. Any ACL type of packet can be used to send data or link control information to any other ACL slave.

#### *4.5.1.2 SCO traffic*

On the SCO logical transport only **HV** and **DV** packet types are used, See Section 6.5.2 on page 123. The synchronous port may continuously load the **next** register in the synchronous buffer. The S2 switches are changed according to the $T_{sco}$ interval. This $T_{sco}$ interval is negotiated between the master and the slave at the time the SCO logical transport is established.

For each new SCO slot, the packet composer reads the **current** register after which the S2 switch is changed. If the SCO slot has to be used to send control information with high priority concerning a control packet between the master and the SCO slave, or a control packet between the master and any other slave, the packet composer will discard the SCO information and use the control information instead. This control information shall be sent in a DM1 packet. Data or link control information may also be exchanged between the master and the SCO slave by using the **DV** or **DM1** packets.

#### *4.5.1.3 Mixed data/voice traffic*

In Section 6.5.2 on page 123, a **DV** packet has been defined that can support both data and voice simultaneously on a single SCO logical transport. When the TYPE is **DV**, the Link Controller reads the data register to fill the data field and the voice register to fill the voice field. Thereafter, the switch S2 is changed. However, the position of S1 depends on the result of the transmission as on the ACL logical transport: only if an ACK has been received will the S1 switch change its position. In each **DV** packet, the voice information is new, but the data information might be retransmitted if the previous transmission failed. If there is no data to be sent, the SCO logical transport will automatically change from **DV** packet type to the current **HV** packet type used before the mixed data/voice transmission. Note that a **flush** command is necessary when the data stream has been interrupted and new data has arrived.

Combined data-voice transmission can also be accomplished by using a separate ACL logical transport in addition to the SCO logical transport(s) if channel capacity permits this.

#### *4.5.1.4 eSCO Traffic*

On the eSCO logical transport only **EV**, **POLL** and **NULL** packet types are used, see Section 6.5.3 on page 124. The synchronous port may continuously load the next register in the synchronous buffer. The S2 switches are changed according to the $T_{eSCO}$ interval. This $T_{eSCO}$ interval is negotiated between the master and the slave at the time the eSCO logical transport is established.

For each new eSCO slot, the packet composer reads the current register after which the S2 switch is changed. If the eSCO slot has to be used to send control information with high priority concerning a control packet between the master and the eSCO slave, or an ACL packet between the master and any other slave, the packet composer will discard the eSCO information and use the control information instead. Control information to the eSCO slave is sent in a DM1 packet on the primary LT_ADDR.

#### *4.5.1.5 Default packet types*

On the ACL links, the default type is always **NULL** both for the master and the slave. This means that if no user information needs to be sent, either a **NULL** packet is sent if there is **ACK** or **STOP** information, or no packet is sent at all. The **NULL** packet can be used by the master to allocate the next slave-to-master slot to a certain slave (namely the one addressed). However, the slave is not forced to respond to the **NULL** packet from the master. If the master requires a response, it sends a **POLL** packet.

The SCO and eSCO packet types are negotiated at the LM level when the SCO or eSCO logical transport is established. The agreed packet type is also the default packet type for the reserved SCO or eSCO slots.

### 4.5.2 RX routine

The RX routine is carried out separately for the ACL logical transport and the synchronous logical transports. However, in contrast to the master TX asynchronous buffer, a single RX buffer is shared among all slaves. For the synchronous buffer, how the different synchronous logical transports are distinguished depends on whether extra synchronous buffers are required or not. Figure 4.2 on page 103 shows the asynchronous and synchronous buffers as used in the RX routine. The RX asynchronous buffer consists of two FIFO registers: one register that can be accessed and loaded by the Link Controller with the payload of the latest RX packet, and one register that can be accessed by the Baseband Resource Manager to read the previous payload. The RX synchronous buffer also consists of two FIFO registers: one register which is filled with newly arrived voice information, and one register which can be read by the voice processing unit.

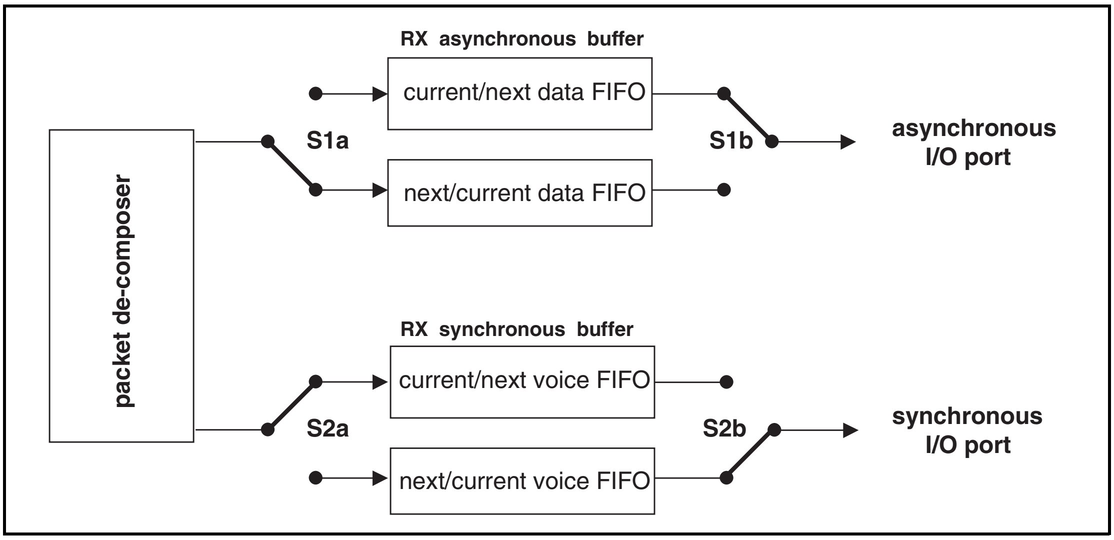


*Figure 4.2: Functional diagram of RX buffering*

Since the TYPE indication in the header (see Section 6.4.2 on page 116) of the received packet indicates whether the payload contains data and/or voice, the packet de-composer can automatically direct the traffic to the proper buffers. The switch S1 changes every time the Baseband Resource Manager reads the old register. If the next payload arrives before the RX register is emptied, a STOP indication is included in the packet header of the next TX packet that is returned. The STOP indication is removed again as soon as the RX register is emptied. The SEQN field is checked before a new ACL payload is stored into the asynchronous register (flush indication in LLID and broadcast messages influence the interpretation of the SEQN field see Section 7.6 on page 144).

The S2 switch is changed every $T_{SCO}$ or $T_{eSCO}$ for SCO and eSCO respectively. If, due to errors in the header, no new synchronous payload arrives, the switch still changes. The synchronous data processing unit then processes the synchronous data to account for the missing parts.

### 4.5.3 Flow control

Since the RX ACL buffer can be full while a new payload arrives, flow control is required. The header field FLOW in the return TX packet may use STOP or GO in order to control the transmission of new data.

#### *4.5.3.1 Destination control*

As long as data can not be received, a STOP indication shall be transmitted which is automatically inserted by the Link Controller into the header of the return packet. STOP shall be returned as long as the RX ACL buffer is not emptied by the Baseband Resource Manager. When new data can be accepted again, the GO indication shall be returned. GO shall be the default value. All packet types not including data can still be received. Voice communication for example is not affected by the flow control. Although a device can not receive new information, it may still continue to transmit information: the flow control shall be separate for each direction.

#### *4.5.3.2 Source control*

On the reception of a STOP signal, the Link Controller shall automatically switch to the default packet type. The ACL packet transmitted just before the reception of the STOP indication shall be kept until a GO signal is received. It may be retransmitted as soon as a GO indication is received. Only default packets shall be sent as long as the STOP indication is received. When no packet is received, GO shall be assumed implicitly. Note that the default packets contain link control information (in the header) for the receive direction (which may still be open) and may contain synchronous data (**HV** or **EV** packets). When a GO indication is received, the Link Controller may resume transmitting the data that is present in the TX ACL buffers.

In a multi-slave configuration, only the transmission to the slave that issued the STOP signal shall be stalled. This means that the master shall only stop transmission from the TX ACL buffer corresponding to the slave that momentarily cannot accept data.

## 4.6 ACTIVE SLAVE BROADCAST TRANSPORT

The active slave broadcast logical transport is used to transport L2CAP user traffic to all devices in the piconet that are currently connected to the piconet physical channel that is used by the ASB. There is no acknowledgement protocol and the traffic is uni-directional from the piconet master to the slaves. The ASB logical transport may only be used for L2CAP group traffic and shall never be used for L2CAP connection-oriented channels, L2CAP control signalling or LMP control signalling.

The ASB logical transport is unreliable. To improve reliability somewhat each packet is transmitted a number of times. An identical sequence number is used to assist with filtering retransmissions at the slave device.

The ASB logical transport is identified by the reserved, all-zero, LT_ADDR. Packets on the ASB logical transport may be sent by the master at any time.

## 4.7 PARKED SLAVE BROADCAST TRANSPORT

The parked slave broadcast logical transport is used for communication from the master to the slaves that are parked. The PSB logical transport is more complex than the other logical transports as it consists of a number of phases, each having a different purpose. These phases are the control information phase (used to carry the LMP logical link), the user information phase (used to carry the L2CAP logical link), and the access phase (carrying baseband signalling).

The PSB logical transport is identified by the reserved, all-zero, LT_ADDR.

### 4.7.1 Parked member address (PM_ADDR)

A slave in the **PARK** state can be identified by its BD_ADDR or by a dedicated parked member address (PM_ADDR). This latter address is an 8-bit member address that separates the parked slaves. The PM_ADDR shall only be valid as long as the slave is parked. When the slave is activated it shall be assigned an LT_ADDR but shall lose the PM_ADDR. The PM_ADDR is assigned to the slave by the master during the parking procedure (see [Part C] Section 4.5.2 on page 272).

The all-zero PM_ADDR shall be reserved for parked slaves that only use their BD_ADDR to be unparked.

### 4.7.2 Access request address (AR_ADDR)

The access request address (AR_ADDR) is used by the parked slave to determine the slave-to-master half slot in the access window where it is allowed to send access request messages, see also Section 8.9.6 on page 192. The AR_ADDR shall be assigned to the slave when it enters the **PARK** state and shall only be valid as long as the slave is parked. The AR_ADDR is not necessarily unique; i.e. different parked slaves may have the same AR_ADDR.

# 5 LOGICAL LINKS

Five logical links are defined:

- Link Control (LC)
- ACL Control (ACL-C)
- User Asynchronous/Isochronous (ACL-U)
- User Synchronous (SCO-S)
- User Extended Synchronous (eSCO-S)

The control logical links LC and ACL-C are used at the link control level and link manager level, respectively. The ACL-U logical link is used to carry either asynchronous or isochronous user information. The SCO-S, and eSCO-S logical links are used to carry synchronous user information. The LC logical link is carried in the packet header, all other logical links are carried in the packet payload. The ACL-C and ACL-U logical links are indicated in the logical link ID, LLID, field in the payload header. The SCO-S and eSCO-S logical links are carried by the synchronous logical transports only; the ACL-U link is normally carried by the ACL logical transport; however, they may also be carried by the data in the DV packet on the SCO logical transport. The ACL-C link may be carried either by the SCO or the ACL logical transport.

## 5.1 LINK CONTROL LOGICAL LINK (LC)

The LC control logical link shall be mapped onto the packet header. This logical link carries low level link control information like ARQ, flow control, and payload characterization. The LC logical link is carried in every packet except in the **ID** packet which does not have packet header.

## 5.2 ACL CONTROL LOGICAL LINK (ACL-C)

The ACL-C logical link shall carry control information exchanged between the link managers of the master and the slave(s). The ACL-C logical link shall use DM1 packets. The ACL-C logical link is indicated by the LLID code 11 in the payload header.

## 5.3 USER ASYNCHRONOUS/ISOCHRONOUS LOGICAL LINK (ACL-U)

The ACL-U logical link shall carry L2CAP asynchronous and isochronous user data. These messages may be transmitted in one or more baseband packets. For fragmented messages, the start packet shall use an LLID code of 10 in the payload header. Remaining continuation packets shall use LLID code 01. If there is no fragmentation, all packets shall use the LLID start code 10.

### 5.3.1 Pausing the ACL-U logical link

When paused by LM, the Link Controller transmits the current packet with ACL-U information, if any, until an ACK is received or, optionally, until an explicit NACK is received. While the ACL-U logical link is paused, the Link Controller shall not transmit any packets with ACL-U logical link information.

If the ACL-U was paused after an ACK, the next sequence number shall be used on the next packet. If the ACL-U was paused after a NAK, the same sequence number shall be used on the next packet and the un-acknowledged packet shall be transmitted once the ACL-U logical link is un-paused.

When the ACL-U logical link is un-paused by LM, the Link Controller may resume transmitting packets with ACL-U information.

## 5.4 USER SYNCHRONOUS DATA LOGICAL LINK (SCO-S)

The SCO-S logical link carries transparent synchronous user data. This logical link is carried over the synchronous logical transport SCO.

## 5.5 USER EXTENDED SYNCHRONOUS DATA LOGICAL LINK (eSCO-S)

The eSCO-S logical link also carries transparent synchronous user data. This logical link is carried over the extended synchronous logical transport eSCO.

## 5.6 LOGICAL LINK PRIORITIES

The ACL-C logical link shall have a higher priority than the ACL-U logical link when scheduling traffic on the shared ACL logical transport, except in the case when retransmissions of unacknowledged ACL packets shall be given priority over traffic on the ACL-C logical link. The ACL-C logical link should also have priority over traffic on the SCO-S and eSCO-S logical links but opportunities for interleaving the logical links should be taken.

# 6 PACKETS

Bluetooth devices shall use the packets as defined in the following sections.

## 6.1 GENERAL FORMAT

### 6.1.1 Basic Rate

The general packet format of Basic Rate packets is shown in Figure 6.1 on page 109. Each packet consists of 3 entities: the access code, the header, and the payload. In the figure, the number of bits per entity is indicated.

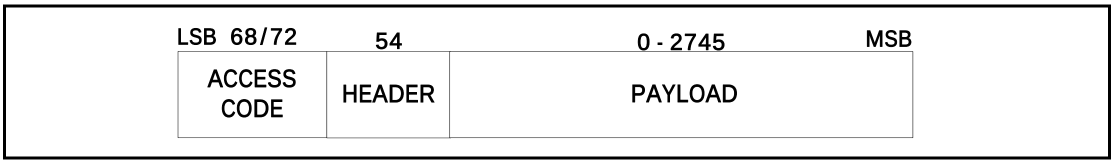


*Figure 6.1: General Basic Rate packet format.*

The access code is 72 or 68 bits and the header is 54 bits. The payload ranges from zero to a maximum of 2745 bits. Different packet types have been defined. Packet may consist of:

- the shortened access code only (see ID packet on page 116)
- the access code and the packet header
- the access code, the packet header and the payload.

### 6.1.2 Enhanced Data Rate

The general format of Enhanced Data Rate packets is shown in General enhanced data rate packet format. The access code and packet header are identical in format and modulation to Basic Rate packets. Enhanced Data Rate packets have a guard time and synchronization sequence following the packet header. Following the payload are two trailer symbols. The guard time, synchronization sequence and trailer are defined in section 6.6.

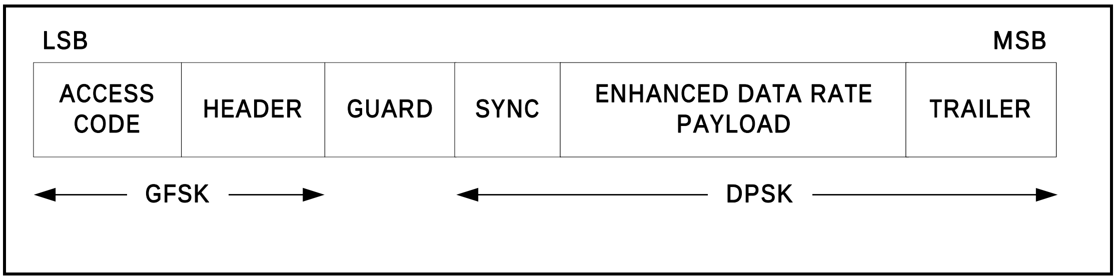


*Figure 6.2: General enhanced data rate packet format*

## 6.2 BIT ORDERING

The bit ordering when defining packets and messages in the *Baseband Specification*, follows the *Little Endian* format. The following rules apply:

- The *least significant bit* (LSB) corresponds to $b_0$;
- The LSB is the first bit sent over the air;
- In illustrations, the LSB is shown on the left side;

Furthermore, data fields generated internally at baseband level, such as the packet header fields and payload header length, shall be transmitted with the LSB first. For instance, a 3-bit parameter X=3 is sent as:

$$b_0 b_1 b_2 = 110$$

over the air where 1 is sent first and 0 is sent last.

## 6.3 ACCESS CODE

Every packet starts with an access code. If a packet header follows, the access code is 72 bits long, otherwise the access code is 68 bits long and is known as a shortened access code. The shortened access code does not contain a trailer. This access code is used for synchronization, DC offset compensation and identification. The access code identifies all packets exchanged on a physical channel: all packets sent in the same physical channel are preceded by the same access code. In the receiver of the device, a sliding correlator correlates against the access code and triggers when a threshold is exceeded. This trigger signal is used to determine the receive timing.

The shortened access code is used in paging, inquiry, and park. In this case, the access code itself is used as a signalling message and neither a header nor a payload is present.

The access code consists of a preamble, a sync word, and possibly a trailer, see Figure 6.3 on page 111. For details see Section 6.3.1 on page 111.

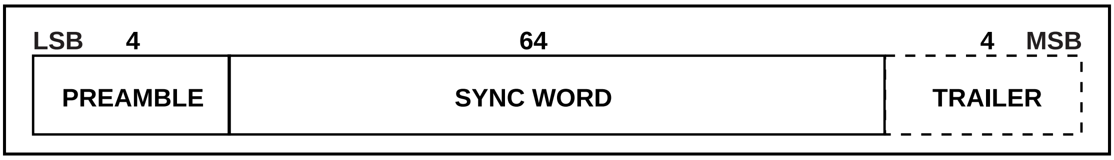


*Figure 6.3: Access code format*

### 6.3.1 Access code types

The different access code types use different Lower Address Parts (LAPs) to construct the sync word. The LAP field of the BD_ADDR is explained in Section 1.2 on page 66. A summary of the different access code types is in Table 6.1 on page 111.

| Code type | LAP | Code length | Comments |
|---|---|---|---|
| CAC | Master | 72 | See also Section 1.3 on page 67 |
| DAC | Paged device | 68/72[1] | |
| GIAC | Reserved | 68/72* | |
| DIAC | Dedicated | 68/72* | |

*Table 6.1: Summary of access code types.*

1. length 72 is only used in combination with FHS packets

The CAC consists of a **preamble**, **sync word**, and **trailer** and its total length is 72 bits. When used as self-contained messages without a header, the DAC and IAC do not include the trailer bits and are of length 68 bits.

### 6.3.2 Preamble

The preamble is a fixed zero-one pattern of 4 symbols used to facilitate DC compensation. The sequence is either 1010 or 0101, depending on whether the LSB of the following sync word is 1 or 0, respectively. The preamble is shown in Figure 6.4 on page 112.


*Figure 6.4: Preamble*

### 6.3.3 Sync word

The sync word is a 64-bit code word derived from a 24 bit address (LAP); for the CAC the master's LAP is used; for the GIAC and the DIAC, reserved, dedicated LAPs are used; for the DAC, the slave LAP is used. The construction guarantees large Hamming distance between sync words based on different LAPs. In addition, the good auto correlation properties of the sync word improve timing acquisition.

#### *6.3.3.1 Synchronization word definition*

The sync words are based on a (64,30) expurgated block code with an overlay (bit-wise XOR) of a 64 bit full length pseudo-random noise (PN) sequence. The expurgated code guarantees large Hamming distance ($d_{min} = 14$) between sync words based on different addresses. The PN sequence improves the auto correlation properties of the access code. The following steps describe how the sync word shall be generated:

1. Generate information sequence;
2. XOR this with the "information covering" part of the PN overlay sequence;
3. Generate the codeword;
4. XOR the codeword with all 64 bits of the PN overlay sequence;

The information sequence is generated by appending 6 bits to the 24 bit LAP (step 1). The appended bits are $001101$ if the MSB of the LAP equals 0. If the MSB of the LAP is 1 the appended bits are $110010$. The LAP MSB together with the appended bits constitute a length-seven Barker sequence. The purpose of including a Barker sequence is to further improve the auto correlation properties. In step 2 the information is pre-scrambled by XORing it with the bits $p_{34} \ldots p_{63}$ of the PN sequence (defined in section 6.3.3.2 on page 115). After generating the codeword (step 3), the complete PN sequence is XORed to the codeword (step 4). This step de-scrambles the information part of the code-word. At the same time the parity bits of the codeword are scrambled. Consequently, the original LAP and Barker sequence are ensured a role as a part of the access code sync word, and the cyclic properties of the underlying code is removed. The principle is depicted in Figure 6.5 on page 113

In the following discussion, binary sequences will be denoted by their corresponding D-transform (in which $D^i$ represents a delay of *i* time units). Let $p'(D) = p'_0 + p'_1 D + \ldots + p'_{62} D^{62}$ be the 63 bit PN sequence, where $p'_0$ is the first bit (LSB) leaving the PRNG (see Figure 6.6 on page 115), and, $p'_{62}$ is the last bit (MSB). To obtain 64 bits, an extra zero is appended at the *end* of this sequence (thus, $p'(D)$ is unchanged). For notational convenience, the reciprocal of this extended polynomial, $p(D) = D^{63} p'(1/D)$, will be used in the following discussion. This is the sequence $p'(D)$ in reverse order. We denote the 24 bit lower address part (LAP) of the Bluetooth device address by $a(D) = a_0 + a_1 D + \ldots + a_{23} D^{23}$ ($a_0$ is the LSB of the Bluetooth device address).

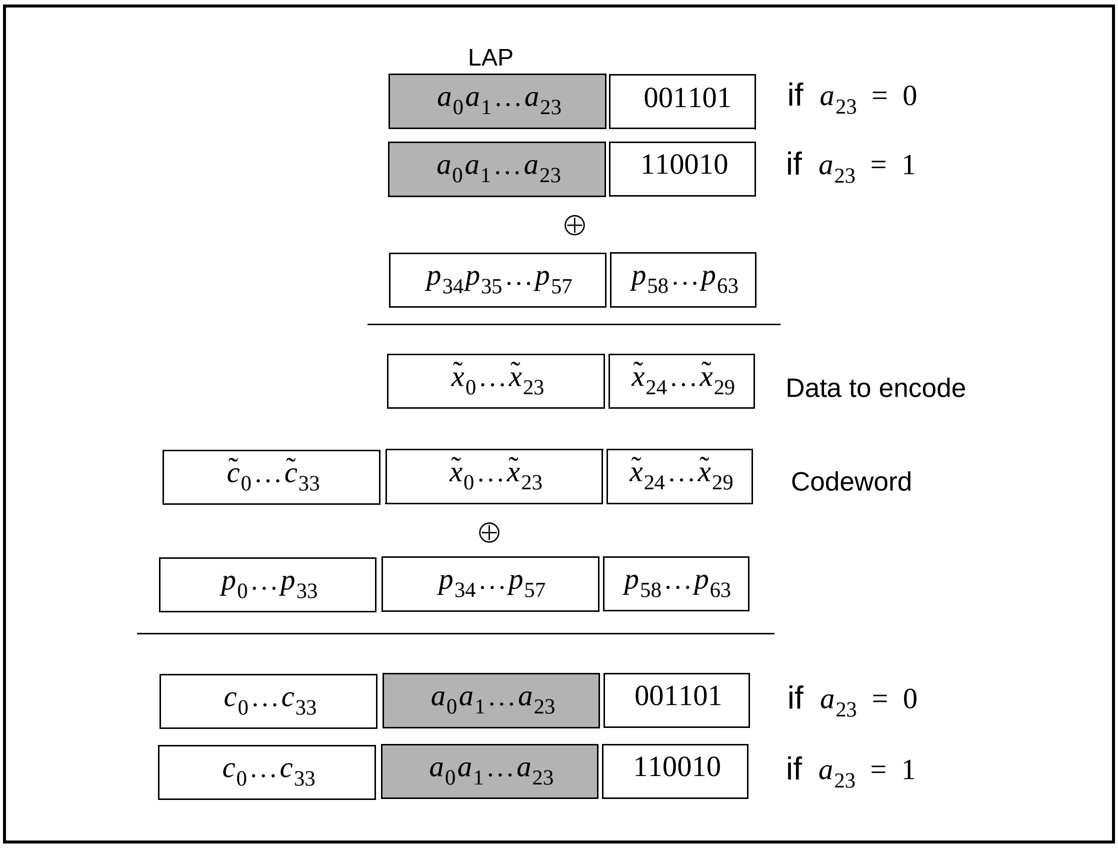


*Figure 6.5: Construction of the sync word.*

The (64,30) block code generator polynomial is denoted $g(D) = (1 + D) g'(D)$, where $g'(D)$ is the generator polynomial `157464165547` (octal notation) of a primitive binary (63,30) BCH code. Thus, in octal notation *g(D)* is

$$g(D) = \texttt{260534236651}, \tag{EQ 8}$$

the left-most bit corresponds to the high-order ($g_{34}$) coefficient.The DC-free four bit sequences `0101` and `1010` can be written

$$\begin{cases} F_0(D) = D + D^3, \\ F_1(D) = 1 + D^2, \end{cases} \tag{EQ 9}$$

respectively. Furthermore,

$$\begin{cases} B_0(D) = D^2 + D^3 + D^5, \\ B_1(D) = 1 + D + D^4, \end{cases} \tag{EQ 10}$$

which are used to create the length seven Barker sequences. Then, the access code shall be generated by the following procedure:

1. Format the 30 information bits to encode:

$$x(D) = a(D) + D^{24} B_{a_{23}}(D).$$

2. Add the information covering part of the PN overlay sequence:

$$\tilde{x}(D) = x(D) + p_{34} + p_{35}D + \ldots + p_{63}D^{29}.$$

3. Generate parity bits of the (64,30) expurgated block code:[1]

$$\tilde{c}(D) = D^{34}\tilde{x}(D) \mod g(D).$$

4. Create the codeword:

$$\tilde{s}(D) = D^{34}\tilde{x}(D) + \tilde{c}(D).$$

5. Add the PN sequence:

$$s(D) = \tilde{s}(D) + p(D).$$

6. Append the (DC-free) preamble and trailer:

$$y(D) = F_{c_0}(D) + D^4 s(D) + D^{68} F_{a_{23}}(D).$$

1. $x(D)$ mod $y(D)$ denotes the remainder when $x(D)$ is divided by $y(D)$.

### *6.3.3.2 Pseudo-random noise sequence generation*

To generate the PN sequence the primitive polynomial $h(D) = 1 + D + D^3 + D^4 + D^6$ shall be used. The LFSR and its starting state are shown in Figure 6.6 on page 115. The PN sequence generated (including the extra terminating zero) becomes (hexadecimal notation) `83848D96BBCC54FC`. The LFSR output starts with the left-most bit of this PN sequence. This corresponds to $p'(D)$ of the previous section. Thus, using the reciprocal $p(D)$ as overlay gives the 64 bit sequence:

$$\mathbf{p} = 3F2A33DD69B121C1, \qquad \text{(EQ 11)}$$

where the left-most bit is $p_0 = 0$ (there are two initial zeros in the binary representation of the hexadecimal digit 3), and $p_{63} = 1$ is the right-most bit.

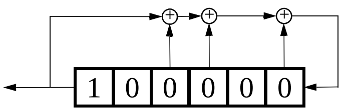


*Figure 6.6: LFSR and the starting state to generate* $p'(D)$.

## 6.3.4 Trailer

The trailer is appended to the sync word as soon as the packet header follows the access code. This is typically the case with the CAC, but the trailer is also used in the DAC and IAC when these codes are used in FHS packets exchanged during page response and inquiry response.

The trailer is a fixed zero-one pattern of four symbols. The trailer together with the three MSBs of the syncword form a 7-bit pattern of alternating ones and zeroes which may be used for extended DC compensation. The trailer sequence is either 1010 or 0101 depending on whether the MSB of the sync word is 0 or 1, respectively. The choice of trailer is illustrated in Figure 6.7 on page 115.


*Figure 6.7: Trailer in CAC when MSB of sync word is 0 (a), and when MSB of sync word is 1 (b).*

## 6.4 PACKET HEADER

The header contains link control (LC) information and consists of 6 fields:

- LT_ADDR: 3- bit logical transport address
- TYPE: 4-bit type code
- FLOW: 1-bit flow control
- ARQN: 1-bit acknowledge indication
- SEQN: 1-bit sequence number
- HEC: 8-bit header error check

The total header, including the HEC, consists of 18 bits, see Figure 6.8 on page 116, and is encoded with a rate 1/3 FEC (not shown but described in Section 7.4 on page 142) resulting in a 54-bit header. The LT_ADDR and TYPE fields shall be sent LSB first.

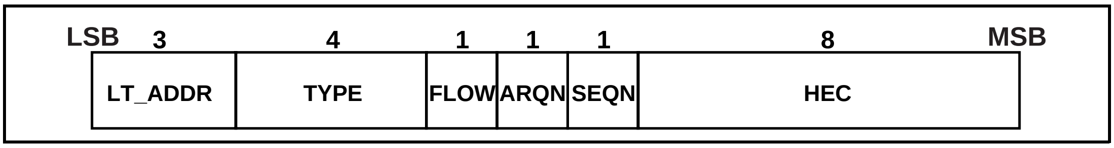


*Figure 6.8: Header format.*

### 6.4.1 LT_ADDR

The 3-bit LT_ADDR field contains the logical transport address for the packet (see Section 4.2 on page 97). This field indicates the destination slave for a packet in a master-to-slave transmission slot and indicates the source slave for a slave-to-master transmission slot.

### 6.4.2 TYPE

Sixteen different types of packets can be distinguished. The 4-bit TYPE code specifies which packet type is used. The interpretation of the TYPE code depends on the logical transport address in the packet. First, it shall be determined whether the packet is sent on an SCO logical transport, an eSCO logical transport, or an ACL logical transport. Second, it shall be determined whether Enhanced Data Rate has been enabled for the logical transport (ACL or eSCO) indicated by LT_ADDR. It can then be determined which type of SCO packet, eSCO packet, or ACL packet has been received. The TYPE code determines how many slots the current packet will occupy (see the slot occupancy column in Table 6.2 on page 119). This allows the non-addressed receivers to refrain from listening to the channel for the duration of the remaining slots. In Section 6.5 on page 118, each packet type is described in more detail.

### 6.4.3 FLOW

The FLOW bit is used for flow control of packets over the ACL logical transport. When the RX buffer for the ACL logical transport in the recipient is full, a STOP indication (FLOW=0) shall be returned to stop the other device from transmitting data temporarily. The STOP signal only affects ACL packets. Packets including only link control information (ID, POLL, and NULL packets), SCO packets or eSCO packets can still be received. When the RX buffer can accept data, a GO indication (FLOW=1) shall be returned. When no packet is received, or the received header is in error, a GO shall be assumed implicitly. In this case, the slave can receive a new packet with CRC although its RX buffer is still not emptied. The slave shall then return a NAK in response to this packet even if the packet passed the CRC check.

The FLOW bit is not used on the eSCO logical transport or the ACL-C logical link and shall be set to one on transmission and ignored upon receipt.

### 6.4.4 ARQN

The 1-bit acknowledgment indication ARQN is used to inform the source of a successful transfer of payload data with CRC, and can be positive acknowledge ACK or negative acknowledge NAK. See Section 7.6 on page 144 for initialization and usage of this bit.

### 6.4.5 SEQN

The SEQN bit provides a sequential numbering scheme to order the data packet stream. See section 7.6.2 on page 147 for initialization and usage of the SEQN bit. For broadcast packets, a modified sequencing method is used, see Section 7.6.5 on page 150.

### 6.4.6 HEC

Each header has a header-error-check to check the header integrity. The HEC is an 8-bit word (generation of the HEC is specified in Section 7.1.1 on page 138). Before generating the HEC, the HEC generator is initialized with an 8-bit value. For FHS packets sent in **master response** substate, the slave upper address part (UAP) shall be used. For FHS packets sent in **inquiry response**, the default check initialization (DCI, see Section 1.2.1 on page 66) shall be used. In all other cases, the UAP of the master device shall be used.

After the initialization, a HEC shall be calculated for the 10 header bits. Before checking the HEC, the receiver shall initialize the HEC check circuitry with the proper 8-bit UAP (or DCI). If the HEC does not check, the entire packet shall be discarded. More information can be found in Section 7.1 on page 138.

## 6.5 PACKET TYPES

The packets used on the piconet are related to the logical transports they are used in. Three logical transports with distinct packet types are defined (see Section 4 on page 97): the SCO logical transport, the eSCO logical transport, and the ACL logical transport. For each of these logical transports, 15 different packet types can be defined.

To indicate the different packets on a logical transport, the 4-bit TYPE code is used. The packet types are divided into four segments. The first segment is reserved for control packets. All control packets occupy a single time slot. The second segment is reserved for packets occupying a single time slot. The third segment is reserved for packets occupying three time slots. The fourth segment is reserved for packets occupying five time slots. The slot occupancy is reflected in the segmentation and can directly be derived from the type code. Table 6.2 on page 119 summarizes the packets defined for the SCO, eSCO, and ACL logical transport types.

All packet types with a payload shall use GFSK modulation unless specified otherwise in the following sections.

ACL logical transports Enhanced Data Rate packet types are explicitly selected via LMP using the *packet_type_table* (ptt) parameter. eSCO Enhanced Data Rate packet types are selected when the eSCO logical transport is established.

.

| Seg-ment | TYPE code $b_3b_2b_1b_0$ | Slot occu-pancy | SCO logical trans-port (1 Mbps) | eSCO logical trans-port (1 Mbps) | eSCO logical trans-port (2-3 Mbps) | ACL logical trans-port (1 Mbps) ptt=0 | ACL logical trans-port (2-3 Mbps) ptt=1 |
|---|---|---|---|---|---|---|---|
| 1 | 0000 | 1 | NULL | NULL | NULL | NULL | NULL |
| | 0001 | 1 | POLL | POLL | POLL | POLL | POLL |
| | 0010 | 1 | FHS | reserved | reserved | FHS | FHS |
| | 0011 | 1 | DM1 | reserved | reserved | DM1 | DM1 |
| 2 | 0100 | 1 | undefined | undefined | undefined | DH1 | 2-DH1 |
| | 0101 | 1 | HV1 | undefined | undefined | undefined | undefined |
| | 0110 | 1 | HV2 | undefined | 2-EV3 | undefined | undefined |
| | 0111 | 1 | HV3 | EV3 | 3-EV3 | undefined | undefined |
| | 1000 | 1 | DV | undefined | undefined | undefined | 3-DH1 |
| | 1001 | 1 | undefined | undefined | undefined | AUX1 | AUX1 |
| 3 | 1010 | 3 | undefined | undefined | undefined | DM3 | 2-DH3 |
| | 1011 | 3 | undefined | undefined | undefined | DH3 | 3-DH3 |
| | 1100 | 3 | undefined | EV4 | 2-EV5 | undefined | undefined |
| | 1101 | 3 | undefined | EV5 | 3-EV5 | undefined | undefined |
| 4 | 1110 | 5 | undefined | undefined | undefined | DM5 | 2-DH5 |
| | 1111 | 5 | undefined | undefined | undefined | DH5 | 3-DH5 |

*Table 6.2: Packets defined for synchronous and asynchronous logical transport types.*

### 6.5.1 Common packet types

There are five common kinds of packets. In addition to the types listed in segment 1 of the previous table, the ID packet is also a common packet type but is not listed in segment 1 because it does not have a packet header.

#### *6.5.1.1 ID packet*

The identity or ID packet consists of the device access code (DAC) or inquiry access code (IAC). It has a fixed length of 68 bits. It is a very robust packet since the receiver uses a bit correlator to match the received packet to the known bit sequence of the ID packet.

#### *6.5.1.2 NULL packet*

The NULL packet has no payload and consists of the channel access code and packet header only. Its total (fixed) length is 126 bits. The NULL packet may be used to return link information to the source regarding the success of the previous transmission (ARQN), or the status of the RX buffer (FLOW). The NULL packet may not have to be acknowledged.

#### *6.5.1.3 POLL packet*

The POLL packet is very similar to the NULL packet. It does not have a payload. In contrast to the NULL packet, it requires a confirmation from the recipient. It is not a part of the ARQ scheme. The POLL packet does not affect the ARQN and SEQN fields. Upon reception of a POLL packet the slave shall respond with a packet even when the slave does not have any information to send unless the slave has scatternet commitments in that timeslot. This return packet is an implicit acknowledgement of the POLL packet. This packet can be used by the master in a piconet to poll the slaves. Slaves shall not transmit the POLL packet.

#### *6.5.1.4 FHS packet*

The FHS packet is a special control packet containing, among other things, the Bluetooth device address and the clock of the sender. The payload contains 144 information bits plus a 16-bit CRC code. The payload is coded with a rate 2/3 FEC with a gross payload length of 240 bits.

Figure 6.9 on page 120 illustrates the format and contents of the FHS payload. The payload consists of eleven fields. The FHS packet is used in page master response, inquiry response and in role switch.

The FHS packet contains real-time clock information. This clock information shall be updated before each retransmission. The retransmission of the FHS payload is different than retransmissions of ordinary data payloads where the same payload is used for each retransmission. The FHS packet is used for frequency hop synchronization before the piconet channel has been established, or when an existing piconet changes to a new piconet.

**LSB** ... **MSB**

| 34 | 24 | 2 | 2 | 2 | 8 | 16 | 24 | 3 | 26 | 3 |
|---|---|---|---|---|---|---|---|---|---|---|
| Parity bits | LAP | Un-defined | SR | Reserved | UAP | NAP | Class of device | LT_ADDR | $CLK_{27-2}$ | Page scan mode |

*Figure 6.9: Format of the FHS payload.*

Each field is described in more detail below:

| | |
|---|---|
| **Parity bits** | This 34-bit field contains the parity bits that form the first part of the sync word of the access code of the device that sends the FHS packet. These bits are derived from the LAP as described in Section 1.2 on page 66. |
| **LAP** | This 24-bit field shall contain the lower address part of the device that sends the FHS packet. |
| **Undefined** | This 2-bit field is reserved for future use and shall be set to zero. |
| **SR** | This 2-bit field is the scan repetition field and indicates the interval between two consecutive page scan windows, see also Table 6.4 and Table 8.1 on page 155 |
| **Reserved** | This 2-bit field shall be set to 10. |
| **UAP** | This 8-bit field shall contain the upper address part of the device that sends the FHS packet. |
| **NAP** | This 16-bit field shall contain the non-significant address part of the device that sends the FHS packet (see also Section 1.2 on page 66 for LAP, UAP, and NAP). |
| **Class of device** | This 24-bit field shall contain the class of device of the device that sends the FHS packet. The field is defined in Bluetooth Assigned Numbers (https://www.bluetooth.org/foundry/assignnumb/document/assigned_numbers). |
| **LT_ADDR** | This 3-bit field shall contain the logical transport address the recipient shall use if the FHS packet is used at connection setup or role switch. A slave responding to a master or a device responding to an inquiry request message shall include an all-zero LT_ADDR field if it sends the FHS packet. |
| **$CLK_{27\text{-}2}$** | This 26-bit field shall contain the value of the native clock of the device that sends the FHS packet, sampled at the beginning of the transmission of the access code of this FHS packet. This clock value has a resolution of 1.25ms (two-slot interval). For each new transmission, this field is updated so that it accurately reflects the real-time clock value. |
| **Page scan mode** | This 3-bit field shall indicate which scan mode is used by default by the sender of the FHS packet. The interpretation of the page scan mode is illustrated in Table 6.5. |

*Table 6.3: Description of the FHS payload*

The device sending the FHS shall set the SR bits according to Table 6.4.

| SR bit format $b_1b_0$ | SR mode |
|---|---|
| 00 | R0 |
| 01 | R1 |
| 10 | R2 |
| 11 | reserved |

*Table 6.4: Contents of SR field*

The device sending the FHS shall set the page scan mode bits according to Table 6.5.

| Bit format $b_2b_1b_0$ | Page scan mode |
|---|---|
| 000 | Mandatory scan mode |
| 001 | Reserved for future use |
| 010 | Reserved for future use |
| 011 | Reserved for future use |
| 100 | Reserved for future use |
| 101 | Reserved for future use |
| 110 | Reserved for future use |
| 111 | Reserved for future use |

*Table 6.5: Contents of page scan mode field*

The LAP, UAP, and NAP together form the 48-bit Bluetooth Device Address of the device that sends the FHS packet. Using the parity bits and the LAP, the recipient can directly construct the channel access code of the sender of the FHS packet.

When initializing the HEC and CRC for the FHS packet of inquiry response, the UAP shall be the DCI.

#### 6.5.1.5 DM1 packet

DM1 is part of segment 1 in order to support control messages in any logical transport that allows the DM1 packet (see Table 6.2 on page 119). However, it may also carry regular user data. Since the DM1 packet can be regarded as an ACL packet, it will be discussed in Section 6.5.4 on page 126.

### 6.5.2 SCO packets

HV and DV packets are used on the synchronous SCO logical transport. The HV packets do not include a CRC and shall not be retransmitted.  DV packets include a CRC on the data section, but not on the synchronous data section. The data section of DV packets shall be retransmitted. SCO packets may be routed to the synchronous I/O port. Four packets are allowed on the SCO logical transport: HV1, HV2, HV3 and DV. These packets are typically used for 64kb/s speech transmission but may be used for transparent synchronous data.

#### *6.5.2.1 HV1 packet*

The **HV1** packet has 10 information bytes. The bytes are protected with a rate 1/3 FEC. No CRC is present. The payload length is fixed at 240 bits. There is no payload header present.

#### *6.5.2.2 HV2 packet*

The **HV2** packet has 20 information bytes. The bytes are protected with a rate 2/3 FEC. No CRC is present. The payload length is fixed at 240 bits. There is no payload header present.

#### *6.5.2.3 HV3 packet*

The **HV3** packet has 30 information bytes. The bytes are not protected by FEC. No CRC is present. The payload length is fixed at 240 bits. There is no payload header present.

#### *6.5.2.4 DV packet*

The **DV** packet is a combined data - voice packet.The DV packet shall only be used in place of an HV1 packet. The payload is divided into a voice field of 80 bits and a data field containing up to 150 bits, see Figure 6.10. The voice field is not protected by FEC. The data field has between 1 and 10 information bytes (including the 1-byte payload header) and includes a 16-bit CRC. The data field is encoded with a rate 2/3 FEC. Since the **DV** packet has to be sent at regular intervals due to its synchronous contents, it is listed under the SCO packet types. The voice and data fields shall be treated separately. The voice field shall be handled in the same way as normal SCO data and shall never be retransmitted; that is, the voice field is always new. The data field is checked for errors and shall be retransmitted if necessary. When the asynchronous data field in the DV packet has not be acknowledged before the SCO logical transport is terminated, the asynchronous data field shall be retransmitted in a DM1 packet.

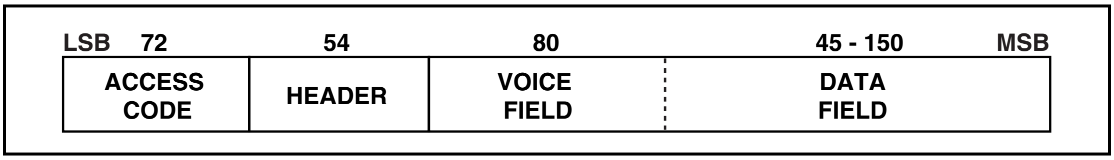


*Figure 6.10: DV packet format*

### 6.5.3 eSCO packets

EV packets are used on the synchronous eSCO logical transport. The packets include a CRC and retransmission may be applied if no acknowledgement of proper reception is received within the retransmission window. eSCO packets may be routed to the synchronous I/O port. Three eSCO packet types (EV3, EV4, EV5) are defined for Basic Rate operation and four additional eSCO packet types (2-EV3, 3-EV3, 2-EV5, 3-EV5) for Enhanced Data Rate operation. The eSCO packets may be used for 64kb/s speech transmission as well as transparent data at 64kb/s and other rates.

#### *6.5.3.1 EV3 packet*

The **EV3** packet has between 1 and 30 information bytes plus a 16-bit CRC code. The bytes are not protected by FEC. The EV3 packet may cover up to a single time slot. There is no payload header present. The payload length is set during the LMP eSCO setup and remains fixed until the link is removed or re-negotiated.

#### *6.5.3.2 EV4 packet*

The **EV4** packet has between 1 and 120 information bytes plus a 16-bit CRC code. The EV4 packet may cover to up three time slots. The information plus CRC bits are coded with a rate 2/3 FEC. There is no payload header present. The payload length is set during the LMP eSCO setup and remains fixed until the link is removed or re-negotiated.

#### *6.5.3.3 EV5 packet*

The **EV5** packet has between 1 and 180 information bytes plus a 16-bit CRC code. The bytes are not protected by FEC. The EV5 packet may cover up to three time slots. There is no payload header present. The payload length is set during the LMP eSCO setup and remains fixed until the link is removed or re-negotiated.

#### *6.5.3.4 2-EV3 packet*

The **2-EV3** packet is similar to the EV3 packet except that the payload is modulated using $\pi/4$-DQPSK. It has between 1 and 60 information bytes plus a 16-bit CRC code. The bytes are not protected by FEC. The 2-EV3 packet covers a single time slot. There is no payload header present. The payload length is set during the LMP eSCO setup and remains fixed until the link is removed or re-negotiated.

#### *6.5.3.5 2-EV5 packet*

The **2-EV5** packet is similar to the EV5 packet except that the payload is modulated using π/4-DQPSK. It has between 1 and 360 information bytes plus a 16-bit CRC code. The bytes are not protected by FEC. The 2-EV5 packet may cover up to three time slots. There is no payload header present. The payload length is set during the LMP eSCO setup and remains fixed until the link is removed or re-negotiated.

#### *6.5.3.6 3-EV3 packet*

The **3-EV3** packet is similar to the EV3 packet except that the payload is modulated using 8DPSK. It has between 1 and 90 information bytes plus a 16-bit CRC code. The bytes are not protected by FEC. The 3-EV3 packet covers a single time slot. There is no payload header present. The payload length is set during the LMP eSCO setup and remains fixed until the link is removed or re-negotiated.

#### *6.5.3.7 3-EV5 packet*

The **3-EV5** packet is similar to the EV5 packet except that the payload is modulated using 8DPSK. It has between 1 and 540 information bytes plus a 16-bit CRC code. The bytes are not protected by FEC. The 3-EV5 packet may cover up to three time slots. There is no payload header present. The payload length is set during the LMP eSCO setup and remains fixed until the link is removed or re-negotiated.

### 6.5.4 ACL packets

ACL packets are used on the asynchronous logical transport. The information carried may be user data or control data.

Seven packet types are defined for Basic Rate operation: DM1, DH1, DM3, DH3, DM5, DH5 and AUX1. Six additional packets are defined for Enhanced Data Rate operation: 2-DH1, 3-DH1, 2-DH3, 3-DH3, 2-DH5 and 3-DH5.

#### *6.5.4.1 DM1 packet*

The DM1 packet carries data information only. The payload has between 1 and 18 information bytes (including the 1-byte payload header) plus a 16-bit CRC code. The DM1 packet occupies a single time slot. The information plus CRC bits are coded with a rate 2/3 FEC. The payload header in the DM1 packet is 1 byte long, see Figure 6.12 on page 130. The length indicator in the payload header specifies the number of user bytes (excluding payload header and the CRC code).

#### *6.5.4.2 DH1 packet*

This packet is similar to the DM1 packet, except that the information in the payload is not FEC encoded. As a result, the DH1 packet has between 1 and 28 information bytes (including the 1-byte payload header) plus a 16-bit CRC code. The DH1 packet occupies a single time slot.

#### *6.5.4.3 DM3 packet*

The DM3 packet may occupy up to three time slots. The payload has between 2 and 123 information bytes (including the 2-byte payload header) plus a 16-bit CRC code. The information plus CRC bits are coded with a rate 2/3 FEC. The payload header in the DM3 packet is 2 bytes long, see Figure 6.13 on page 131. The length indicator in the payload header specifies the number of user bytes (excluding payload header and the CRC code).

#### *6.5.4.4 DH3 packet*

This packet is similar to the DM3 packet, except that the information in the payload is not FEC encoded. As a result, the DH3 packet has between 2 and 185 information bytes (including the 2-byte payload header) plus a 16-bit CRC code. The DH3 packet may occupy up to three time slots.

#### *6.5.4.5 DM5 packet*

The DM5 packet may occupy up to five time slots. The payload has between 2 and 226 information bytes (including the 2-byte payload header) plus a 16-bit

CRC code. The payload header in the DM5 packet is 2 bytes long. The information plus CRC bits are coded with a rate 2/3 FEC. The length indicator in the payload header specifies the number of user bytes (excluding payload header and the CRC code).

#### *6.5.4.6 DH5 packet*

This packet is similar to the DM5 packet, except that the information in the payload is not FEC encoded. As a result, the DH5 packet has between 2 and 341 information bytes (including the2-byte payload header) plus a 16-bit CRC code. The DH5 packet may occupy up to five time slots.

#### *6.5.4.7 AUX1 packet*

This packet resembles a DH1 packet but has no CRC code. The AUX1 packet has between 1 and 30 information bytes (including the 1-byte payload header). The AUX1 packet occupies a single time slot. The AUX1 packet shall not be used for the ACL-U or ACL-C logical links. An AUX1 packet may be discarded.

#### *6.5.4.8 2-DH1 packet*

This packet is similar to the DH1 packet except that the payload is modulated using $\pi$/4-DQPSK. The 2-DH1 packet has between 2 and 56 information bytes (including the 2-byte payload header) plus a 16-bit CRC code. The 2-DH1 packet occupies a single time slot.

#### *6.5.4.9 2-DH3 packet*

This packet is similar to the DH3 packet except that the payload is modulated using $\pi$/4-DQPSK. The 2-DH3 packet has between 2 and 369 information bytes (including the 2-byte payload header) plus a 16-bit CRC code. The 2-DH3 packet may occupy up to three time slots.

#### *6.5.4.10 2-DH5 packet*

This packet is similar to the DH5 packet except that the payload is modulated using $\pi$/4-DQPSK. The 2-DH5 packet has between 2 and 681 information bytes (including the 2-byte payload header) plus a 16-bit CRC code. The 2-DH5 packet may occupy up to five time slots.

#### *6.5.4.11 3-DH1 packet*

This packet is similar to the DH1 packet except that the payload is modulated using 8DPSK. The 3-DH1 packet has between 2 and 85 information bytes (including the 2-byte payload header) plus a 16-bit CRC code. The 3-DH1 packet occupies a single time slot.

##### *6.5.4.12 3-DH3 packet*

This packet is similar to the DH3 packet except that the payload is modulated using 8DPSK. The 3-DH3 packet has between 2 and 554 information bytes (including the 2-byte payload header) plus a 16-bit CRC code. The 3-DH3 packet may occupy up to three time slots.

##### *6.5.4.13 3-DH5 packet*

This packet is similar to the DH5 packet except that the payload is modulated using 8DPSK. The 3-DH5 packet has between 2 and 1023 information bytes (including the 2-byte payload header) plus a 16-bit CRC code. The 3-DH5 packet may occupy up to five time slots.

## 6.6 PAYLOAD FORMAT

In the payload, two fields are distinguished: the synchronous data field and the asynchronous data field. The ACL packets only have the asynchronous data field and the SCO and eSCOpackets only have the synchronous data field – with the exception of the DV packets which have both.

### 6.6.1 Synchronous data field

In SCO, which is only supported in Basic Rate mode, the synchronous data field has a fixed length and consists only of the synchronous data body portion. No payload header is present.

In Basic Rate eSCO, the synchronous data field consists of two segments: a synchronous data body and a CRC code. No payload header is present.

In Enhanced Data Rate eSCO, the synchronous data field consists of five segments: a guard time, a synchronization sequence, a synchronous data body, a CRC code and a trailer. No payload header is present.

**1. Enhanced Data Rate Guard Time**

For Enhanced Data Rate packets the guard time is defined as the period starting at the end of the last GFSK symbol of the header and ending at the start of the reference symbol of the synchronization sequence. The length of the guard time shall be between 4.75 µsec and 5.25 µsec.

## 2. Enhanced Data Rate Synchronization Sequence

For Enhanced Data Rate packets the symbol timing at the start of the synchronization sequence shall be within ±¼ µsec of the symbol timing of the last GFSK symbol of the packet header. The length of the synchronization sequence is 11 µsec (11 DPSK symbols) and consists of a reference symbol (with arbitrary phase) followed by ten DPSK symbols.

The phase changes between the DPSK symbols (shown in Synchronization sequence) shall be

$$\{\varphi_1, \varphi_2, \varphi_3, \varphi_4, \varphi_5, \varphi_6, \varphi_7, \varphi_8, \varphi_9, \varphi_{10}\} = \{3\pi/4, -3\pi/4, 3\pi/4, -3\pi/4, 3\pi/4, -3\pi/4, -3\pi/4, 3\pi/4, 3\pi/4, 3\pi/4\} \quad \text{(EQ 12)}$$

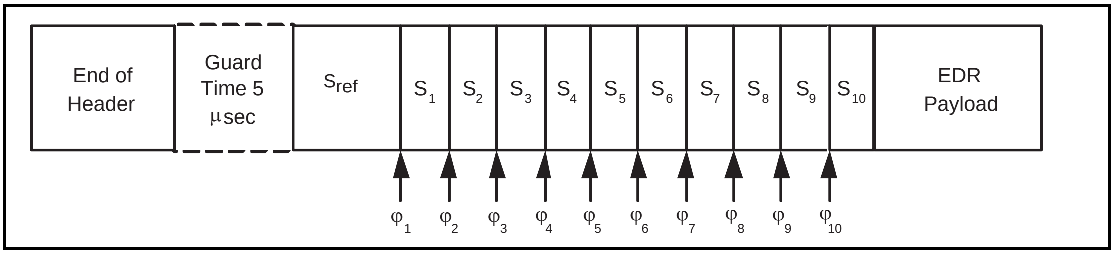


*Figure 6.11: Synchronization sequence*

Sref is the reference symbol. $\varphi_1$ is the phase change between the reference symbol and the first DPSK symbol $S_1$. $\varphi_k$ is the phase change between the k-1$^{th}$ symbol $S_{k-1}$ and the k$^{th}$ symbol $S_k$

Note: the synchronization sequence may be generated using the modulator by pre-pending the data with bits that generate the synchronization sequence.

For $\pi$/4-DQPSK, the bit sequence used to generate the synchronization sequence is 0,1,1,1,0,1,1,1,0,1,1,1,1,1,0,1,0,1,0,1.

For 8DPSK, the bit sequence used to generate the synchronization sequence is 0,1,0,1,1,1,0,1,0,1,1,1,0,1,0,1,1,1,1,1,1,0,1,0,0,1,0,0,1,0.

## 3. Synchronous data body

For HV and DV packets, the synchronous data body length is fixed. For EV packets, the synchronous data body length is negotiated during the LMP eSCO setup. Once negotiated, the synchronous data body length remains constant unless re-negotiated. The synchronous data body length may be different for each direction of the eSCO logical transport.

## 4. CRC code

The 16-bit CRC in the payload is generated as specified in Section 7.1 on page 138. The 8-bit UAP of the master is used to initialize the CRC generator.

Only the Synchronous data body segment is used to generate the CRC code.

**5. Enhanced Data Rate Trailer**

For Enhanced Data Rate packets, two trailer symbols shall be added to the end of the payload. The trailer bits shall be all zero, i.e. {00, 00} for the $\pi/4$-DQPSK and {000, 000} for the 8DPSK.

### 6.6.2 Asynchronous data field

Basic rate ACL packets have an asynchronous data field consisting of two or three segments: a payload header, a payload body, and possibly a CRC code (the AUX1 packet does not carry a CRC code).

Enhanced Data Rate ACL packets have an asynchronous data field consisting of six segments: a guard time, a synchronization sequence, a payload header, a payload body, a CRC and a trailer.

**1. Enhanced Data Rate Guard time**

This is the same as defined for the Synchronous data field in section 6.6.1.

**2. Enhanced Data Rate Synchronization sequence**

This is the same as defined for the Synchronous data field in section 6.6.1.

**3. Payload header**

The payload header is one or two bytes long. Basic rate packets in segments one and two have a 1-byte payload header; Basic Rate packets in segments three and four and all Enhanced Data Rate packets have a 2-byte payload header. The payload header specifies the logical link (2-bit LLID indication), controls the flow on the logical channels (1-bit FLOW indication), and has a payload length indicator (5 bits and 10 bits for 1-byte and 2-byte payload headers, respectively). In the case of a 2-byte payload header, the length indicator is extended by five bits into the next byte. The remaining three bits of the second byte are reserved for future use and shall be set to zero. The formats of the 1-byte and 2-byte payload headers are shown in Figure 6.12 on page 130 and Figure 6.13 on page 131.

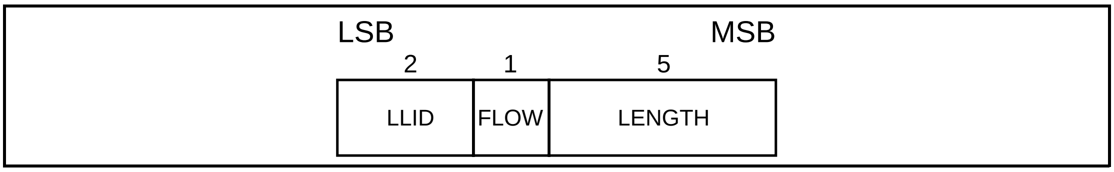


*Figure 6.12: Payload header format for Basic Rate single-slot ACL packets.*

LSB → MSB

| 2 | 1 | 10 | 3 |
|---|---|---|---|
| LLID | FLOW | LENGTH | RESERVED |

*Figure 6.13: Payload header format for multi-slot ACL packets and all EDR ACL packets.*

The LLID field shall be transmitted first, the length field last. In Table 6.6 on page 132, more details about the contents of the LLID field are listed.

| LLID code $b_1b_0$ | Logical Link | Information |
|---|---|---|
| 00 | NA | undefined |
| 01 | ACL-U | Continuation fragment of an L2CAP message |
| 10 | ACL-U | Start of an L2CAP message or no fragmentation |
| 11 | ACL-C | LMP message |

*Table 6.6: Logical link LLID field contents*

An L2CAP message may be fragmented into several packets. Code 10 shall be used for an ACL-U packet carrying the first fragment of such a message; code 01 shall be used for continuing fragments. If there is no fragmentation, code 10 shall be used for every packet. Code 11 shall be used for LMP messages. Code 00 is reserved for future use.

The flow indicator in the payload is used to control the flow at the L2CAP level. It is used to control the flow per logical link. FLOW=1 means flow-on (GO) and FLOW=0 means flow-off (STOP). After a new connection has been established the flow indicator shall be set to GO. When a device receives a payload header with the flow bit set to STOP, it shall stop the transmission of ACL packets before an additional amount of payload data is sent. This amount is defined as the flow control lag, expressed as a number of bytes. The shorter the flow control lag, the less buffering the other device must dedicate to this function. The flow control lag shall not exceed 1792 bytes ($7 \times 256$ bytes). In order to allow devices to optimize the selection of packet length and buffer space, the flow control lag of a given implementation shall be provided in the LMP_features_res message.

If a packet containing the payload flow bit of STOP is received, with a valid packet header but bad payload, the payload flow control bit shall be ignored. The baseband ACK contained in the packet header will be received and a further ACL packet may be transmitted. Each occurrence of this situation allows a further ACL packet to be sent in spite of the flow control request being sent via the payload header flow control bit. It is recommended that devices that use the payload header flow bit should ensure that no further ACL packets are sent until the payload flow bit has been correctly received. This can be accomplished by simultaneously turning on the flow bit in the packet header and keeping it on until an ACK is received back (ARQN=1). This will typically be only one round trip time. Since they lack a payload CRC, AUX1 packets should not be used with a payload flow bit of STOP.

The Baseband Resource Manager is responsible for setting and processing the flow bit in the payload header. Real-time flow control shall be carried out at the packet level by the link controller via the flow bit in the packet header (see Section 6.4.3 on page 117). With the payload flow bit, traffic from the remote end can be controlled. It is allowed to generate and send an ACL packet with payload length zero irrespective of flow status. L2CAP start-fragment and continue-fragment indications (LLID=10 and LLID=01) also retain their meaning when the payload length is equal to zero (i.e. an empty start-fragment shall not be sent in the middle of an on-going ACL-U packet transmission). It is always safe to send an ACL packet with length=0 and LLID=01. The payload flow bit has its own meaning for each logical link (ACL-U or ACL-C), Table 6.7 on page 133. On the ACL-C logical link, no flow control is applied and the payload FLOW bit shall always be set to one.

| LLID code $b_1b_0$ | Usage and semantics of the ACL payload header FLOW bit |
|---|---|
| 00 | Not defined, reserved for future use. |
| 01 or 10 | Flow control of the ACL-U channel (L2CAP messages) |
| 11 | Always set FLOW=1 on transmission and ignore the bit on reception |

*Table 6.7: Use of payload header flow bit on the logical links.*

The length indicator shall be set to the number of bytes (i.e. 8-bit words) in the payload excluding the payload header and the CRC code; i.e. the payload body only. With reference to Figure 6.12 and Figure 6.13, the MSB of the length field in a 1-byte header is the last (right-most) bit in the payload header; the MSB of the length field in a 2-byte header is the fourth bit (from left) of the second byte in the payload header.

### 4. Payload body

The payload body includes the user information and determines the effective user throughput. The length of the payload body is indicated in the length field of the payload header.

### 5. CRC code generation

The 16-bit cyclic redundancy check code in the payload is generated as specified in Section 7.1 on page 138. Before determining the CRC code, an 8-bit value is used to initialize the CRC generator. For the CRC code in the FHS packets sent in **master response** substate, the UAP of the slave is used. For the FHS packet sent in **inquiry response** substate, the DCI (see Section 1.2.1 on page 66) is used. For all other packets, the UAP of the master is used.

Only the Payload header and Payload body segments are used to generate the CRC code.

### 6. Enhanced Data Rate Trailer

This is the same as defined for the Synchronous data field in section 6.6.1.

## 6.7 PACKET SUMMARY

A summary of the packets and their characteristics is shown in Table 6.8, Table 6.9 and Table 6.10. The payload represents the packet payload excluding FEC, CRC, and payload header.

| Type | Payload (bytes) | FEC | CRC | Symmetric Max. Rate | Asymmetric Max. Rate |
|---|---|---|---|---|---|
| ID | na | na | na | na | na |
| NULL | na | na | na | na | na |
| POLL | na | na | na | na | na |
| FHS | 18 | 2/3 | yes | na | na |

*Table 6.8: Link control packets*

| Type | Payload Header (bytes) | User 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 |
| 2-DH1 | 2 | 0-54 | no | yes | 345.6 | 345.6 | 345.6 |
| 2-DH3 | 2 | 0-367 | no | yes | 782.9 | 1174.4 | 172.8 |
| 2-DH5 | 2 | 0-679 | no | yes | 869.7 | 1448.5 | 115.2 |
| 3-DH1 | 2 | 0-83 | no | yes | 531.2 | 531.2 | 531.2 |
| 3-DH3 | 2 | 0-552 | no | yes | 1177.6 | 1766.4 | 235.6 |
| 3-DH5 | 2 | 0-1021 | no | yes | 1306.9 | 2178.1 | 177.1 |

*Table 6.9: ACL packets*

| Type | Payload Header (bytes) | User 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 |
| 2-EV3 | na | 1-60 | No | Yes | 192 |
| 2-EV5 | na | 1-360 | No | Yes | 576 |
| 3-EV3 | na | 1-90 | No | Yes | 288 |
| 3-EV5 | na | 1-540 | No | Yes | 864 |

*Table 6.10: Synchronous packets*

1. Items followed by ‘D’ relate to data field only.

# 7 BITSTREAM PROCESSING

Bluetooth devices shall use the bitstream processing schemes as defined in the following sections.

Before the payload is sent over the air interface, several bit manipulations are performed in the transmitter to increase reliability and security. An HEC is added to the packet header, the header bits are scrambled with a whitening word, and FEC coding is applied. In the receiver, the inverse processes are carried out. Figure 7.1 on page 137 shows the processes carried out for the packet header both at the transmit and the receive side. All header bit processes are mandatory.

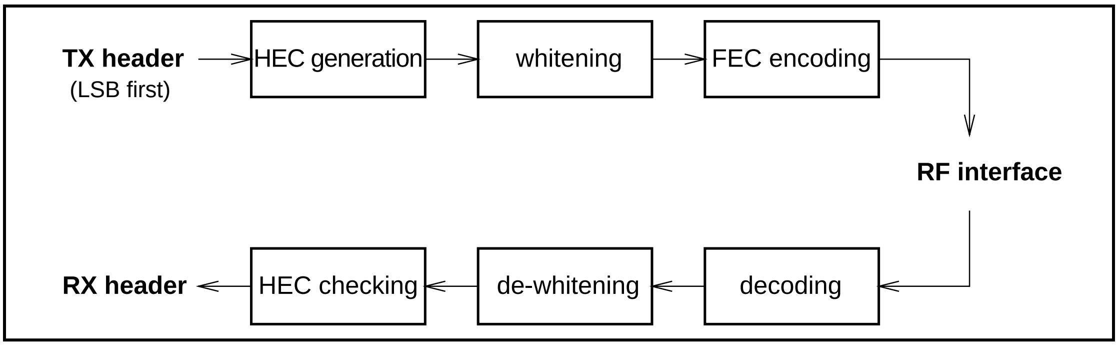


*Figure 7.1: Header bit processes.*

Figure 7.2 on page 137 shows the processes that may be carried out on the payload. In addition to the processes defined for the packet header, encryption can be applied on the payload. Only whitening and de-whitening, as explained in Section 7.2 on page 141, are mandatory for every payload; all other processes are optional and depend on the packet type (see Section 6.6 on page 128) and whether encryption is enabled. In Figure 7.2 on page 137, optional processes are indicated by dashed blocks.

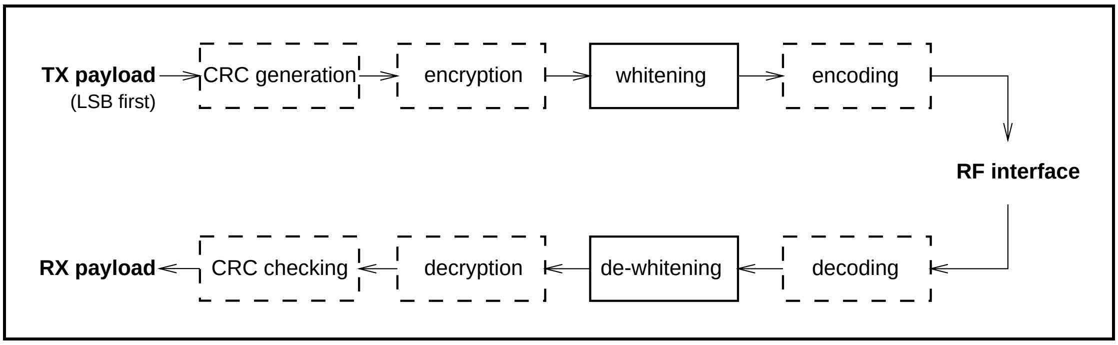


*Figure 7.2: Payload bit processes.*

## 7.1 ERROR CHECKING

The packet can be checked for errors or wrong delivery using the channel access code, the HEC in the header, and the CRC in the payload. At packet reception, the access code is checked first. Since the 64-bit sync word in the channel access code is derived from the 24-bit master LAP, this checks if the LAP is correct, and prevents the receiver from accepting a packet of another piconet (provided the LAP field of the master's BD_ADDR is different).

The HEC and CRC computations are normally initialized with the UAP of the master. Even though the access code may be the same for two piconets the different UAP values will typically cause the HEC and CRC to fail. However, there is an exception where no common UAP is available in the transmitter and receiver. This is the case when the HEC and CRC are generated for the FHS packet in **inquiry response** substate. In this case the DCI value shall be used.

The generation and check of the HEC and CRC are summarized in Figure 7.5 on page 139 and Figure 7.8 on page 140. Before calculating the HEC or CRC, the shift registers in the HEC/CRC generators shall be initialized with the 8-bit UAP (or DCI) value. Then the header and payload information shall be shifted into the HEC and CRC generators, respectively (with the LSB first).

### 7.1.1 HEC generation

The HEC generating LFSR is depicted in Figure 7.3 on page 138. The generator polynomial is $g(D) = (D+1)(D^7+D^4+D^3+D^2+1) = D^8+D^7+D^5+D^2+D+1$ . Initially this circuit shall be pre-loaded with the 8-bit UAP such that the LSB of the UAP (denoted $UAP_0$) goes to the left-most shift register element, and, $UAP_7$ goes to the right-most element. The initial state of the HEC LFSR is depicted in Figure 7.4 on page 139. Then the data shall be shifted in with the switch S set in position 1. When the last data bit has been clocked into the LFSR, the switch S shall be set in position 2, and, the HEC can be read out from the register. The LFSR bits shall be read out from right to left (i.e., the bit in position 7 is the first to be transmitted, followed by the bit in position 6, etc.).

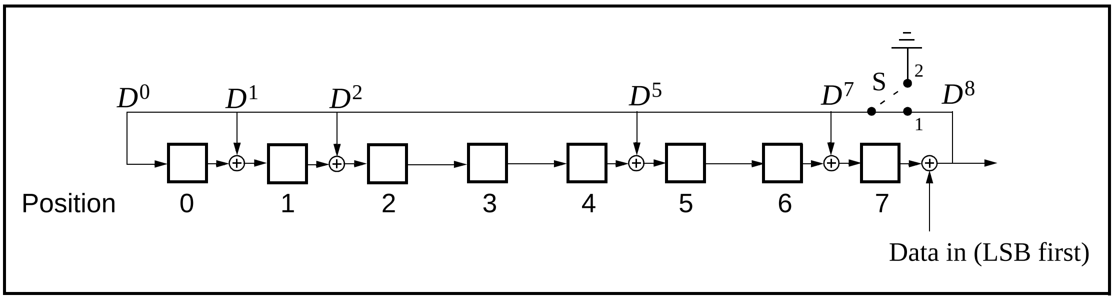


*Figure 7.3: The LFSR circuit generating the HEC.*

| Position: | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| LFSR: | $UAP_0$ | $UAP_1$ | $UAP_2$ | $UAP_3$ | $UAP_4$ | $UAP_5$ | $UAP_6$ | $UAP_7$ |

*Figure 7.4: Initial state of the HEC generating circuit.*

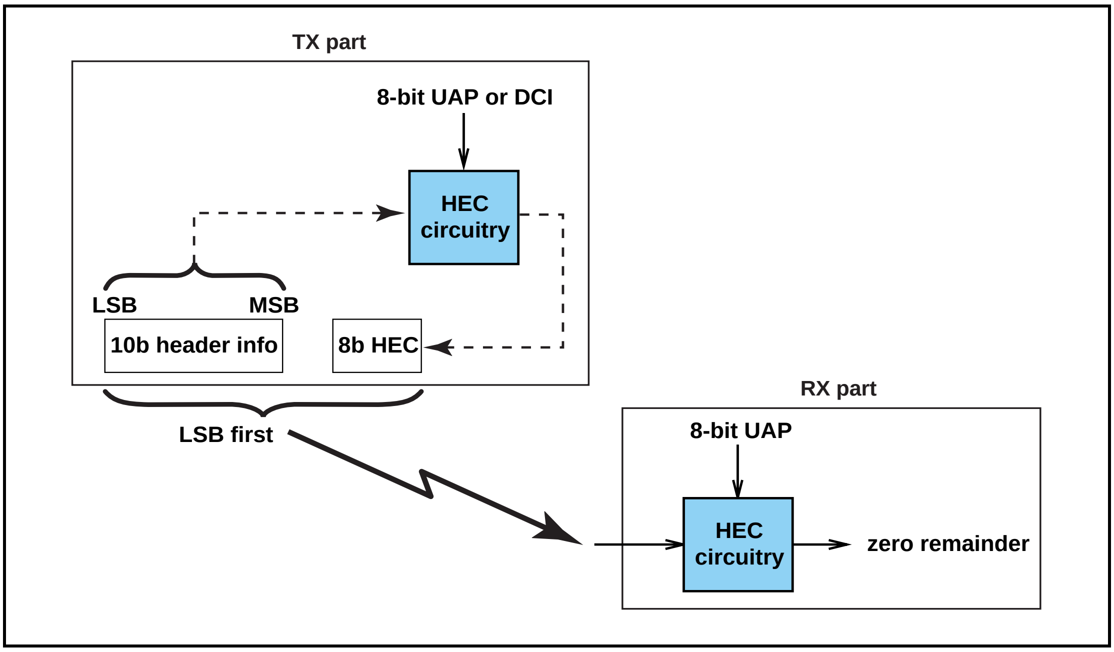


*Figure 7.5: HEC generation and checking.*

## 7.1.2 CRC generation

The 16 bit LFSR for the CRC is constructed similarly to the HEC using the CRC-CCITT generator polynomial $g(D) = D^{16} + D^{12} + D^5 + 1$ (i.e. `210041` in octal representation) (see Figure 7.6 on page 140). For this case, the 8 left-most bits shall be initially loaded with the 8-bit UAP ($UAP_0$ to the left and $UAP_7$ to the right) while the 8 right-most bits shall be reset to zero. The initial state of the 16 bit LFSR is specified in Figure 7.7 on page 140. The switch S shall be set in position 1 while the data is shifted in. After the last bit has entered the LFSR, the switch shall be set in position 2, and, the register's contents shall be transmitted, from right to left (i.e., starting with position 15, then position 14, etc.).

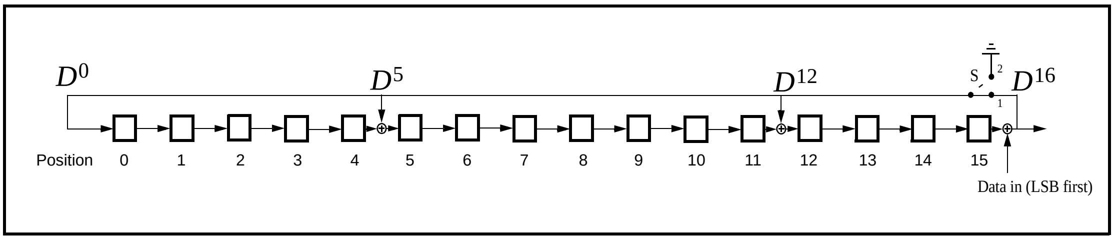


*Figure 7.6: The LFSR circuit generating the CRC.*

| **Position:** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **LFSR:** | $UAP_0$ | $UAP_1$ | $UAP_2$ | $UAP_3$ | $UAP_4$ | $UAP_5$ | $UAP_6$ | $UAP_7$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

*Figure 7.7: Initial state of the CRC generating circuit.*

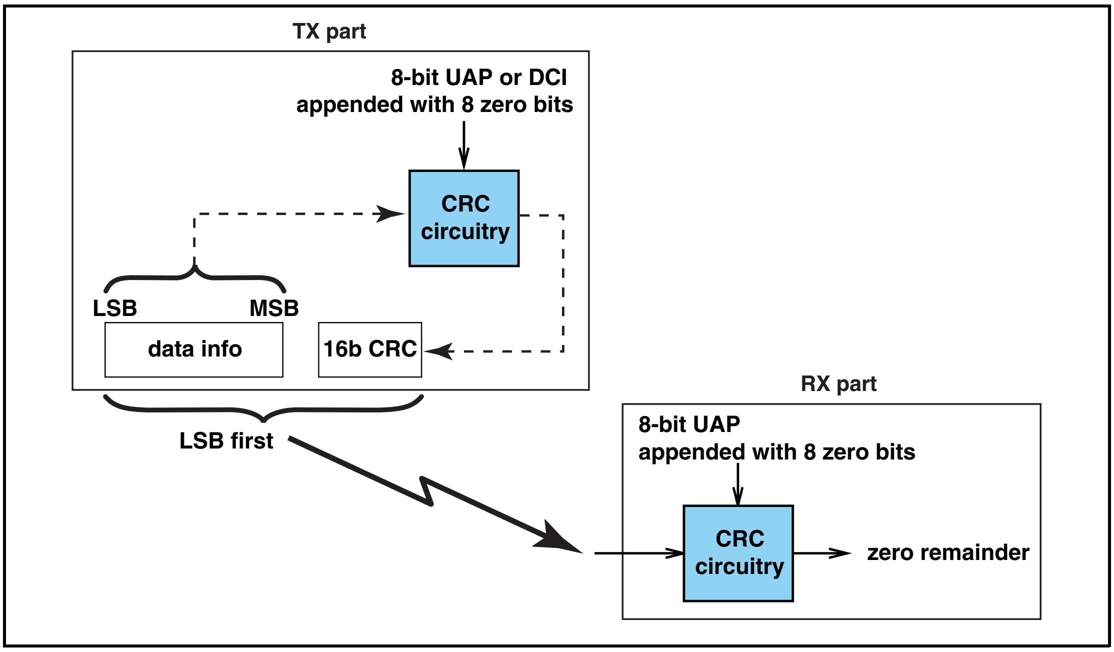


*Figure 7.8: CRC generation and checking*.

## 7.2 DATA WHITENING

Before transmission, both the header and the payload shall be scrambled with a data whitening word in order to randomize the data from highly redundant patterns and to minimize DC bias in the packet. The scrambling shall be performed prior to the FEC encoding.

At the receiver, the received data shall be descrambled using the same whitening word generated in the recipient. The descrambling shall be performed after FEC decoding.

The whitening word is generated with the polynomial $g(D) = D^7 + D^4 + 1$ (i.e., `221` in octal representation) and shall be subsequently XORed with the header and the payload. The whitening word is generated with the linear feedback shift register shown in Figure 7.9 on page 141. Before each transmission, the shift register shall be initialized with a portion of the master Bluetooth clock, $CLK_{6-1}$, extended with an MSB of value one. This initialization shall be carried out with $CLK_1$ written to position 0, $CLK_2$ written to position 1, etc. An exception is the FHS packet sent during page response or inquiry, where initialization of the whitening register shall be carried out differently. Instead of the master clock, the X-input used in the **inquiry** or **page response** (depending on current state) routine shall be used, see Table 2.2. The 5-bit value shall be extended with two MSBs of value 1. During register initialization, the LSB of X (i.e., $X_0$) shall be written to position 0, $X_1$ shall be written to position 1, etc.

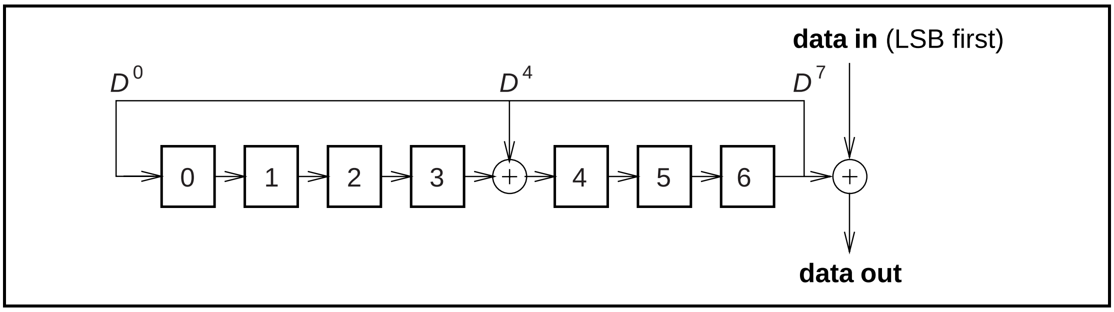


*Figure 7.9: Data whitening LFSR.*

After initialization, the packet header and the payload (including the CRC) are whitened. The payload whitening shall continue from the state the whitening LFSR had at the end of HEC. There shall be no re-initialization of the shift register between packet header and payload. The first bit of the “data in” sequence shall be the LSB of the packet header.

For Enhanced Data Rate packets, whitening shall not be applied to the guard, synchronization and trailer portions of the Enhanced Data Rate packets. During the periods where whitening is not applied the LFSR shall be paused.

## 7.3 ERROR CORRECTION

There are three error correction schemes defined for Bluetooth:

- 1/3 rate FEC
- 2/3 rate FEC
- ARQ scheme for the data

The purpose of the FEC scheme on the data payload is to reduce the number of retransmissions. However, in a reasonable error-free environment, FEC gives unnecessary overhead that reduces the throughput. Therefore, the packet definitions given in Section 6 on page 109 have been kept flexible to use FEC in the payload or not, resulting in the **DM** and **DH** packets for the ACL logical transport, **HV** packets for the SCO logical transport, and **EV** packets for the eSCO logical transport. The packet header is always protected by a 1/3 rate FEC since it contains valuable link information and is designed to with-stand more bit errors.

Correction measures to mask errors in the voice decoder are not included in this section. This matter is discussed in Section 9.3 on page 198.

## 7.4 FEC CODE: RATE 1/3

A simple 3-times repetition FEC code is used for the header. The repetition code is implemented by repeating each bit three times, see the illustration in Figure 7.10 on page 142. The 3-times repetition code is used for the entire header, as well as for the synchronous data field in the **HV1** packet.

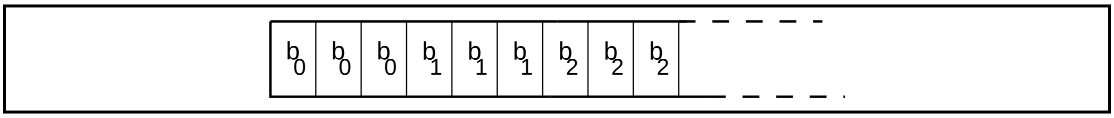


*Figure 7.10: Bit-repetition encoding scheme.*

## 7.5 FEC CODE: RATE 2/3

The other FEC scheme is a (15,10) shortened Hamming code. The generator polynomial is $g(D) = (D+1)(D^4+D+1)$ . This corresponds to 65 in octal notation. The LFSR generating this code is depicted in Figure 7.11 on page 143. Initially all register elements are set to zero. The 10 information bits are sequentially fed into the LFSR with the switches S1 and S2 set in position 1. Then, after the final input bit, the switches S1 and S2 are set in position 2, and the five parity bits are shifted out. The parity bits are appended to the information bits. Subsequently, each block of 10 information bits is encoded into a 15 bit codeword. This code can correct all single errors and detect all double errors in each codeword. This 2/3 rate FEC is used in the **DM** packets, in the data field of the **DV** packet, in the **FHS** packet, in the **HV2** packet, and in the **EV4** packet. Since the encoder operates with information segments of length 10, tail bits with value zero shall be appended after the CRC bits to bring the total number of bits equal to a multiple of 10. The number of tail bits to append shall be the least possible that achieves this (i.e., in the interval 0...9). These tail bits are not included in the payload length indicator for ACL packets or in the payload length field of the eSCO setup LMP command.

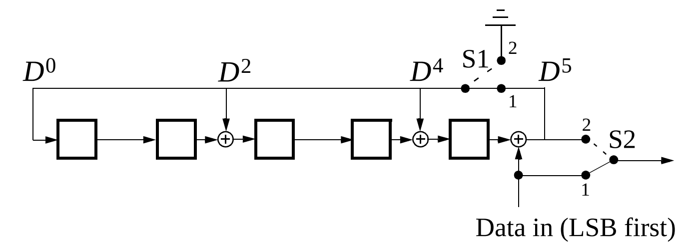


*Figure 7.11: LFSR generating the (15,10) shortened Hamming code.*

## 7.6 ARQ SCHEME

With an automatic repeat request scheme, **DM, DH** the data field of **DV** packets, and **EV** packets shall be transmitted until acknowledgement of a successful reception is returned by the destination (or timeout is exceeded). The acknowledgement information shall be included in the header of the return packet. The ARQ scheme is only used on the payload in the packet and only on packets that have a CRC. The packet header and the synchronous data payload of HV and DV packets are not protected by the ARQ scheme.

### 7.6.1 Unnumbered ARQ

Bluetooth uses a fast, unnumbered acknowledgment scheme. An ACK (ARQN=1) or a NAK (ARQN=0) is returned in response to the receipt of previously received packet. The slave shall respond in the slave-to-master slot directly following the master-to-slave slot unless the slave has scatternet commitments in that timeslot; the master shall respond at the next event addressing the same slave (the master may have addressed other slaves between the last received packet from the considered slave and the master response to this packet). For a packet reception to be successful, at least the HEC must pass. In addition, the CRC must pass if present.

In the first POLL packet at the start of a new connection (as a result of a page, page scan, role switch or unpark) the master shall initialize the ARQN bit to NAK. The response packet sent by the slave shall also have the ARQN bit set to NAK. The subsequent packets shall use the following rules. The initial value of the master's eSCO ARQN at link set-up shall be NAK.

The ARQ bit shall only be affected by data packets containing CRC and empty slots. As shown in Figure 7.12 on page 145, upon successful reception of a CRC packet, the ARQN bit shall be set to ACK. If, in any receive slot in the slave, or, in a receive slot in the master following transmission of a packet, one of these events applies:

1. no access code is detected,
2. the HEC fails,
3. the CRC fails,

then the ARQN bit shall be set to NAK. In eSCO the ARQN bit may be set to ACK even when the CRC on an EV packet has failed thus enabling delivery of erroneous packets.

Packets that have correct HEC but that are addressed to other slaves, or packets other than DH, DM, DV or EV packets, shall not affect the ARQN bit, except as noted in Section 7.6.2.2 on page 148. In these cases the ARQN bit shall be left as it was prior to reception of the packet. For ACL packets, if a CRC packet with a correct header has the same SEQN as the previously received CRC packet, the ARQN bit shall be set to ACK and the payload shall be ignored without checking the CRC. For eSCO packets, the SEQN shall not be used when determining the ARQN. If an eSCO packet has been received successfully within the eSCO window subsequent receptions within the eSCO window shall be ignored. At the end of the eSCO window, the master's ARQN shall be retained for the first master-to-slave transmission in the next eSCO window.

The ARQ bit in the FHS packet is not meaningful. Contents of the ARQN bit in the FHS packet shall not be checked.

Broadcast packets shall be checked on errors using the CRC, but no ARQ scheme shall be applied. Broadcast packets shall never be acknowledged.

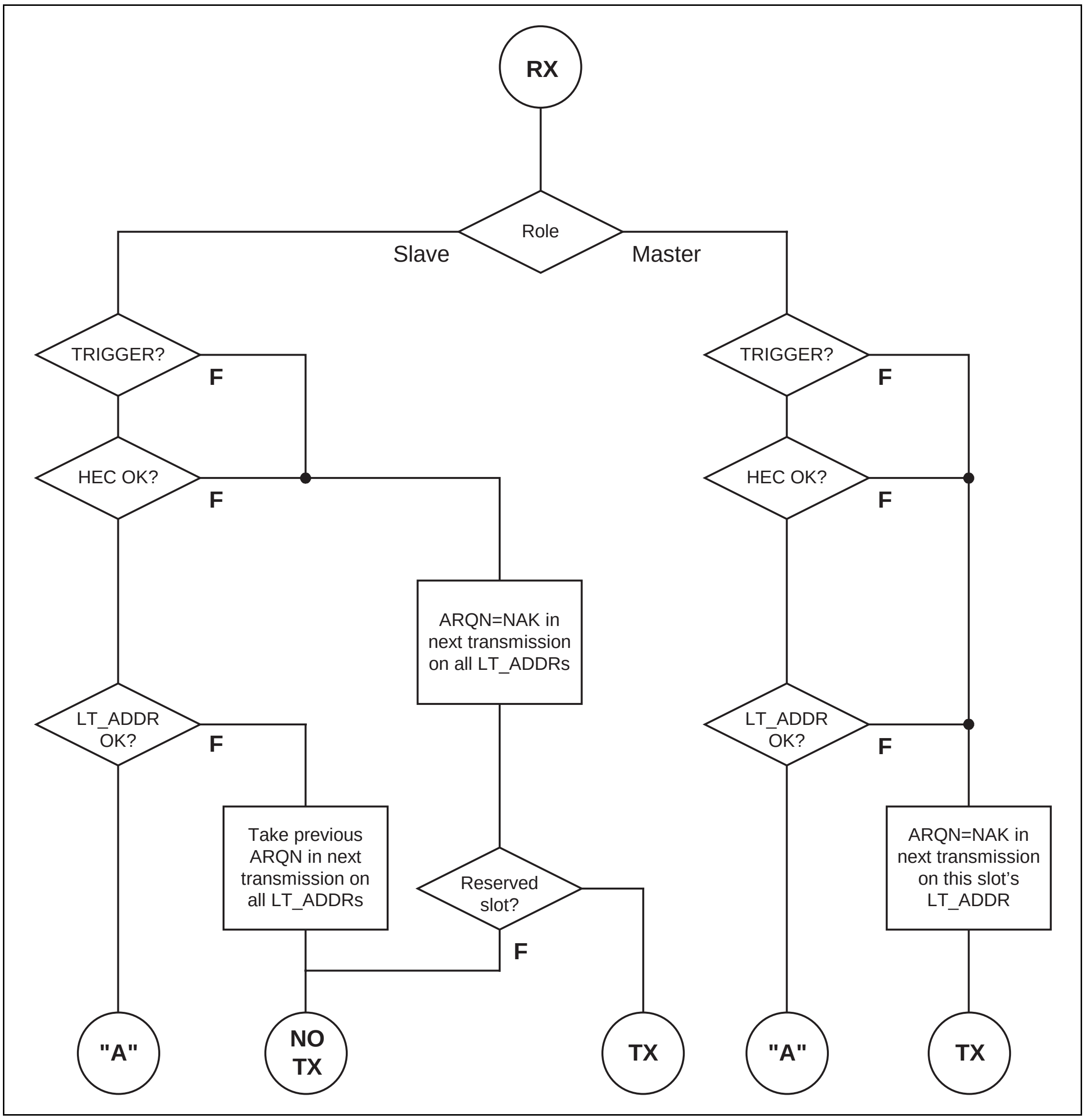


*Figure 7.12: Stage 1 of the receive protocol for determining the ARQN bit.*

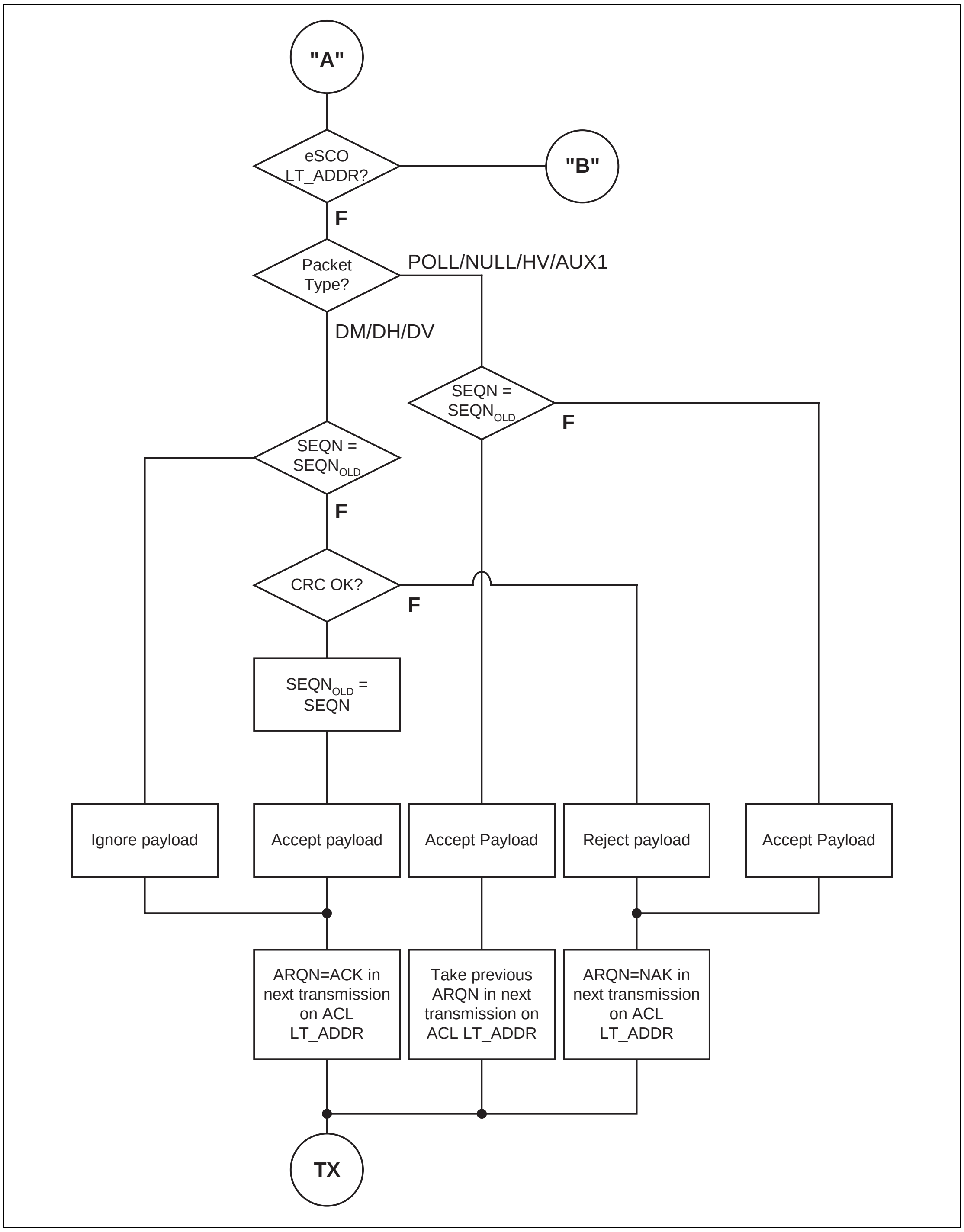


*Figure 7.13: Stage 2 (ACL) of the receive protocol for determining the ARQN bit.*

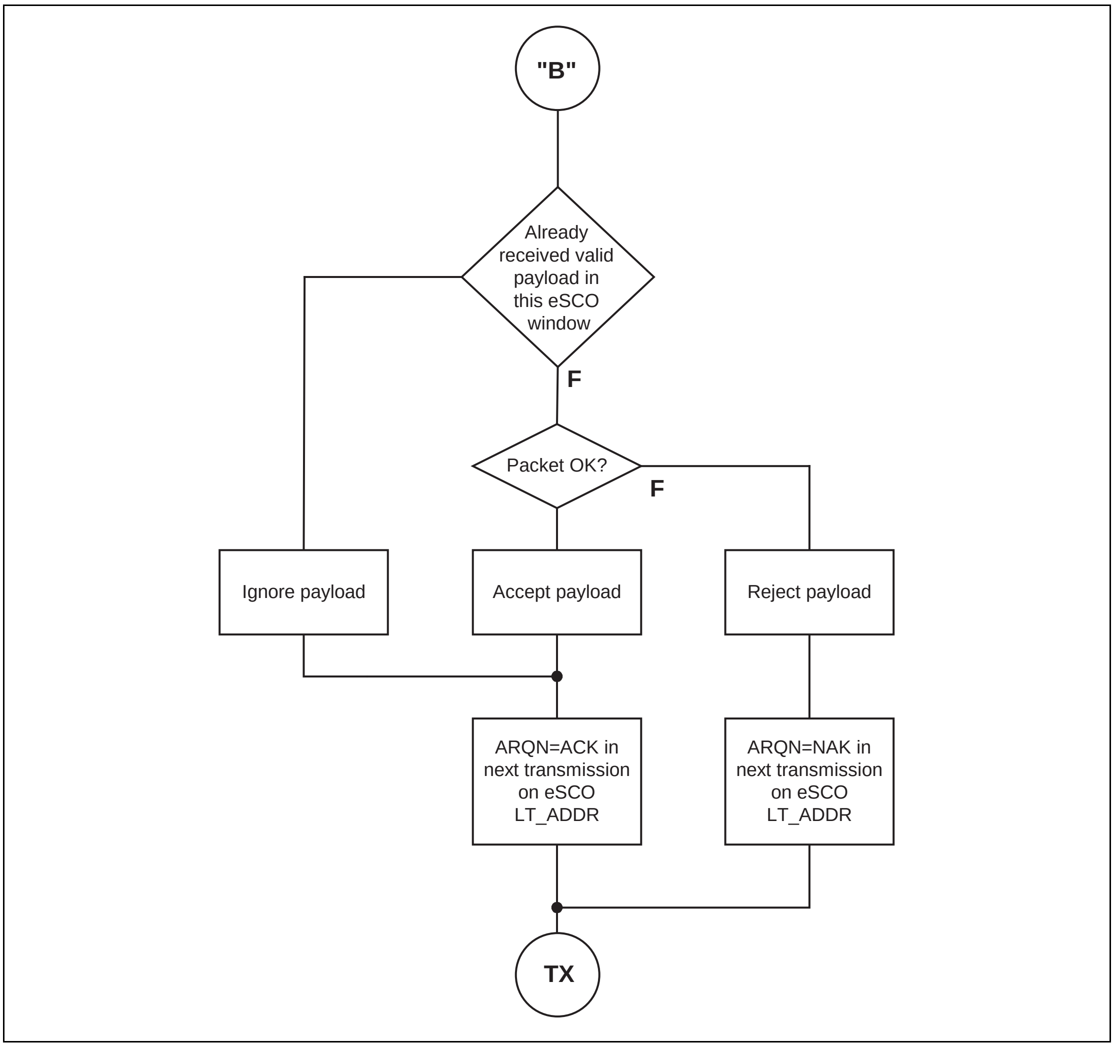


*Figure 7.14: Stage 2 (eSCO) of the receive protocol for determining the ARQN bit.*

## 7.6.2 Retransmit filtering

The data payload shall be transmitted until a positive acknowledgment is received or a timeout is exceeded. A retransmission shall be carried out either because the packet transmission itself failed, or because the acknowledgment transmitted in the return packet failed (note that the latter has a lower failure probability since the header is more heavily coded). In the latter case, the destination keeps receiving the same payload over and over again. In order to filter out the retransmissions in the destination, the SEQN bit is present in the header. Normally, this bit is alternated for every new CRC data payload transmission. In case of a retransmission, this bit shall not be changed so the destination can compare the SEQN bit with the previous SEQN value. If different, a new data payload has arrived; otherwise it is the same data payload and may be ignored. Only new data payloads shall be transferred to the Baseband Resource Manager. Note that CRC data payloads can be carried only by **DM**, **DH**, **DV** or **EV** packets.

#### *7.6.2.1 Initialization of SEQN at start of new connection*

The SEQN bit of the first CRC data packet at the start of a connection (as a result of page, page scan, role switch or unpark) on both the master and the slave sides shall be set to 1. The subsequent packets shall use the rules in the following sections.

#### *7.6.2.2 ACL and SCO retransmit filtering*

The SEQN bit shall only be affected by the CRC data packets as shown in Figure 7.15. It shall be inverted every time a new CRC data packet is sent. The CRC data packet shall be retransmitted with the same SEQN number until an ACK is received or the packet is flushed. When an ACK is received, a new payload may be sent and on that transmission the SEQN bit shall be inverted. If a device decides to flush (see Section 7.6.3 on page 150), and it has not received an acknowledgement for the current packet, it shall replace the current packet with an ACL-U continuation packet with the same sequence number as the current packet and length zero. If it replaces the current packet in this way it shall not move on to transmit the next packet until it has received an ack.

If the slave receives a packet other than DH, DM, DV or EV with the SEQN bit inverted from that in the last header succesfully received on the same LT_ADDR, it shall set the ARQN bit to NAK until a DH, DM, DV or EV packet is successfully received.

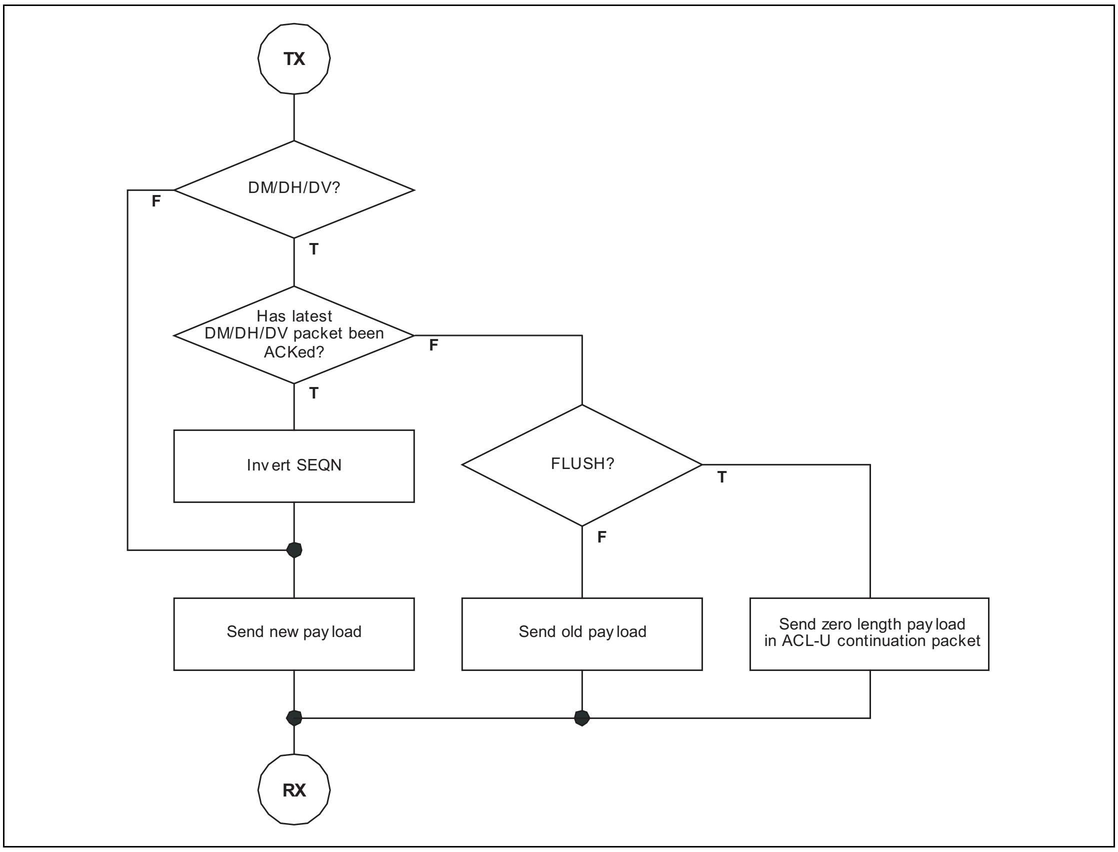


*Figure 7.15: Transmit filtering for packets with CRC.*

#### *7.6.2.3 eSCO retransmit filtering*

In eSCO, the SEQN bit shall be toggled every eSCO window. The value shall be constant for the duration of the eSCO window. The initial value of SEQN shall be zero.

For a given eSCO window the SEQN value shall be constant.

#### *7.6.2.4 FHS retransmit filtering*

The SEQN bit in the FHS packet is not meaningful. This bit may be set to any value. Contents of the SEQN bit in the FHS packet shall not be checked.

#### *7.6.2.5 Packets without CRC retransmit filtering*

During transmission of packets without a CRC the SEQN bit shall remain the same as it was in the previous packet.

### 7.6.3 Flushing payloads

In ACL, the ARQ scheme can cause variable delay in the traffic flow since retransmissions are inserted to assure error-free data transfer. For certain communication links, only a limited amount of delay is allowed: retransmissions are allowed up to a certain limit at which the current payload shall be ignored. This data transfer is indicated as **isochronous traffic**. This means that the retransmit process must be overruled in order to continue with the next data payload. Aborting the retransmit scheme is accomplished by *flushing* the old data and forcing the link controller to take the next data instead.

Flushing results in loss of remaining portions of an L2CAP message. Therefore, the packet following the flush shall have a start packet indication of LLID = 10 in the payload header for the next L2CAP message. This informs the destination of the flush. (see Section 6.6 on page 128). Flushing will not necessarily result in a change in the SEQN bit value, see the previous section.

The Flush Timeout defines a maximum period after which all segments of the ACL-U packet are flushed from the Controller buffer. The Flush Timeout shall start when the First segment of the ACL-U packet is stored in the Controller buffer. After the Flush timeout has expired the Link Controller may continue transmissions according to the procedure described in Section 7.6.2.2 on page 148, however the Baseband Resource Manager shall not continue the transmission of the ACL-U packet to the Link Controller. If the Baseband Resource Manager has further segments of the packet queued for transmission to the Link Controller it shall delete the remaining segments of the ACL-U packet from the queue. In case the complete ACL-U packet was not stored in the Controller buffer yet, any Continuation segments, received for the ACL logical transport, shall be flushed, until a First segment is received. When the complete ACL-U packet has been flushed, the Link Manager shall continue transmission of the next ACL-U packet for the ACL logical transport. The default Flush Timeout shall be infinite, i.e. re-transmissions are carried out until physical link loss occurs. This is also referred to as a 'reliable channel'. All devices shall support the default Flush Timeout.

In eSCO, packets shall be automatically flushed at the end of the eSCO window.

### 7.6.4 Multi-slave considerations

In a piconet with multiple logical transports, the master shall carry out the ARQ protocol independently on each logical transport.

### 7.6.5 Broadcast packets

Broadcast packets are packets transmitted by the master to all the slaves simultaneously. (see paragraph 8.6.4) If multiple hop sequences are being used each transmission may only be received by some of the slaves. In this case the master shall repeat the transmission on each hop sequence. A broadcast packet shall be indicated by the all-zero LT_ADDR (note; the FHS packet is the only packet which may have an all-zero LT_ADDR but is not a broadcast packet). Broadcast packets shall not be acknowledged (at least not at the LC level).

Since broadcast messages are not acknowledged, each broadcast packet is transmitted at least a fixed number of times. A broadcast packet should be transmitted $N_{BC}$ times before the next broadcast packet of the same broadcast message is transmitted, see Figure 7.16 on page 152. Optionally, a broadcast packet may be transmitted $N_{BC}$ + 1 times. Note: $N_{BC}$=1 means that each broadcast packet should be sent only once, but optionally may be sent twice. However, time-critical broadcast information may abort the ongoing broadcast train. For instance, unpark messages sent at beacon instances may do this, see Section 8.9.5 on page 192.

If multiple hop sequences are being used then the master may transmit on the different hop sequences in any order, providing that transmission of a new broadcast packet shall not be started until all transmissions of any previous broadcast packet have completed on all hop sequences. The transmission of a single broadcast packet may be interleaved among the hop sequences to minimize the total time to broadcast a packet. The master has the option of transmitting only $N_{BC}$ times on channels common to all hop sequences.

Broadcast packets with a CRC shall have their own sequence number. The SEQN of the first broadcast packet with a CRC shall be set to SEQN = 1 by the master and shall be inverted for each new broadcast packet with CRC thereafter. Broadcast packets without a CRC have no influence on the sequence number. The slave shall accept the SEQN of the first broadcast packet it receives in a connection and shall check for change in SEQN for subsequent broadcast packets. Since there is no acknowledgement of broadcast messages and there is no end packet indication, it is important to receive the start packets correctly. To ensure this, repetitions of the broadcast packets that are L2CAP start packets and LMP packets shall not be filtered out. These packets shall be indicated by LLID=1X in the payload header as explained in section 6.6 on page 128. Only repetitions of the L2CAP continuation packets shall be filtered out.

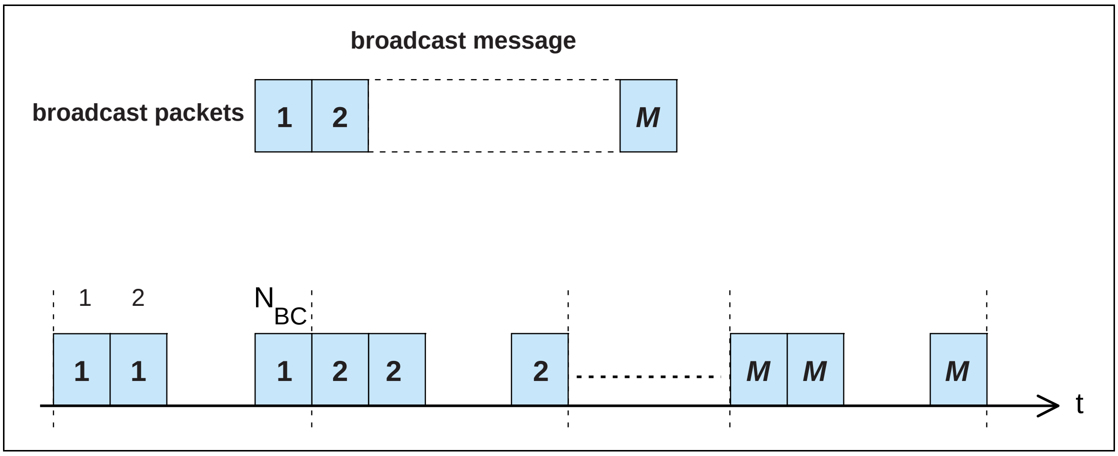


*Figure 7.16: Broadcast repetition scheme*

# 8 LINK CONTROLLER OPERATION

This section describes how a piconet is established and how devices can be added to and released from the piconet. Several states of operation of the devices are defined to support these functions. In addition, the operation of several piconets with one or more common members, the scatternet, is discussed.

## 8.1 OVERVIEW OF STATES

Figure 8.1 on page 153 shows a state diagram illustrating the different states used in the link controller. There are three major states: **STANDBY**, **CONNECTION**, and **PARK**; in addition, there are seven substates, **page**, **page scan**, **inquiry**, **inquiry scan**, **master response**, **slave response**, and **inquiry response**. The substates are interim states that are used to establish connections and enable device discovery. To move from one state or substate to another, either commands from the link manager are used, or internal signals in the link controller are used (such as the trigger signal from the correlator and the timeout signals).

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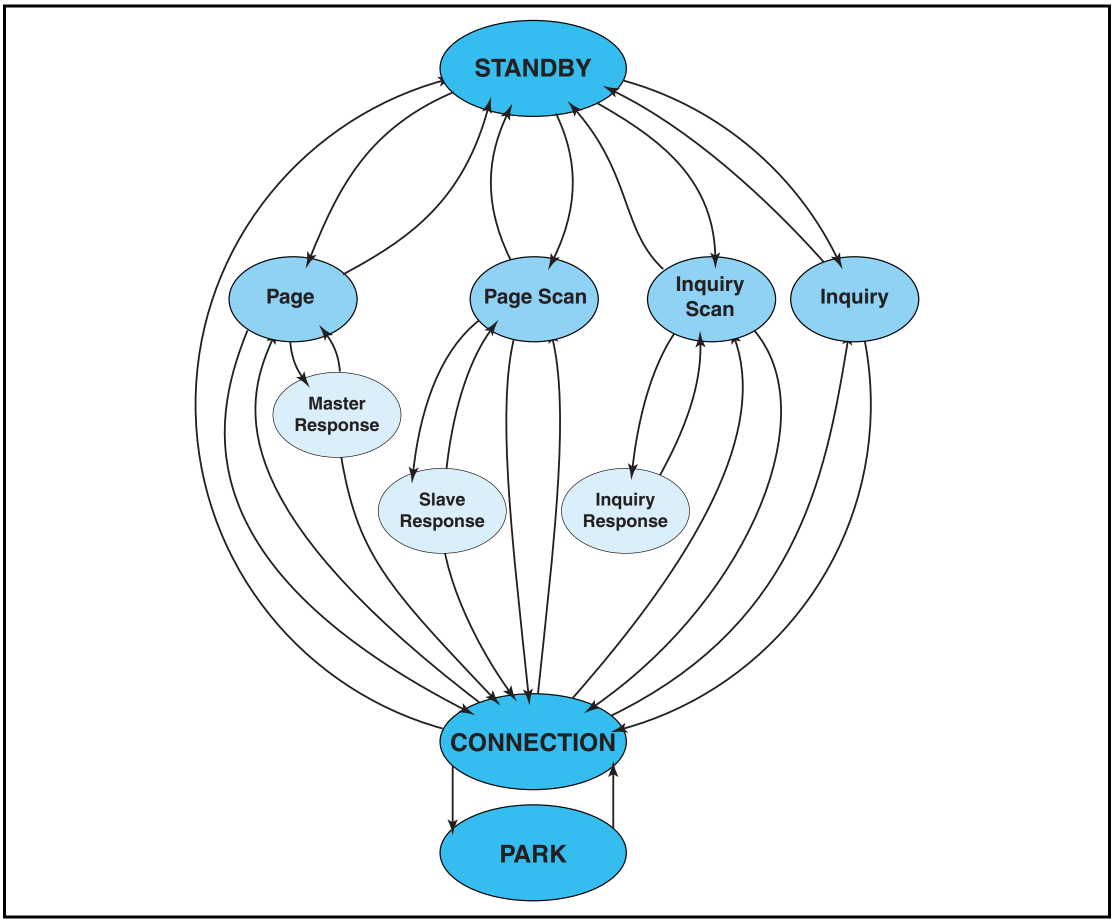


*Figure 8.1: State diagram of link controller.*

## 8.2 STANDBY STATE

The **STANDBY** state is the default state in the device. In this state, the device may be in a low-power mode. Only the native clock is running at the accuracy of the LPO (or better).

The controller may leave the **STANDBY** state to scan for page or inquiry messages, or to page or inquiry itself.

## 8.3 CONNECTION ESTABLISHMENT SUBSTATES

In order to establish new connections the paging procedure is used. Only the Bluetooth device address is required to set up a connection. Knowledge about the clock, obtained from the inquiry procedure (see Section 8.4 on page 163) or from a previous connection with this device, and the page scanning mode of the other device will accelerate the setup procedure. A device that establishes a connection carries out a page procedure and will automatically become the master of the connection.

### 8.3.1 Page scan substate

In the **page scan** substate, a device may be configured to use either the standard or interlaced scanning procedure. During a standard scan, a device listens for the duration of the scan window $T_{w\_page\_scan}$ (11.25ms default, see HCI [Part E] Section 7.3.20 on page 494), while the interlaced scan is performed as two back to back scans of $T_{w\_page\_scan}$. If the scan interval is not at least twice the scan window, then interlaced scan shall not be used. During each scan window, the device shall listen at a single hop frequency, its correlator matched to its device access code (DAC). The scan window shall be long enough to completely scan 16 page frequencies.

When a device enters the **page scan** substate, it shall select the scan frequency according to the page hopping sequence determined by the device's Bluetooth device address, see Section 2.6.4.1 on page 91. The phase in the sequence shall be determined by $CLKN_{16-12}$ of the device's native clock; that is, every 1.28s a different frequency is selected.

In the case of a standard scan, if the correlator exceeds the trigger threshold during the **page scan**, the device shall enter the **slave response** substate described in Section 8.3.3.1 on page 160. The scanning device may also use interlaced scan. In this case, if the correlator does not exceed the trigger threshold during the first scan it shall scan a second time using the phase in the sequence determined by $[CLKN_{16-12} + 16] \bmod 32$. If on this second scan the correlator exceeds the trigger threshold the device shall enter the **slave response** substate using $[CLKN_{16-12} + 16] \bmod 32$ as the frozen CLKN* in the calculation for Xprs[(79)], see Section 2.6.4.3 on page 92 for details. If the correlator does not exceed the trigger threshold during a scan in normal mode or during the second scan in interlaced scan mode it shall return to either the **STANDBY** or **CONNECTION** state.

The **page scan** substate can be entered from the **STANDBY** state or the **CONNECTION** state. In the **STANDBY** state, no connection has been established and the device can use all the capacity to carry out the **page scan**. Before entering the **page scan** substate from the **CONNECTION** state, the device should reserve as much capacity as possible for scanning. If desired, the device may place ACL connections in Hold, Park or Sniff, see Section 8.8 on page 185 and Section 8.9 on page 185. Synchronous connections should not be interrupted by the page scan, although eSCO retransmissions should be paused during the scan. The page scan may be interrupted by the reserved synchronous slots which should have higher priority than the **page scan**. SCO packets should be used requiring the least amount of capacity (**HV3** packets). The scan window shall be increased to minimize the setup delay. If one SCO logical transport is present using **HV3** packets and $T_{SCO}$=6 slots or one eSCO logical transport is present using **EV3** packets and $T_{ESCO}$=6 slots, a total scan window $T_{w\ page\ scan}$ of at least 36 slots (22.5ms) is recommended; if two SCO links are present using **HV3** packets and $T_{SCO}$=6 slots or two eSCO links are present using **EV3** packets and $T_{ESCO}$=6 slots, a total scan window of at least 54 slots (33.75ms) is recommended.

The scan interval $T_{page\ scan}$ is defined as the interval between the beginnings of two consecutive page scans. A distinction is made between the case where the scan interval is equal to the scan window $T_{w\ page\ scan}$ (continuous scan), the scan interval is maximal 1.28s, or the scan interval is maximal 2.56s. These three cases shall determine the behavior of the paging device; that is, whether the paging device shall use R0, R1 or R2, see also Section 8.3.2 on page 156. Table 8.1 illustrates the relationship between $T_{page\ scan}$ and modes R0, R1 and R2. Although scanning in the R0 mode is continuous, the scanning may be interrupted for example by reserved synchronous slots. The scan interval information is included in the SR field in the FHS packet.

| SR mode | $T_{page\ scan}$ |
|---|---|
| R0 | $\leq$ 1.28s and = $T_{w\ page\ scan}$ |
| R1 | $\leq$ 1.28s |
| R2 | $\leq$ 2.56s |
| Reserved | - |

*Table 8.1: Relationship between scan interval, and paging modes R0, R1 and R2.*

### 8.3.2 Page substate

The **page** substate is used by the master (source) to activate and connect to a slave (destination) in the **page scan** substate. The master tries to coincide with the slave's scan activity by repeatedly transmitting the paging message consisting of the slave's device access code (DAC) in different hop channels. Since the Bluetooth clocks of the master and the slave are not synchronized, the master does not know exactly when the slave wakes up and on which hop frequency. Therefore, it transmits a train of identical page scan messages at different hop frequencies and listens in between the transmit intervals until it receives a response from the slave.

The page procedure in the master consists of a number of steps. First, the Host communicates the BD_ADDR of the slave to the Controller. This BD_ADDR shall be used by the master to determine the page hopping sequence, see Section 2.6.4.2 on page 92. The slave's BD_ADDR shall be used to determine the page hopping sequence, see Section 2.6.4.2 on page 92. For the phase in the sequence, the master shall use an estimate of the slave's clock. For example, this estimate can be derived from timing information that was exchanged during the last encounter with this particular device (which could have acted as a master at that time), or from an inquiry procedure. With this estimate CLKE of the slave's Bluetooth clock, the master can predict on which hop channel the slave starts page scanning.

The estimate of the Bluetooth clock in the slave can be completely wrong. Although the master and the slave use the same hopping sequence, they use different phases in the sequence and might never select the same frequency. To compensate for the clock drifts, the master shall send its page message during a short time interval on a number of wake-up frequencies. It shall transmit also on hop frequencies just before and after the current, predicted hop frequency. During each TX slot, the master shall sequentially transmit on two different hop frequencies. In the following RX slot, the receiver shall listen sequentially to two corresponding RX hops for ID packet. The RX hops shall be selected according to the page response hopping sequence. The page response hopping sequence is strictly related to the page hopping sequence: for each page hop there is a corresponding page response hop. The RX/TX timing in the **page** substate is described in Section 2.2.5 on page 72, see also Figure 2.7 on page 77. In the next TX slot, it shall transmit on two hop frequencies different from the former ones. Note: The hop rate is increased to 3200 hops/s.

With the increased hopping rate as described above, the transmitter can cover 16 different hop frequencies in 16 slots or 10 ms. The page hopping sequence is divided over two paging trains **A** and **B** of 16 frequencies. Train **A** includes the 16 hop frequencies surrounding the current, predicted hop frequency *f(k)*, where k is determined by the clock estimate $CLKE_{16\text{-}12}$. The first train consists of hops

f(k-8), f(k-7),...,f(k),...,f(k+7)

When the difference between the Bluetooth clocks of the master and the slave is between -8x1.28 s and +7x1.28 s, one of the frequencies used by the master will be the hop frequency the slave will listen to. Since the master does not know when the slave will enter the **page scan** substate, the master has to repeat this train **A** $N_{page}$ times or until a response is obtained, whichever is shorter. If the slave scan interval corresponds to R1, the repetition number is at least 128; if the slave scan interval corresponds to R2 or if the master has not previously read the slave's SR mode, the repetition number is at least 256. If the master has not previously read the slave's SR mode it shall use Npage >= 256. Note that $CLKE_{16-12}$ changes every 1.28 s; therefore, every 1.28 s, the trains will include different frequencies of the page hopping set.

When the difference between the Bluetooth clocks of the master and the slave is less than -8x1.28 s or larger than +7x1.28 s, the remaining 16 hops are used to form the new 10 ms train **B.** The second train consists of hops

f(k-16), f(k-15),...,f(k-9),f(k+8)...,f(k+15)

Train **B** shall be repeated for $N_{page}$ times. If no response is obtained, train **A** shall be tried again $N_{page}$ times. Alternate use of train A and train B shall be continued until a response is received or the timeout *pageTO* is exceeded. If a response is returned by the slave, the master device enters the **master response** substate.

The **page** substate may be entered from the **STANDBY** state or the **CONNECTION** state. In the **STANDBY** state, no connection has been established and the device can use all the capacity to carry out the page. Before entering the **page** substate from the **CONNECTION** state, the device should free as much capacity as possible for scanning. To ensure this, it is recommended that the ACL connections are put on hold or park. However, the synchronous connections shall not be disturbed by the page. This means that the page will be interrupted by the reserved SCO and eSCO slots which have higher priority than the page. In order to obtain as much capacity for paging, it is recommended to use the SCO packets which use the least amount of capacity (**HV3** packets). If SCO or eSCO links are present, the repetition number $N_{page}$ of a single train shall be increased, see Table 8.2. Here it has been assumed that the **HV3** packet are used with an interval $T_{SCO}$=6 slots or **EV3** packets are used with an interval of $T_{ESCO}$=6 slots, which would correspond to a 64 kb/s synchronous link.

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| SR mode | no synchronous link | one synchronous link (HV3) | two synchronous links (HV3) |
|---|---|---|---|
| R0 | $N_{page} \geq 1$ | $N_{page} \geq 2$ | $N_{page} \geq 3$ |
| R1 | $N_{page} \geq 128$ | $N_{page} \geq 256$ | $N_{page} \geq 384$ |
| R2 | $N_{page} \geq 256$ | $N_{page} \geq 512$ | $N_{page} \geq 768$ |

*Table 8.2: Relationship between train repetition, and paging modes R0, R1 and R2 when synchronous links are present.*

The construction of the page train shall be independent of the presence of synchronous links; that is, synchronous packets are sent on the reserved slots but shall not affect the hop frequencies used in the unreserved slots, see Figure 8.2 on page 158.

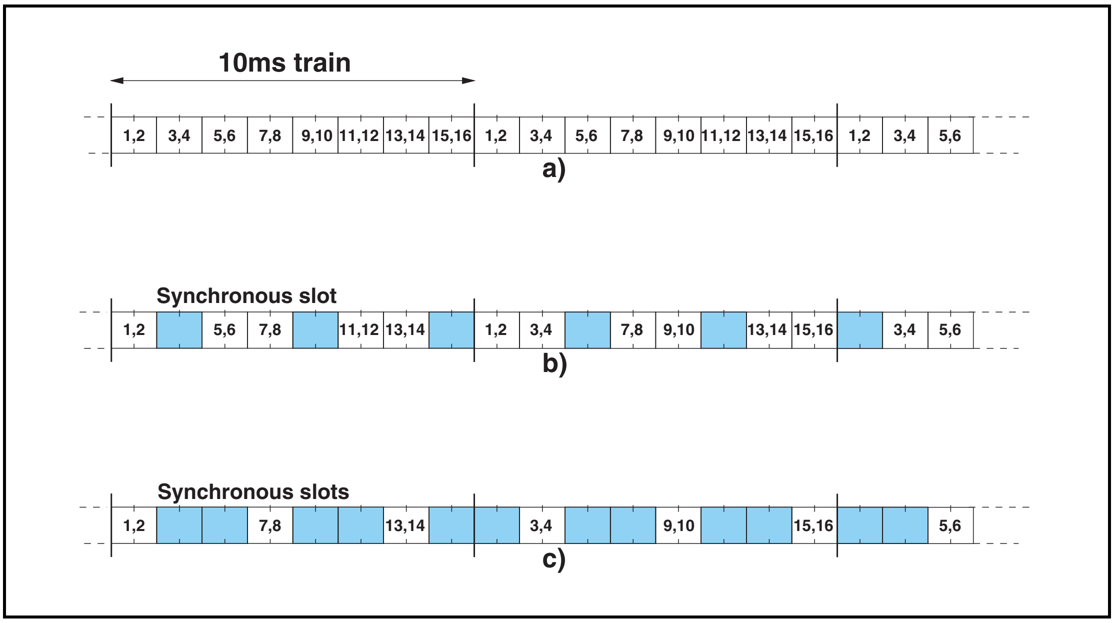


*Figure 8.2: Conventional page (a), page while one synchronous link present (b), page while two synchronous links present (c).*

### 8.3.3 Page response substates

When a page message is successfully received by the slave, there is a coarse FH synchronization between the master and the slave. Both the master and the slave enter a response substate to exchange vital information to continue the connection setup. It is important for the piconet connection that both devices shall use the same channel access code, use the same channel hopping sequence, and their clocks are synchronized. These parameters shall be derived from the master device. The device that initializes the connection (starts paging) is defined as the master device (which is thus only valid during the time the piconet exists). The channel access code and channel hopping sequence shall be derived from the Bluetooth device address (BD_ADDR) of the master. The timing shall be determined by the master clock. An offset shall be added to the slave's native clock to temporarily synchronize the slave clock to the master clock. At start-up, the master parameters are transmitted from the master to the slave. The messaging between the master and the slave at start-up is specified in this section.

The initial messaging between master and slave is shown in Table 8.3 on page 159 and in Figure 8.3 on page 160 and Figure 8.4 on page 160. In those two figures frequencies f (k), f(k+1), etc. are the frequencies of the page hopping sequence determined by the slave's BD_ADDR. The frequencies f'(k), f'(k+1), etc. are the corresponding page_response frequencies (slave-to-master). The frequencies g(m) belong to the basic channel hopping sequence.

| Step | Message | Packet Type | Direction | Hopping Sequence | Access Code and Clock |
|---|---|---|---|---|---|
| 1 | Page | ID | Master to slave | Page | Slave |
| 2 | First slave page response | ID | Slave to master | Page response | Slave |
| 3 | Master page response | FHS | Master to slave | Page | Slave |
| 4 | Second slave page response | ID | Slave to master | Page response | Slave |
| 5 | 1st packet master | POLL | Master to slave | Channel | Master |
| 6 | 1st packet slave | Any type | Slave to master | Channel | Master |

*Table 8.3: Initial messaging during start-up.*

In step 1 (see Table 8.3 on page 159), the master device is in **page** substate and the slave device in the **page scan** substate. Assume in this step that the page message sent by the master reaches the slave. On receiving the page message, the slave enters the **slave response** in step 2. The master waits for a reply from the slave and when this arrives in step 2, it will enter the **master response** in step 3. Note that during the initial message exchange, all parameters are derived from the slave's device address, and that only the page hopping and page response hopping sequences are used (are also derived from the slave's device address). Note that when the master and slave enter the response states, their clock input to the page and page response hop selection is frozen as is described in Section 2.6.4.3 on page 92.

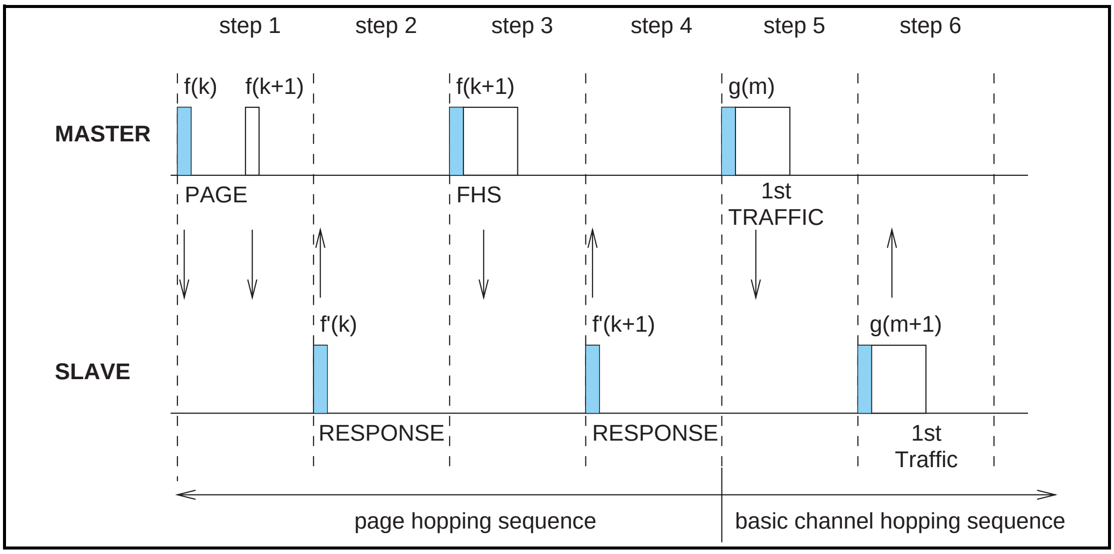


*Figure 8.3: Messaging at initial connection when slave responds to first page message.*

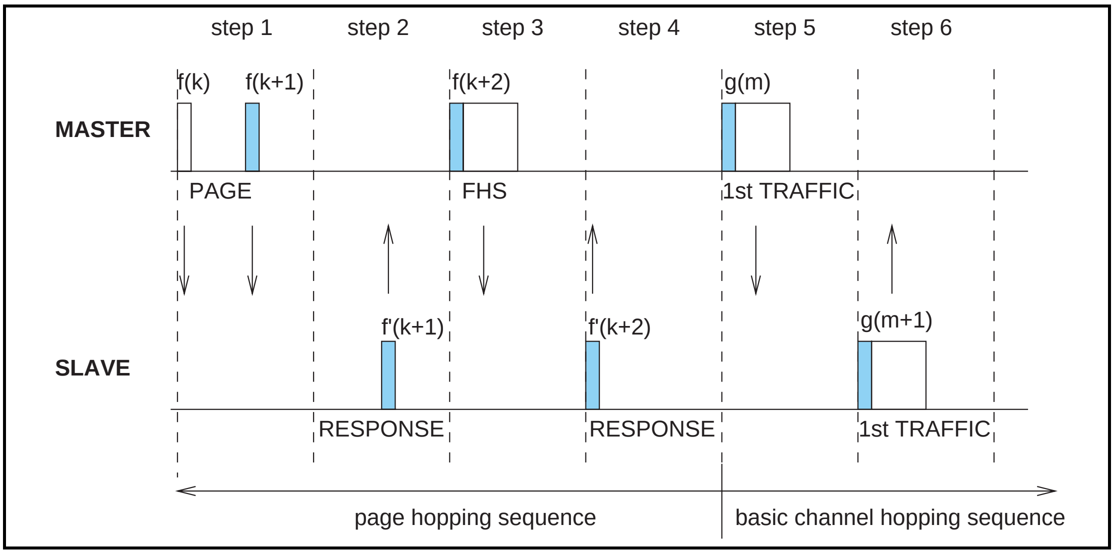


*Figure 8.4: Messaging at initial connection when slave responds to second page message.*

## *8.3.3.1 Slave response substate*

After having received the page message in step 1, the slave device shall transmit a slave page response message (the slave's device access code) in step 2. This response message shall be the slave's device access code. The slave shall transmit this response 625 μs after the beginning of the received page message and at the response hop frequency that corresponds to the hop frequency in which the page message was received. The slave transmission is therefore time aligned to the master transmission. During initial messaging, the slave shall still use the page response hopping sequence to return information to the master. The clock input $CLKN_{16-12}$ shall be frozen at the value it had at the time the page message was received.

After having sent the response message, the slave's receiver shall be activated 312.5 µs after the start of the response message and shall await the arrival of an **FHS** packet. Note that an **FHS** packet can arrive 312.5 µs after the arrival of the page message as shown in Figure 8.4 on page 160, and not after 625 µs as is usually the case in the piconet physical channel RX/TX timing. More details about the timing can be found in Section 2.4.4 on page 78.

If the setup fails before the **CONNECTION** state has been reached, the following procedure shall be carried out. The slave shall listen as long as no **FHS** packet is received until *pagerespTO* is exceeded. Every 1.25 ms, however, it shall select the next master-to-slave hop frequency according to the page hop sequence. If nothing is received after *pagerespTO*, the slave shall return back to the **page scan** substate for one scan period. Length of the scan period depends on the synchronous reserved slots present. If no page message is received during this additional scan period, the slave shall resume scanning at its regular scan interval and return to the state it was in prior to the first page scan state.

If an **FHS** packet is received by the slave in the **slave response** substate, the slave shall return a slave page response message in step 4 to acknowledge reception of the **FHS** packet. This response shall use the page response hopping sequence. The transmission of the slave page response packet is based on the reception of the **FHS** packet. Then the slave shall change to the master's channel access code and clock as received from the **FHS** packet. Only the 26 MSBs of the master clock are transferred: the timing shall be such that $CLK_1$ and $CLK_0$ are both zero at the time the **FHS** packet was received as the master transmits in even slots only. The offset between the master's clock and the slave's clock shall be determined from the master's clock in the **FHS** packet and reported to the slave's Baseband Resource Manager.

Finally, the slave enters the **CONNECTION** state in step 5. From then on, the slave shall use the master's clock and the master's BD_ADDR to determine the basic channel hopping sequence and the channel access code. The slave shall use the LT_ADDR in the **FHS** payload as the primary LT_ADDR in the **CONNECTION** state. The connection mode shall start with a POLL packet transmitted by the master. The slave may respond with any type of packet. If the POLL packet is not received by the slave, or the response packet is not received by the master, within *newconnectionTO* number of slots after FHS packet acknowledgement, the master and the slave shall return to **page** and **page scan** substates, respectively. See Section 8.5 on page 167

### *8.3.3.2 Master response substate*

When the master has received a slave page response message in step 2, it shall enter the **master response** routine. It shall freeze the current clock input to the page hop selection scheme. The master shall then transmit an **FHS** packet in step 3 containing the master's real-time Bluetooth clock, the master's BD_ADDR, the BCH parity bits, and the class of device. The **FHS** packet contains all information to construct the channel access code without requiring a mathematical derivation from the master's Bluetooth device address. The LT_ADDR field in the packet header of FHS packets in the master response substate shall be set to all-zeros. The **FHS** packet shall be transmitted at the beginning of the master-to-slave slot following the slot in which the slave responded. The FHS packet shall carry the all-zero LT_ADDR. The TX timing of the **FHS** is not based on the reception of the response packet from the slave. The **FHS** packet may therefore be sent 312.5 μs after the reception of the response packet like shown in Figure 8.4 on page 160 and not 625 μs after the received packet as is usual in the piconet physical channel RX/TX timing, see also Section 2.4.4 on page 78.

After the master has sent its **FHS** packet, it shall wait for a second slave page response message in step 4 acknowledging the reception of the **FHS** packet. This response shall be the slave's device access code. If no response is received, the master shall retransmit the **FHS** packet with an updated clock and still using the slave's parameters. It shall retransmit the FHS packet with the clock updated each time until a second slave page response message is received, or the timeout of *pagerespTO* is exceeded. In the latter case, the master shall return to the **page** substate and send an error message to the Baseband Resource Manager. During the retransmissions of the **FHS** packet, the master shall use the page hopping sequence.

If the slave's response is received, the master shall change to using the master parameters, so it shall use the channel access code and the master clock. The lower clock bits $CLK_0$ and $CLK_1$ shall be reset to zero at the start of the **FHS** packet transmission and are not included in the **FHS** packet. Finally, the master enters the **CONNECTION** state in step 5. The master BD_ADDR shall be used to change to a new hopping sequence, the *basic channel hopping sequence*. The basic channel hopping sequence uses all 79 hop channels in a pseudo-random fashion, see also Section 2.6.4.7 on page 94. The master shall now send its first traffic packet in a hop determined with the new (master) parameters. This first packet shall be a POLL packet. See Section 8.5 on page 167. This packet shall be sent within *newconnectionTO* number of slots after reception of the FHS packet acknowledgement. The slave may respond with any type of packet. If the POLL packet is not received by the slave or the POLL packet response is not received by the master within *newconnectionTO* number of slots, the master and the slave shall return to **page** and **page scan** substates, respectively.

## 8.4 DEVICE DISCOVERY SUBSTATES

In order to discover other devices a device shall enter **inquiry** substate. In this substate, it shall repeatedly transmit the inquiry message (ID packet, see Section 6.5.1.1 on page 119) at different hop frequencies. The **inquiry** hop sequence is derived from the LAP of the GIAC. Thus, even when DIACs are used, the applied hopping sequence is generated from the GIAC LAP. A device that allows itself to be discovered, shall regularly enter the **inquiry scan** substate to respond to inquiry messages. The following sections describe the message exchange and contention resolution during inquiry response. The inquiry response is optional: a device is not forced to respond to an inquiry message.

During the **inquiry** substate, the discovering device collects the Bluetooth device addresses and clocks of all devices that respond to the inquiry message. It can then, if desired, make a connection to any one of them by means of the previously described page procedure.

The inquiry message broadcast by the source does not contain any information about the source. However, it may indicate which class of devices should respond. There is one general inquiry access code (GIAC) to inquire for any device, and a number of dedicated inquiry access codes (DIAC) that only inquire for a certain type of device. The inquiry access codes are derived from reserved Bluetooth device addresses and are further described in Section 6.3.1 on page 111.

### 8.4.1 Inquiry scan substate

The **inquiry scan** substate is very similar to the **page scan** substate. However, instead of scanning for the device's device access code, the receiver shall scan for the inquiry access code long enough to completely scan for 16 inquiry frequencies. Two types of scans are defined: standard and interlaced. In the case of a standard scan the length of this scan period is denoted $T_{w\_inquiry\_scan}$ (11.25ms default, see HCI [Part E] Section 7.3.22 on page 496). The standard scan is performed at a single hop frequency as defined by $Xir_{4-0}$ (see Section 2.6.4.6 on page 94). The interlaced scan is performed as two back to back scans of $T_{w\_inquiry\_scan}$ where the first scan is on the normal hop frequency and the second scan is defined by $[Xir_{4-0} + 16] \bmod 32$. If the scan interval is not at least twice the scan window then interlaced scan shall not be used. The inquiry procedure uses 32 dedicated inquiry hop frequencies according to the inquiry hopping sequence. These frequencies are determined by the general inquiry address. The phase is determined by the native clock of the device carrying out the **inquiry scan**; the phase changes every 1.28s.

Instead of, or in addition to, the general inquiry access code, the device may scan for one or more dedicated inquiry access codes. However, the scanning shall follow the inquiry scan hopping sequence determined by the general inquiry address. If an inquiry message is received during an inquiry wake-up period, the device shall enter the **inquiry response** substate.

The **inquiry scan** substate can be entered from the **STANDBY** state or the **CONNECTION** state. In the **STANDBY** state, no connection has been established and the device can use all the capacity to carry out the **inquiry scan**. Before entering the **inquiry scan** substate from the **CONNECTION** state, the device should reserve as much capacity as possible for scanning. If desired, the device may place ACL logical transports in Sniff, Hold, or Park. Synchronous logical transports are preferably not interrupted by the **inquiry scan**, although eSCO retransmissions should be paused during the scan. In this case, the **inquiry scan** may be interrupted by the reserved synchronous slots. SCO packets should be used requiring the least amount of capacity (**HV3** packets). The scan window, $T_{w\ inquiry\ scan}$, shall be increased to increase the probability to respond to an inquiry message. If one SCO logical transport is present using HV3 packets and $T_{SCO}$=6 slots or one eSCO logical transport is present using EV3 packets and $T_{ESCO}$=6 slots, a total scan window of at least 36 slots (22.5ms) is recommended; if two SCO links are present using HV3 packets and $T_{SCO}$=6 slots or two eSCO links are present using EV3 packets and $T_{ESCO}$=6 slots, a total scan window of at least 54 slots (33.75ms) is recommended.

The scan interval $T_{inquiry\ scan}$ is defined as the interval between two consecutive inquiry scans. The **inquiry scan** interval shall be less than or equal to 2.56 s.

### 8.4.2 Inquiry substate

The **inquiry** substate is used to discover new devices. This substate is very similar to the **page** substate; the TX/RX timing shall be the same as in paging, see Section 2.4.4 on page 78 and Figure 2.7 on page 77. The TX and RX frequencies shall follow the inquiry hopping sequence and the inquiry response hopping sequence, and are determined by the general inquiry access code and the native clock of the discovering device. In between inquiry transmissions, the receiver shall scan for inquiry response messages. When a response is received, the entire packet (an **FHS** packet) is read, after which the device shall continue with inquiry transmissions. The device in an **inquiry** substate shall not acknowledge the inquiry response messages. If enabled by the Host (see HCI [Part E] Section 7.3.54 on page 533), the RSSI value of the inquiry response message shall be measured. It shall keep probing at different hop channels and in between listening for response packets. As in the **page** substate, two 10 ms trains **A** and **B** are defined, splitting the 32 frequencies of the inquiry hopping sequence into two 16-hop parts. A single train shall be repeated for at least $N_{inquiry}$=256 times before a new train is used. In order to collect all responses in an error-free environment, at least three train switches must have taken place. As a result, the **inquiry** substate may have to last for 10.24 s unless the inquirer collects enough responses and aborts the **inquiry** substate earlier. If desired, the inquirer may also prolong the **inquiry** substate to increase the probability of receiving all responses in an error-prone environment. If an inquiry procedure is automatically initiated periodically (say a 10 s period every minute), then the interval between two inquiry instances shall be determined randomly. This is done to avoid two devices synchronizing their inquiry procedures.

The **inquiry** substate is continued until stopped by the Baseband Resource Manager (when it decides that it has sufficient number of responses), when a timeout has been reached (*inquiryTO*), or by a command from the host to cancel the inquiry procedure.

The **inquiry** substate can be entered from the **STANDBY** state or the **CONNECTION** state. In the **STANDBY** state, no connection has been established and the device can use all the capacity to carry out the inquiry. Before entering the **inquiry** substate from the **CONNECTION** state, the device should free as much capacity as possible for scanning. To ensure this, it is recommended that the ACL logical transports are placed in Sniff, Hold, or Park. However, the reserved slots of synchronous logical transports shall not be disturbed by the inquiry. This means that the inquiry will be interrupted by the reserved SCO and eSCO slots which have higher priority than the inquiry. In order to obtain as much capacity as possible for inquiry, it is recommended to use the SCO packets which use the least amount of capacity (**HV3** packets). If SCO or eSCO links are present, the repetition number $N_{inquiry}$ shall be increased, see Table 8.4 on page 166.
Here it has been assumed that **HV3** packets are used with an interval $T_{SCO}$=6

slots or **EV3** packets are used with an interval of $T_{ESCO}$=6 slots, which would correspond to a 64 kb/s synchronous link.

| | No synchronous links | One synchronous link (HV3) | Two synchronous links (HV3) |
|---|---|---|---|
| $N_{inquiry}$ | ≥ 256 | ≥ 512 | ≥ 768 |

*Table 8.4: Increase of train repetition when synchronous links are present.*

### 8.4.3 Inquiry response substate

The slave response substate for inquiries differs completely from the slave response substate applied for pages. When the inquiry message is received in the **inquiry scan** substate, the recipient shall return an inquiry response (FHS) packet containing the recipient's device address (BD_ADDR) and other parameters.

The following protocol in the slave's **inquiry response** shall be used. On the first inquiry message received in this substate the slave shall enter the **inquiry response** substate and shall return an **FHS** response packet to the master 625us after the inquiry message was received. A contention problem may arise when several devices are in close proximity to the inquiring device and all respond to an inquiry message at the same time. However, because every device has a free running clock it is highly unlikely that they all use the same phase of the inquiry hopping sequence. In order to avoid repeated collisions between devices that wake up in the same inquiry hop channel simultaneously, a device shall back-off for a random period of time. Thus, if the device receives an inquiry message and returns an FHS packet, it shall generate a random number, RAND, between 0 and MAX_RAND. For scanning intervals ≥ 1.28s MAX_RAND shall be 1023, however, for scanning intervals < 1.28s MAX_RAND may be as small as 127. A profile that uses a special DIAC may choose to use a smaller MAX_RAND than 1023 even when the scanning interval is ≥ 1.28s. The slave shall return to the **CONNECTION** or **STANDBY** state for the duration of at least RAND time slots. Before returning to the **CONNECTION** and **STANDBY** state, the device may go through the **page scan** substate. After at least RAND slots, the device shall add an offset of 1 to the phase in the inquiry hop sequence (the phase has a 1.28 s resolution) and return to the **inquiry scan** substate again. If the slave is triggered again, it shall repeat the procedure using a new RAND. The offset to the clock accumulates each time an **FHS** packet is returned. During a probing window, a slave may respond multiple times, but on different frequencies and at different times. Reserved synchronous slots should have priority over response packets; that is, if a response packet overlaps with a reserved synchronous slot, it shall not be sent but the next inquiry message is awaited.

The messaging during the inquiry routines is summarized in Table 8.5 on page 167. In step 1, the master transmits an inquiry message using the inquiry access code and its own clock. The slave responds with the **FHS** packet containing the slave's Bluetooth device address, native clock and other slave information. This **FHS** packet is returned at times that tend to be random. The **FHS** packet is not acknowledged in the inquiry routine, but it is retransmitted at other times and frequencies as long as the master is probing with inquiry messages.

| Step | Message | Packet Type | Direction | Hopping Sequence | Access Code and Clock |
|---|---|---|---|---|---|
| 1 | Inquiry | ID | master to slave | inquiry | inquiry |
| 2 | Inquiry response | FHS | slave to master | inquiry response | inquiry |

*Table 8.5: Messaging during inquiry routines.*

## 8.5 CONNECTION STATE

In the **CONNECTION** state, the connection has been established and packets can be sent back and forth. In both devices, the channel (master) access code, the master's Bluetooth clock, and the AFH_channel_map are used. **CONNECTION** state uses the *basic* or *adapted channel hopping sequence*.

The **CONNECTION** state starts with a POLL packet sent by the master to verify the switch to the master's timing and channel frequency hopping. The slave may respond with any type of packet. If the slave does not receive the POLL packet or the master does not receive the response packet for *newconnectionTO* number of slots, both devices shall return to **page**/**page scan** substates.

The first information packets in the **CONNECTION** state contain control messages that characterize the link and give more details regarding the devices. These messages are exchanged between the link managers of the devices. For example, they may define the SCO logical transport and the sniff parameters. Then the transfer of user information can start by alternately transmitting and receiving packets.

The **CONNECTION** state is left through a **detach** or **reset** command. The **detach** command is used if the link has been disconnected in the normal way; all configuration data in the link controller shall remain valid. The **reset** command is a soft reset of the link controller. The functionality of the soft reset is described in [Part E] Section 7.3.2 on page 469.

In the **CONNECTION** state, if a device is not going to be nominally present on the channel at all times it may describe its unavailability by using sniff mode or hold mode (see Figure 8.5 on page 168).

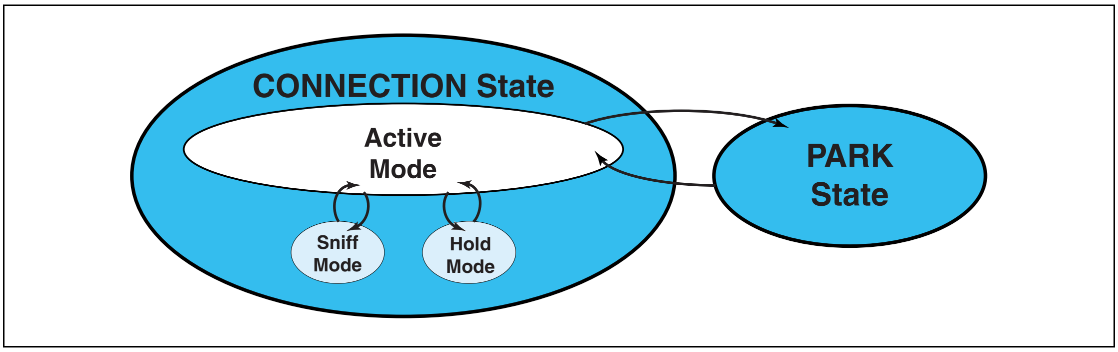


*Figure 8.5: Connection state.*

## 8.6 ACTIVE MODE

In the active mode, both master and slave actively participate on the channel. Up to seven slaves may be in the active mode at any given time. The master schedules the transmission based on traffic demands to and from the different slaves. In addition, it supports regular transmissions to keep slaves synchronized to the channel. Slaves in the active mode listen in the master-to-slave slots for packets. These devices are known as *active slaves*. If an active slave is not addressed, it may sleep until the next new master transmission. Slaves can derive the number of slots the master has reserved for transmission from TYPE field in the packet header; during this time, the non-addressed slaves do not have to listen on the master-to-slave slots. When a device is participating in multiple piconets it should listen in the master-to-slave slot for the current piconet. It is recommended that a device not be away from each piconet in which it is participating for more than $T_{poll}$ slots. A periodic master transmission is required to keep the slaves synchronized to the channel. Since the slaves only need the channel access code to synchronize, any packet type can be used for this purpose.

Only the slave that is addressed by one of its LT_ADDRs (primary or secondary) may return a packet in the next slave-to-master slot. If no valid packet header is received, the slave may only respond in its reserved SCO or eSCO slave-to-master slot. In the case of a broadcast message, no slave shall return a packet (an exception is the access window for access requests in the **PARK** state, see Section 8.9 on page 185).

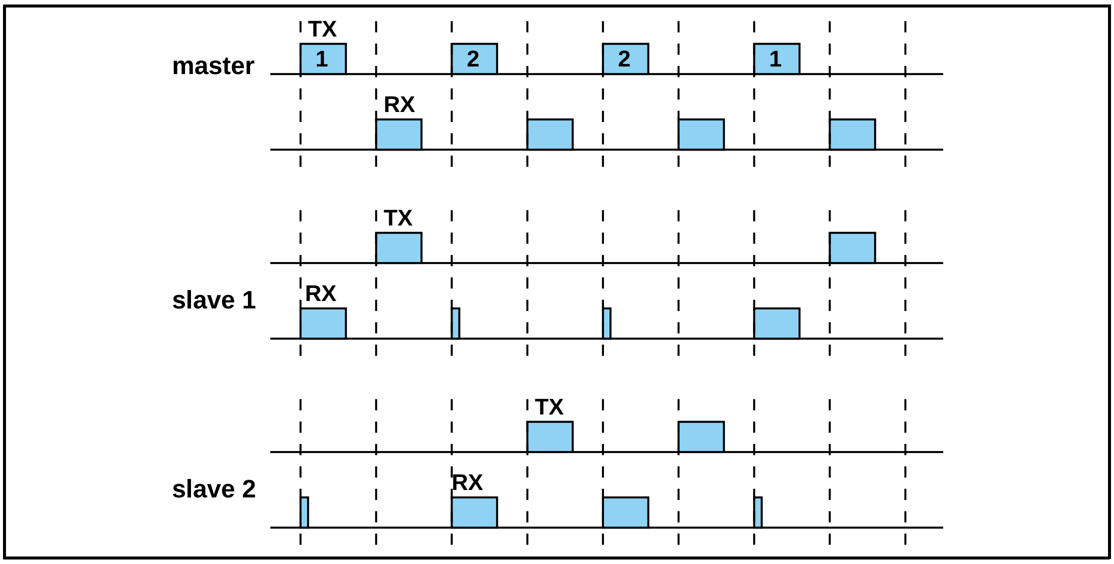


*Figure 8.6: RX/TX timing in multi-slave configuration*

For ACL logical transports the mode selection may be left to real time packet type selections. The packet type table (ptt) in section 6.5 allows the selection of Basic Rate or Enhanced Data Rate for each of the packet type codes, however; the DM1 packet is available in all packet type tables. ACL traffic over this given physical or logical link shall utilize the packet types in the given column of Packets defined for synchronous and asynchronous logical transport types.

### 8.6.1 Polling in the active mode

The master always has full control over the piconet. Due to the TDD scheme, slaves can only communicate with the master and not other slaves. In order to avoid collisions on the ACL logical transport, a slave is only allowed to transmit in the slave-to-master slot when addressed by the LT_ADDR in the packet header in the preceding master-to-slave slot. If the LT_ADDR in the preceding slot does not match, or a valid packet header was not received, the slave shall not transmit.

The master normally attempts to poll a slave's ACL logical transport no less often than once every $T_{poll}$ slots. $T_{poll}$ is set by the Link Manager (see [Part C] Section 4.1.8 on page 244).

The slave's ACL logical transport may be polled with any packet type except for FHS and ID. For example, polling during SCO may use HV packets, since the slave may respond to an HV packet with a DM1 packet (see Section 8.6.2 on page 169).

### 8.6.2 SCO

The SCO logical transport shall be established by the master sending an SCO setup message via the LM protocol. This message contains timing parameters including the SCO interval $T_{SCO}$ and the offset $D_{SCO}$ to specify the reserved slots.

In order to prevent clock wrap-around problems, an initialization flag in the LMP setup message indicates whether initialization procedure 1 or 2 is being used. The slave shall apply the initialization method as indicated by the initialization flag. The master shall use initialization 1 when the MSB of the current master clock ($CLK_{27}$) is 0; it shall use initialization 2 when the MSB of the current master clock ($CLK_{27}$) is 1. The master-to-slave SCO slots reserved by the master and the slave shall be initialized on the slots for which the clock satisfies the applicable equation:

$$CLK_{27\text{-}1} \bmod T_{SCO} = D_{SCO} \qquad \text{for initialization 1}$$

$$(\overline{CLK_{27}}, CLK_{26\text{-}1}) \bmod T_{SCO} = D_{SCO} \qquad \text{for initialization 2}$$

The slave-to-master SCO slots shall directly follow the reserved master-to-slave SCO slots. After initialization, the clock value CLK(k+1) for the next master-to-slave SCO slot shall be derived by adding the fixed interval $T_{SCO}$ to the clock value of the current master-to-slave SCO slot:

$$CLK(k+1) = CLK(k) + T_{SCO}$$

The master will send SCO packets to the slave at regular intervals (the SCO interval $T_{SCO}$ counted in slots) in the reserved master-to-slave slots. An HV1 packet can carry 1.25ms of speech at a 64 kb/s rate. An HV1 packet shall therefore be sent every two time slots ($T_{SCO}$=2). An HV2 packet can carry 2.5ms of speech at a 64 kb/s rate. An HV2 packet shall therefore be sent every four time slots ($T_{SCO}$=4). An HV3 packet can carries 3.75ms of speech at a 64 kb/s rate. An HV3 packet shall therefore be sent every six time slots ($T_{SCO}$=6).

The slave is allowed to transmit in the slot reserved for its SCO logical transport unless the (valid) LT_ADDR in the preceding slot indicates a different slave. If no valid LT_ADDR can be derived in the preceding slot, the slave may still transmit in the reserved SCO slot.

Since the DM1 packet is recognized on the SCO logical transport, it may be sent during the SCO reserved slots if a valid packet header with the primary LT_ADDR is received in the preceding slot. DM1 packets sent during SCO reserved slots shall only be used to send ACL-C data.

The slave shall not transmit anything other than an HV packet in a reserved SCO slot unless it decodes its own slave address in the packet header of the packet in the preceding master-to-slave transmission slot.

### 8.6.3 eSCO

The eSCO logical transport is established by the master sending an eSCO setup message via the LM protocol. This message contains timing parameters including the eSCO interval $T_{ESCO}$ and the offset $D_{ESCO}$ to specify the reserved slots.

To enter eSCO, the master or slave shall send an eSCO setup command via the LM protocol. This message shall contain the eSCO interval $T_{ESCO}$ and an offset $D_{ESCO}$. In order to prevent clock wrap-around problems, an initialization flag in the LMP setup message indicates whether initialization procedure 1 or 2 shall be used. The initiating device shall use initialization 1 when the MSB of the current master clock ($CLK_{27}$) is 0; it shall use initialization 2 when the MSB of the current master clock ($CLK_{27}$) is 1. The responding device shall apply the initialization method as indicated by the initialization flag. The master-to-slave eSCO slots reserved by the master and the slave shall be initialized on the slots for which the clock satisfies the applicable equation:

$$CLK_{27-1} \bmod T_{ESCO} = D_{ESCO} \quad \text{for initialization 1}$$

$$(\overline{CLK}_{27}, CLK_{26-1}) \bmod T_{ESCO} = D_{ESCO} \quad \text{for initialization 2}$$

The slave-to-master eSCO slots shall directly follow the reserved master-to-slave eSCO slots. After initialization, the clock value CLK(k+1) for the next master-to-slave eSCO slot shall be found by adding the fixed interval $T_{ESCO}$ to the clock value of the current master-to-slave eSCO slot:

$$CLK(k+1) = CLK(k) + T_{ESCO}$$

When an eSCO logical transport is established, the master shall assign an additional LT_ADDR to the slave. This provides the eSCO logical transport with an ARQ scheme that is separate from that of the ACL logical transport. All traffic on a particular eSCO logical transport, and only that eSCO traffic, is carried on the eSCO LT_ADDR. The eSCO ARQ scheme uses the ARQN bit in the packet header, and operates similarly to the ARQ scheme on ACL links.

There are two different polling rules in eSCO. In the eSCO reserved slots, the polling rule is the same as to the SCO reserved slots. The master may send a packet in the master slot. The slave may transmit on the eSCO LT_ADDR in the following slot either if it received a packet on the eSCO LT_ADDR in the previous slot, or if it did not receive a valid packet header in the previous slot. When the master-to-slave packet type is a three-slot packet, the slave's transmit slot is the fourth slot of the eSCO reserved slots. A master shall transmit in an eSCO retransmission window on a given eSCO LT_ADDR only if it addressed that eSCO LT_ADDR in the immediately preceding eSCO reserved slots. A slave may transmit on an eSCO LT_ADDR in the eSCO reserved slots only if the slave did not received a valid packet header with a different LT_ADDR in the eSCO reserved slots. Inside retransmission windows, the same polling rule as for ACL traffic is used: the slave shall transmit on the eSCO channel only if it received a valid packet header and correct LT_ADDR on the eSCO channel in the previous master-to-slave transmission slot. The master may transmit on any non-eSCO LT_ADDR in any master-to-slave transmission slot inside the eSCO retransmission window. The master shall only transmit on an eSCO LT_ADDR in the retransmission window if there are enough slots left for both the master and slave packets to complete in the retransmission window. The master may refrain from transmitting in any slot during the eSCO retransmission window. When there is no data to transmit from master to slave, either due to the traffic being unidirectional or due to the master-to-slave packet having been ACK'ed, the master shall use the POLL packet. When the master-to-slave packet has been ACK'ed, and the slave-to-master packet has been correctly received, the master shall not address the slave on the eSCO LT_ADDR until the next eSCO reserved slot, with the exception that the master may transmit a NULL packet with ARQN=ACK on the eSCO LT_ADDR. When there is no data to transmit from slave to master, either due to the traffic being unidirectional or due to the slave-to-master packet having been ACK'ed, the slave shall use NULL packets. eSCO traffic should be given priority over ACL traffic in the retransmission window.

Figure 8.7 on page 172 shows the eSCO window when single slot packets are used.

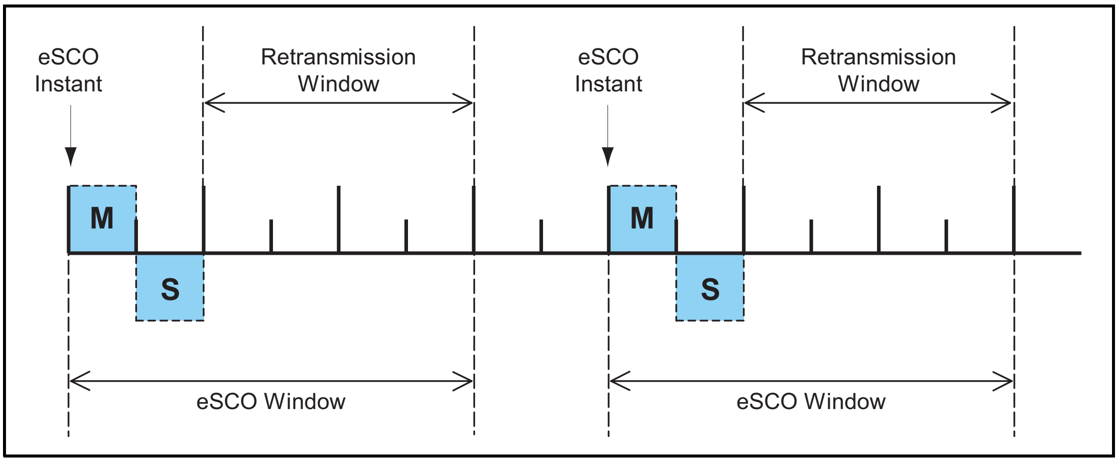


*Figure 8.7: eSCO Window Details for Single-Slot Packets*

When multi-slot packets are used in either direction of the eSCO logical transport, the first transmission continues into the following slots. The retransmission window in this case starts the slot after the end of the slave-to-master packet, i.e. two, four or six slots immediately following the eSCO instant are reserved and should not be used for other traffic. Figure 8.8 on page 173 shows the eSCO window when multi-slot packets are used in one direction and single-slot packets are used in the other direction.

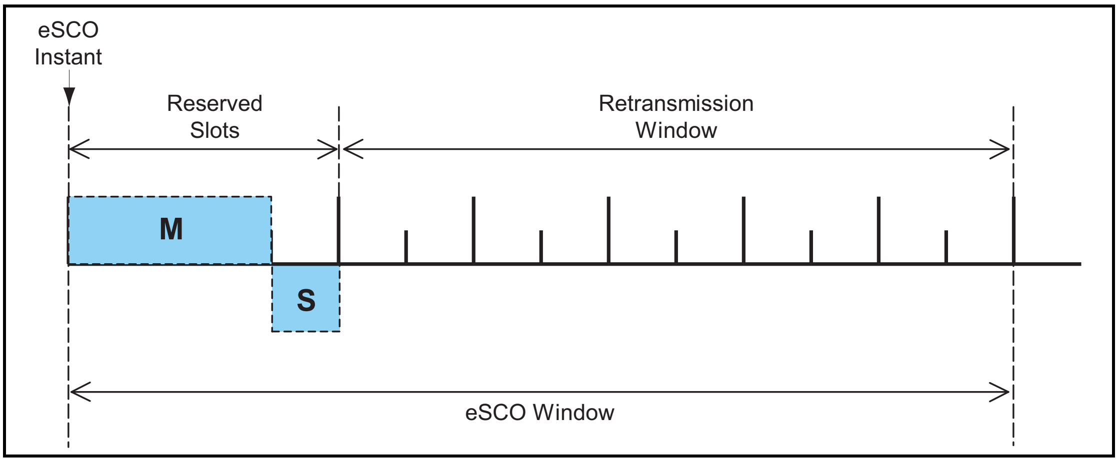


*Figure 8.8: eSCO Window Details for Asymmetric Traffic*

eSCO windows may overlap on the master, but shall not overlap on an individual slave.

In the reserved slots both master and slave shall only listen and transmit at their allocated slots at the first transmission time of each eSCO window. Intermittent lapses due to, for instance, time-critical signaling during connection establishment are allowed. Both master and slave may refrain from sending data and may use instead POLL and NULL packets respectively. When the master transmits a POLL packet instead of an EV4 or EV5 packet the slave shall transmit starting in the same slot as if the master transmitted an EV4 or EV5 packet. If the slave does not receive anything in the reserved master-to-slave transmission slot it shall transmit in the same slot as if the master had transmitted the negotiated packet type. For example, if the master had negotiated an EV5 packet the slave would transmit three slots later. [If the master does not receive a slave transmission in response to an eSCO packet it causes an implicit NAK of the packet in question. The listening requirements for the slave during the retransmission window are the same as for an active ACL logical transport.

### 8.6.4 Broadcast scheme

The master of the piconet can broadcast messages to all slaves on the ASB-U, PSB-C, and PSB-U logical transports. A broadcast packet shall have an LT_ADDR set to all zero. Each new broadcast message (which may be carried by a number of packets) shall start with the start of L2CAP message indication (LLID=10).

The Broadcast LT_ADDR shall use a ptt=0.

A broadcast packet shall never be acknowledged. In an error-prone environment, the master may carry out a number of retransmissions to increase the probability for error-free delivery, see also Section 7.6.5 on page 150.

In order to support the **PARK** state (as described in Section 8.9 on page 185), a master transmission shall take place at fixed intervals. This master transmission will act as a beacon to which slaves can synchronize. If no traffic takes place at the beacon event, broadcast packets shall be sent. More information is given in Section 8.9 on page 185.

### 8.6.5 Role switch

There are several occasions when a role switch is used.

- a role switch is necessary when joining an existing piconet by paging, since by definition, the paging device is initially master of a "small" piconet only involving the pager (master) and the paged (slave) device.
- a role switch is necessary in order for a slave in an existing piconet to set up a new piconet with itself as master and the original piconet master as slave. If the original piconet had more than one slave, then this implies a double role for the original piconet master; it becomes a slave in the new piconet while still maintaining the original piconet as master.

Prior to the role switch, encryption if present, shall be stopped in the old piconet. A role switch shall not be performed if the physical link is in Sniff or Hold mode, in the **PARK** state, or has any synchronous logical transports.

For the master and slave involved in the role switch, the switch results in a reversal of their TX and RX timing: a TDD switch. Additionally, since the piconet parameters are derived from the Bluetooth device address and clock of the master, a role switch inherently involves a redefinition of the piconet as well: a piconet switch. The new piconet's parameters shall be derived from the former slave's device address and clock.

Assume device A is to become master; device B was the former master. Then there are two alternatives: either the slave initiates the role switch or the master initiates the role switch. These alternatives are described in Link Manager Protocol, [Part C] Section 4.4.2 on page 268. The baseband procedure is the same regardless of which alternative is used.

In step 1, the slave A and master B shall perform a TDD switch using the former hopping scheme (still using the Bluetooth device address and clock of device B), so there is no piconet switch yet. The slot offset information sent by slave A shall not be used yet but shall be used in step 3. Device A now becomes the master, device B the slave. The LT_ADDR formerly used by device A in its slave role, shall now be used by slave B.

At the moment of the TDD switch, both devices A and B shall start a timer with a time out of *newconnectionTO*. The timer shall be stopped in slave B as soon as it receives an FHS packet from master A on the TDD-switched channel. The timer shall be stopped in master A as soon as it receives an ID packet from slave B. If the *newconnectionTO* expires, the master and slave shall return to the old piconet timing and AFH state, taking their old roles of master and slave. The FHS packet shall be sent by master A using the "old" piconet parameters. The LT_ADDR in the FHS packet header shall be the former LT_ADDR used by device A. The LT_ADDR carried in the FHS payload shall be the new LT_ADDR intended for device B when operating on the new piconet. After the FHS acknowledgment, which is the ID packet and shall be sent by the slave on the old hopping sequence, both master A and slave B shall use the new channel parameters of the new piconet as indicated by the FHS with the sequence selection set to *basic channel hopping sequence*. If the new master has physical links that are *AFH enabled*, following the piconet switch the new master is responsible for controlling the AFH operational mode of its new slave.

Since the old and new masters' clocks are synchronized, the clock information sent in the FHS payload shall indicate the new master's clock at the beginning of the FHS packet transmission. Furthermore, the 1.25 ms resolution of the clock information given in the FHS packet is not sufficient for aligning the slot boundaries of the two piconets. The slot-offset information in the LMP message previously sent by device A shall be used to provide more accurate timing information. The slot offset indicates the delay between the start of the master-to-slave slots of the old and new piconet channels. This timing information ranges from 0 to 1249 μs with a resolution of 1μs. It shall be used together with the clock information in the FHS packet to accurately position the correlation window when switching to the new master's timing after acknowledgment of the FHS packet.

After reception of the FHS packet acknowledgment, the new master A shall switch to its own timing with the sequence selection set to the *basic channel hopping sequence* and shall send a POLL packet to verify the switch. Both the master and the slave shall start a new timer with a time out of *newconnectionTO* on FHS packet acknowledgment. The start of this timer shall be aligned with the beginning of the first master TX slot boundary of the new piconet, following the FHS packet acknowledgment. The slave shall stop the timer when the POLL packet is received; the master shall stop the timer when the POLL packet is acknowledged. The slave shall respond with any type of packet to acknowledge the POLL. Any pending AFH_Instant shall be cancelled once the POLL packet has been received by the slave. If no response is received, the master shall re-send the POLL packet until *newconnectionTO* is reached. If this timer expires, both the slave and the master shall return to the old piconet timing with the old master and slave roles. Expiry of the timer shall also restore the state associated with AFH (including any pending AFH_Instant), Channel Quality Driven Data Rate (CQDDR, Link Manager Protocol [Part C] Section 4.1.7 on page 243) and power control (Link Manager Protocol [Part C] Section 4.1.3 on page 235). The procedure may then start again beginning at step 1. Aligning the timer with TX boundaries of the new piconet ensures that no device returns to the old piconet timing in the middle of a master RX slot.

After the role switch the ACL logical transport is reinitialized as if it were a new connection. For example, the SEQN of the first data packet containing a CRC on the new piconet channel shall be set according to the rules in section 7.6.2 on page 147.

A parked slave must be unparked before it can participate in a role switch.

### 8.6.6 Scatternet

Multiple piconets may cover the same area. Since each piconet has a different master, the piconets hop independently, each with their own hopping sequence and phase as determined by the respective master. In addition, the packets carried on the channels are preceded by different channel access codes as determined by the master device addresses. As more piconets are added, the probability of collisions increases; a graceful degradation of performance results as is common in frequency-hopping spread spectrum systems.

If multiple piconets cover the same area, a device can participate in two or more overlaying piconets by applying time multiplexing. To participate on the proper channel, it shall use the associated master device address and proper clock offset to obtain the correct phase. A device can act as a slave in several piconets, but only as a master in a single piconet: since two piconets with the same master are synchronized and use the same hopping sequence, they are one and the same piconet. A group of piconets in which connections exist between different piconets is called a *scatternet*.

A master or slave can become a slave in another piconet by being paged by the master of this other piconet. On the other hand, a device participating in one piconet can page the master or slave of another piconet. Since the paging device always starts out as master, a master-slave role switch is required if a slave role is desired. This is described in the Section 8.6.5 on page 175.

#### *8.6.6.1 Inter-piconet communications*

Time multiplexing must be used to switch between piconets. Devices may achieve the time multiplexing necessary to implement scatternet by using sniff mode or by remaining in an active ACL connection. For an ACL connection in piconets where the device is a slave in the **CONNECTION** state, it may choose not to listen in every master slot. In this case it should be recognized that the quality of service on this link may degrade abruptly if the slave is not present enough to match up with the master polling that slave. Similarly, in piconets where the device is master it may choose not to transmit in every master slot. In this case it is important to honor $T_{poll}$ as much as possible. Devices in sniff mode may have sufficient time to visit another piconet in between sniff slots. When the device is a slave using sniff mode and there are not sufficient idle slots, the device may choose to not listen to all master transmission slots in the sniff_attempts period or during the subsequent sniff_timeout period. A master is not required to transmit during sniff slots and therefore has flexibility for scatternet. If SCO or eSCO links are established, other piconets shall only be visited in the non-reserved slots in between reserved slots. This is only possible if there is a single SCO logical transport using HV3 packets or eSCO links where at least four slots remain in between the reserved slots. Since the multiple piconets are not synchronized, guard time must be left to account for misalignment. This means that only 2 slots can effectively be used to visit another piconet in between the HV3 packets.

Since the clocks of two masters of different piconets are not synchronized, a slave device participating in two piconets shall maintain two offsets that, added to its own native clock, create the two master clocks. Since the two master clocks drift independently, the slave must regularly update the offsets in order to keep synchronization to both masters.

### 8.6.7 Hop sequence switching

Hop sequence adaptation is controlled by the master and can be set to either *enabled* or *disabled*. Once enabled, hop sequence adaptation shall apply to all logical transports on a physical link. Once enabled, the master may periodically update the set of *used* and *unused* channels as well as disable hop sequence adaptation on a physical link. When a master has multiple physical links the state of each link is independent of all other physical links.

When hop sequence adaptation is enabled, the *sequence selection* hop selection kernel input is set to *adapted channel hopping sequence* and the *AFH_channel_map* input is set to the appropriate set of *used* and *unused* channels. Additionally, the *same channel* mechanism shall be used. When hop sequence adaptation is enabled with all channels *used* this is known as AHS(79).

When hop sequence adaptation is disabled, the *sequence selection* input of the hop selection kernel is set to *basic channel hopping sequence* (the *AFH_channel_map* input is unused in this case) and the *same channel* mechanism shall not be used.

The hop sequence adaptation state shall be changed when the master sends the LMP_set_AFH PDU and a baseband acknowledgement is received. When the baseband acknowledgement is received prior to the hop sequence switch instant, *AFH_Instant*, (See Link Manager Protocol [Part C] Section 4.1.4 on page 237) the hop sequence proceeds as shown in Figure 8.9 on page 178.

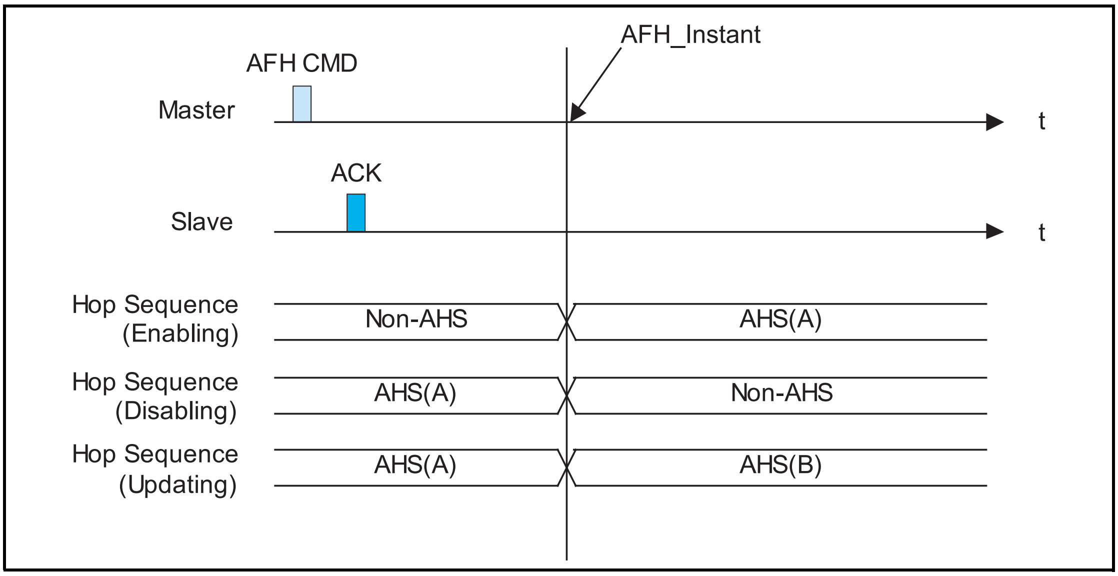


*Figure 8.9: Successful hop sequence switching*

When the baseband acknowledgement is not received prior to the *AFH_Instant* the master shall use a recovery hop sequence for the slave(s) that did not respond with an acknowledgement (this may be because the slave did not hear the master's transmission or the master did not hear the slave's transmission). When hop sequence adaptation is being enabled or disabled the recovery sequence shall be the *AFH_channel_map* specified in the LMP_set_AFH PDU. When the *AFH_channel_map* is being updated the master shall choose a recovery sequence that includes all of the RF channels marked as *used* in either the old or new *AFH_channel_map,* e.g. AHS(79). Once the baseband acknowledgement is received the master shall use the *AFH_channel_map* in the LMP_set_AFH PDU starting with the next transmission to the slave. See Figure 8.10 on page 179.

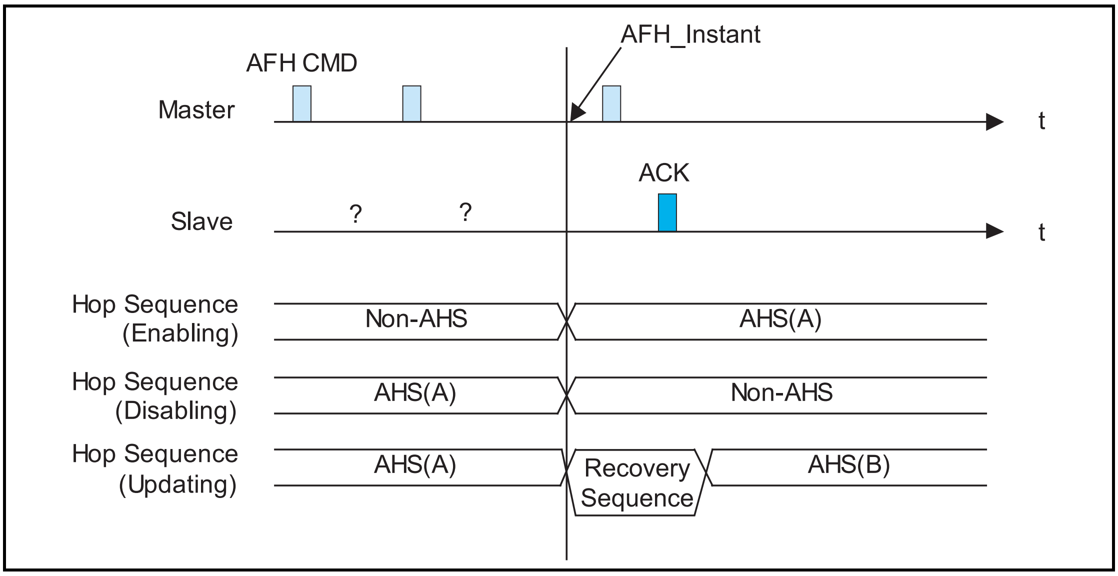


*Figure 8.10: Recovery hop sequences*

When the *AFH_Instant* occurs during a multi-slot packet transmitted by the master, the slave shall use the same hopping sequence parameters as the master used at the start of the multi-slot packet. An example of this is shown in Figure 8.11 on page 180. In this figure the *basic channel hopping sequence* is designated f. The first *adapted channel hopping sequence* is designated with f', and the second *adapted channel hopping sequence* is designated f''.

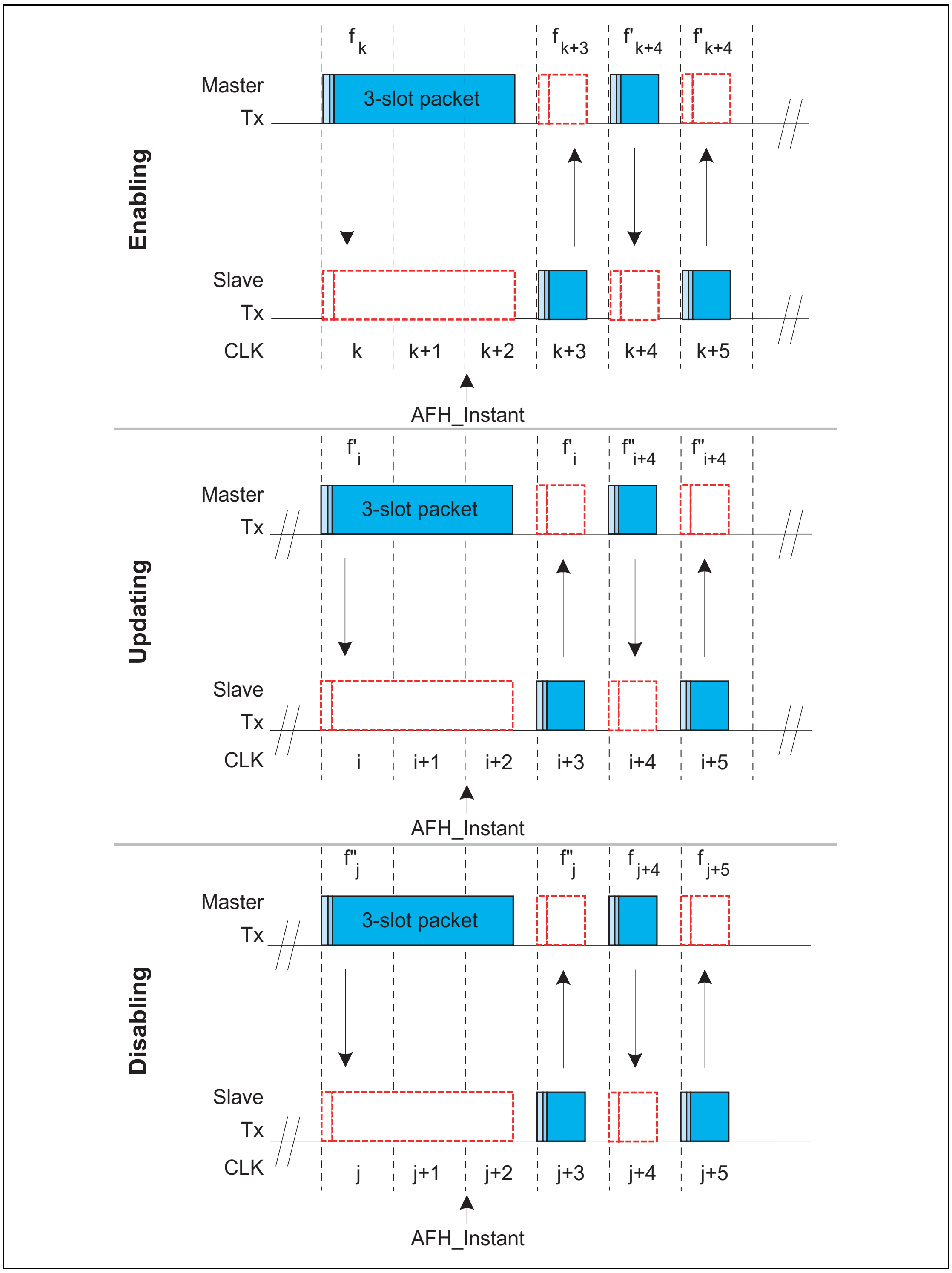


*Figure 8.11: AFH_Instant changes during multi-slot packets transmitted by the master.*

### 8.6.8 Channel classification and channel map selection

RF channels are classified as being *unknown, bad or good*. These classifications are determined individually by the master and slaves based on local information (e.g. active or passive channel assessment methods or from the Host via HCI). Information received from other devices via LMP (e.g. an *AFH_channel_map* from a master or a channel classification report from a slave) shall not be included in a device's channel classification.

The three possible channel classifications shall be as defined in Table 8.6 on page 181.

| Classification | Definition |
|---|---|
| *unknown* | A channel shall be classified as *unknown* if the channel assessment measurements are insufficient to reliably classify the channel, and the channel is not marked as *bad* in the most recent HCI *Set_AFH_Channel_Classification*. |
| *bad* | A channel may be classified as *bad* if an ACL or synchronous throughput failure measure associated with it has exceeded a threshold (defined by the particular channel assessment algorithm employed).<br>A channel may also be classified as *bad* if an interference-level measure associated with it, determining the interference level that the link poses upon other systems in the vicinity, has exceeded a threshold (defined by the particular channel assessment algorithm employed).<br>A channel shall be classified as *bad* when it is marked as *bad* in the most recent HCI *Set_AFH_Channel_Classification* command. |
| *good* | A channel shall be classified as *good* if it is not either *unknown* or *bad*. |

*Table 8.6: Channel classification descriptions*

A master with AFH enabled physical links shall determine an *AFH_channel_map* based on any combination of the following information:

- Channel classification from local measurements (e.g. active or passive channel assessment in the Controller), if supported and enabled. The Host may enable or disable local measurements using the HCI *Write_AFH_Channel_Classification_Mode* command, defined in the HCI Functional Specification [Part E] Section 7.3.58 on page 537 if HCI is present.
- Channel classification information from the Host using the HCI *Set_AFH_channel_classification* command, defined in the HCI Functional Specification [Part E] Section 7.3.58 on page 537 if HCI is present. Channels classified as *bad* in the most recent *AFH_Host_Channel_Classification* shall be marked as *unused* in the *AFH_channel_map*.
- Channel classification reports received from slaves in *LMP_channel_classification* PDUs, defined in the LMP Specification [Part C] Section 4.1.5 on page 240.

The algorithm used by the master to combine these information sources and generate the *AFH_channel_map* is not defined in the specification and will be implementation specific. At no time shall the number of channels used be less than $N_{min}$, defined in Section 2.3.1 on page 75.

If a master that determines that all channels should be *used* it may keep AFH operation enabled using an *AFH_channel_map* of 79 *used* channels, i.e. AHS(79).

### 8.6.9 Power Management

Features are provided to allow low-power operation. These features are both at the microscopic level when handling the packets, and at the macroscopic level when using certain operation modes.

#### *8.6.9.1 Packet handling*

In order to minimize power consumption, packet handling is minimized both at TX and RX sides. At the TX side, power is minimized by only sending useful data. This means that if only link control information needs to be exchanged, **NULL** packets may be used. No transmission is required if there is no link control information to be sent, or if the transmission would only involve a NAK (NAK is implicit on no reply). If there is data to be sent, the payload length shall be adapted in order to send only the valid data bytes. At the RX side, packet processing takes place in different steps. If no valid access code is found in the search window, the transceiver may return to sleep. If an access code is found, the receiver device shall start to process the packet header. If the HEC fails, the device may return to sleep after the packet header. A valid header indicates if a payload will follow and how many slots are involved.

#### *8.6.9.2 Slot occupancy*

As was described in Section 6.5 on page 118, the packet type indicates how many slots a packet may occupy. A slave not addressed in the packet header may go to sleep for the remaining slots the packet occupies. This can be read from the TYPE code.

#### *8.6.9.3 Recommendations for low-power operation*

The most common and flexible methods for reducing power consumption are the use of sniff and park. Hold can also be used by repeated negotiation of hold periods.

### *8.6.9.4 Enhanced Data Rate*

Enhanced Data Rate provides power saving because of the ability to send a given amount of data in either fewer packets or with the same (or similar) number of packets but with shorter payloads.

## 8.7 SNIFF MODE

In sniff mode, the duty cycle of the slave's activity in the piconet may be reduced. If a slave is in active mode on an ACL logical transport, it shall listen in every ACL slot to the master traffic, unless that link is being treated as a scatternet link or is absent due to hold mode. With sniff mode, the time slots when a slave is listening are reduced, so the master shall only transmit to a slave in specified time slots. The sniff anchor points are spaced regularly with an interval of $T_{sniff}$.

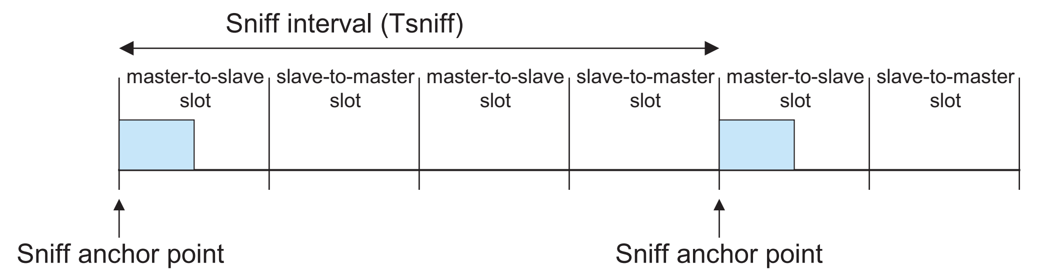


*Figure 8.12: Sniff anchor points*

The slave listens in master-to-slave transmission slots starting at the sniff anchor point. It shall use the following rules to determine whether to continue listening:

- If fewer than $N_{sniff\ attempt}$ master-to-slave transmission slots have elapsed since the sniff anchor point then the slave shall continue listening.
- If the slave has received a packet with a matching LT_ADDR that contains ACL data (DM, DH, DV, or AUX1 packets) in the preceding $N_{sniff\ timeout}$ master-to-slave transmission slots then it shall continue listening.
- If the slave has transmitted a packet containing ACL data (DM, DH, DV, or AUX1 packets) in the preceding $N_{sniff\ timeout}$ slave-to-master transmission slots then it shall continue listening.
- If the slave has received any packet with a matching LT_ADDR in the preceding $N_{sniff\ timeout}$ master-to-slave transmission slots then it may continue listening.
- A device may override the rules above and stop listening prior to $N_{sniff\ timeout}$ or the remaining $N_{sniff\ attempt}$ slots if it has activity in another piconet.

It is possible that activity from one sniff timeout may extend to the next sniff anchor point. Any activity from a previous sniff timeout shall not affect activity after the next sniff anchor point. So in the above rules, only the slots since the last sniff anchor point are considered.

Note that $N_{sniff\ attempt}$ =1 and $N_{sniff\ timeout}$ =0 cause the slave to listen only at the slot beginning at the sniff anchor point, irrespective of packets received from the master.

$N_{sniff\ attempt}$ =0 shall not be used.

Sniff mode only applies to asynchronous logical transports and their associated LT_ADDR.  sniff mode shall not apply to synchronous logical transports, therefore, both masters and slaves shall still respect the reserved slots and retransmission windows of synchronous links.

To enter sniff mode, the master or slave shall issue a sniff command via the LM protocol. This message includes the sniff interval $T_{sniff}$ and an offset $D_{sniff.}$ In addition, an initialization flag indicates whether initialization procedure 1 or 2 shall be used. The device shall use initialization 1 when the MSB of the current master clock ($CLK_{27}$) is 0; it shall use initialization 2 when the MSB of the current master clock ($CLK_{27}$) is 1. The slave shall apply the initialization method as indicated by the initialization flag irrespective of its clock bit value $CLK_{27}$. The sniff anchor point determined by the master and the slave shall be initialized on the slots for which the clock satisfies the applicable equation:

$CLK_{27\text{-}1} \bmod T_{sniff} = D_{sniff}$ for initialization 1

$(\overline{CLK_{27}},CLK_{26\text{-}1}) \bmod T_{sniff} = D_{sniff}$ for initialization 2

this implies that $D_{sniff}$ must be even

After initialization, the clock value CLK(k+1) for the next sniff anchor point shall be derived by adding the fixed interval $T_{sniff}$ to the clock value of the current sniff anchor point:

$CLK(k+1) = CLK(k) + T_{sniff}$

### 8.7.1 Sniff Transition Mode

Sniff transition mode is a special mode which is used during the transition between sniff and active mode. It is required because during this transition it is unclear which mode (Sniff or Active) the slave is in and it is necessary to ensure that the slave is polled correctly regardless of which mode it is in.

In sniff transition mode the master shall maintain the active mode poll interval in case the slave is in active mode. In addition the master shall poll the slave at least once in the sniff attempt transmit slots starting at each sniff instant: note that this transmission counts for the active mode polling as well. The master must use its high power accurate clock when in Sniff Transition Mode.

The precise circumstances under which the master enters Sniff Transition Mode are defined in [Part C] Section 4.5.3.1 on page 279.

## 8.8 HOLD MODE

During the **CONNECTION** state, the ACL logical transport to a slave can be put in a **hold** mode. In **hold** mode the slave temporarily shall not support ACL packets on the channel. Any synchronous packet during reserved synchronous slots (from SCO and eSCO links) shall be supported. With the **hold** mode, capacity can be made free to do other things like scanning, paging, inquiring, or attending another piconet. The device in **hold** mode can also enter a low-power sleep mode. During **hold** mode, the slave device keeps its logical transport address(es) (LT_ADDR).

Prior to entering hold mode, master and slave agree on the time duration the slave remains in hold mode. A timer shall be initialized with the *holdTO* value. When the timer is expired, the slave shall wake up, synchronize to the traffic on the channel and will wait for further master transmissions.

## 8.9 PARK STATE

When a slave does not need to participate on the piconet channel, but still needs to remain synchronized to the channel, it can enter **PARK** state. **PARK** state is a state with very little activity in the slave. In the **PARK** state, the slave shall give up its logical transport address LT_ADDR. Instead, it shall receive two new addresses to be used in the **PARK** state

- PM_ADDR: 8-bit Parked Member Address
- AR_ADDR: 8-bit Access Request Address

The PM_ADDR distinguishes a parked slave from the other parked slaves. This address may be used in the master-initiated unpark procedure. In addition to the PM_ADDR, a parked slave may also be unparked by its 48-bit BD_ADDR. The all-zero PM_ADDR is a reserved address: if a parked device has the all-zero PM_ADDR it can only be unparked by the BD_ADDR. In that case, the PM_ADDR has no meaning. The AR_ADDR shall be used by the slave in the slave-initiated unpark procedure. All messages sent to the parked slaves are carried by broadcast packets.

The parked slave wakes up at regular intervals to listen to the channel in order to re-synchronize and to check for broadcast messages. To support the synchronization and channel access of the parked slaves, the master supports a beacon train described in the next section. The beacon structure is communicated to the slave when it is parked. When the beacon structure changes, the parked slaves are updated through broadcast messages.

The master shall maintain separate non-overlapping park beacon structures for each hop sequence. The beacon structures shall not overlap either their beacon slots or access windows.

In addition for using it for low power consumption, park is used to connect more than seven slaves to a single master. At any one time, only seven slaves can be in the **CONNECTION** state. However, by swapping active and parked slaves out respectively in the piconet, the number of slaves can be much larger (255 if the PM_ADDR is used, and an arbitrarily large number if the BD_ADDR is used).

### 8.9.1 Beacon train

To support parked slaves, the master establishes a beacon train when one or more slaves are parked. The beacon train consists of one beacon slot or a train of equidistant beacon slots which is transmitted periodically with a constant time interval. The beacon train is illustrated in Figure 8.13 on page 188. A train of $N_B$ ($N_B \geq 1$) beacon slots is defined with an interval of $T_B$ slots. The beacon slots in the train are separated by $\Delta_B$. The start of the first beacon slot is referred to as the **beacon instant** and serves as the beacon timing reference. The beacon parameters $N_B$ and $T_B$ are chosen such that there are sufficient beacon slots for a parked slave to synchronize to during a certain time window in an error-prone environment.

When parked, the slave shall receive the beacon parameters through an LMP command. In addition, the timing of the beacon instant is indicated through the offset $D_B$. As with the SCO logical transport (see Section 8.6.2 on page 169), two initialization procedures 1 or 2 are used. The master shall use initialization 1 when the MSB of the current master clock ($CLK_{27}$) is 0; it shall use initialization 2 when the MSB of the current master clock ($CLK_{27}$) is 1. The chosen initialization procedure shall also be carried by an initialization flag in the LMP command. The slave shall apply the initialization method as indicated by the initialization flag irrespective of its clock bit $CLK_{27}$. The master-to-slave slot positioned at the beacon instant shall be initialized on the slots for which the clock satisfies the applicable equation:

$CLK_{27-1} \bmod T_B = D_B$ for initialization 1

$(\overline{CLK_{27}}, CLK_{26-1}) \bmod T_B = D_B$ for initialization 2

this implies that DB will be even

After initialization, the clock value CLK(k+1) for the next beacon instant shall be derived by adding the fixed interval $T_B$ to the clock value of the current beacon instant:

$$CLK(k+1) = CLK(k) + T_B$$

The beacon train serves four purposes:

1. transmission of master-to-slave packets which the parked slaves can use for re-synchronization
2. carrying messages to the parked slaves to change the beacon parameters

3. carrying general broadcast messages to the parked slaves
4. unparking of one or more parked slaves

Since a slave can synchronize to any packet which is preceded by the proper channel access code, the packets carried on the beacon slots do not have to contain specific broadcast packets for parked slaves to be able to synchronize; any packet may be used. The only requirement placed on the beacon slots is that there is a master-to-slave transmission present on the hopping sequence associated with the park structure. If there is no information to be sent, **NULL** packets may be transmitted by the master. If there is indeed broadcast information to be sent to the parked slaves, the first packet of the broadcast message shall be repeated in every beacon slot of the beacon train. However, synchronous traffic in the synchronous reserved slots may interrupt the beacon transmission if it is on the same hopping sequence as the parked slaves. The master shall configure its park beacon structure so that reserved slots of synchronous logical transports do not cause slaves to miss synchronization on a beacon slot. For example, a master that has active slaves using AHS, and parked slaves using Non-AHS shall ensure that the Park beacons cannot be interrupted by AHS synchronous reserved slots.

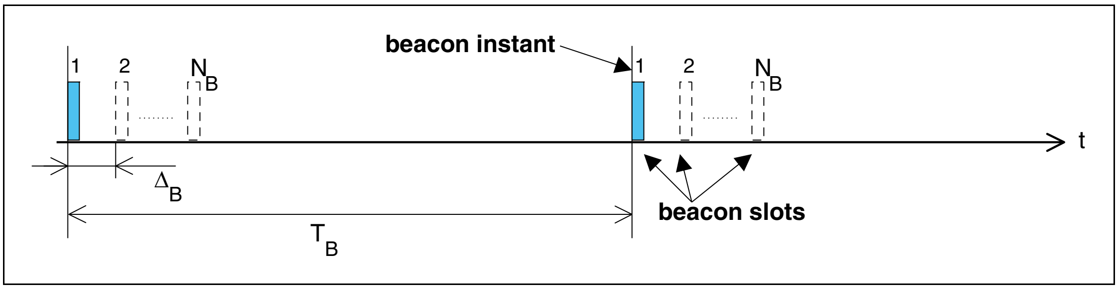


*Figure 8.13: General beacon train format*

The master can place parked slaves in any of the AFH operating modes, but shall ensure that all parked slaves use the same hop sequence. Masters should use AHS(79) or AHS when all the slaves in the Piconet are AFH capable.

A master that switches a slave between AFH enabled, AFH disabled or AHS(79) operation shall ensure that the AFH_Instant occurs before transmission of the beacon train using this hop sequence.

The master communicates with parked slaves using broadcast messages. Since these messages can be time - critical, an ongoing repetition train of broadcast message may be prematurely aborted by broadcast information destined to parked slaves in beacon slots and in access windows (see Section 8.9.2 on page 189).

### 8.9.2 Beacon access window

In addition to the beacon slots, an access window is defined where the parked slaves can send requests to be unparked. To increase reliability, the access window may be repeated $M_{access}$ times ($M_{access}$ ≥1), see Figure 8.14 on page 189. The access window starts a fixed delay $D_{access}$ after the beacon instant. The width of the access window is $T_{access}$.

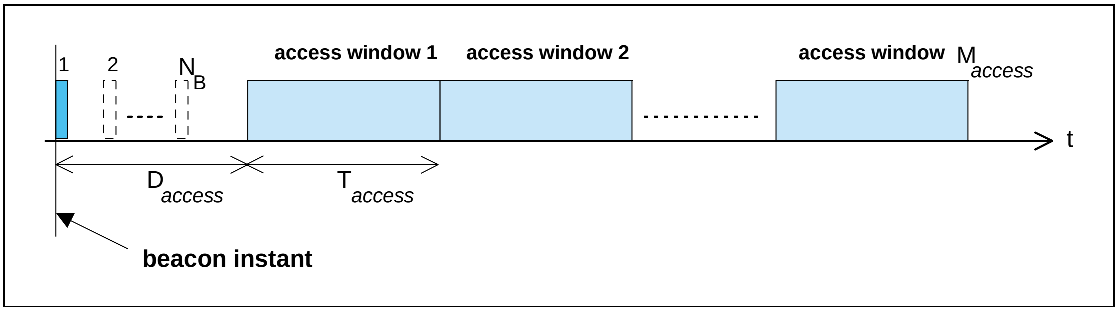


*Figure 8.14: Definition of access window*

The access window supports a polling slave access technique. The format of the polling technique is shown in Figure 8.15 on page 189. The same TDD structure is used as on the piconet channel, i.e. master-to-slave transmission is alternated with slave-to-master transmission. The slave-to-master slot is divided into two half slots of 312.5 µs each. The half slot a parked slave is allowed to respond in corresponds to its access request address (AR_ADDR), see also section 8.9.6 on page 192. For counting the half slots to determine the access request slot, the start of the access window is used, see Figure 8.15 on page 189. The slave shall only send an access request in the proper slave-to-master half slot if a broadcast packet has been received in the preceding master-to-slave slot. In this way, the master polls the parked slaves.

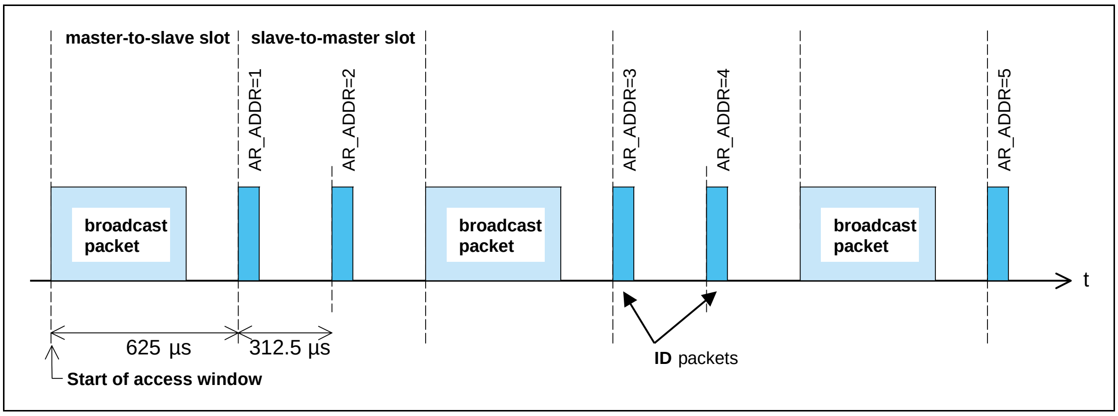


*Figure 8.15: Access procedure applying the polling technique.*

The slots of the access window may also be used for traffic on the piconet if required. For example, if a synchronous connection has to be supported, the slots reserved for the synchronous link may carry synchronous information instead of being used for access requests, i.e. if the master-to-slave slot in the access window contains a packet different from a broadcast packet, the following slave-to-master slot shall not be used for slave access requests. If the master transmits a broadcast packet in the access window then it shall use the hop sequence associated with the park structure. Slots in the access window not affected by piconet traffic may still be used according to the defined access structure, (an example is shown in Figure 8.16 on page 190) the access procedure shall be continued as if no interruption had taken place.

When the slave is parked, the master shall indicate what type of access scheme will be used. For the polling scheme, the number of slave-to-master access slots $N_{acc\_slot}$ is indicated.

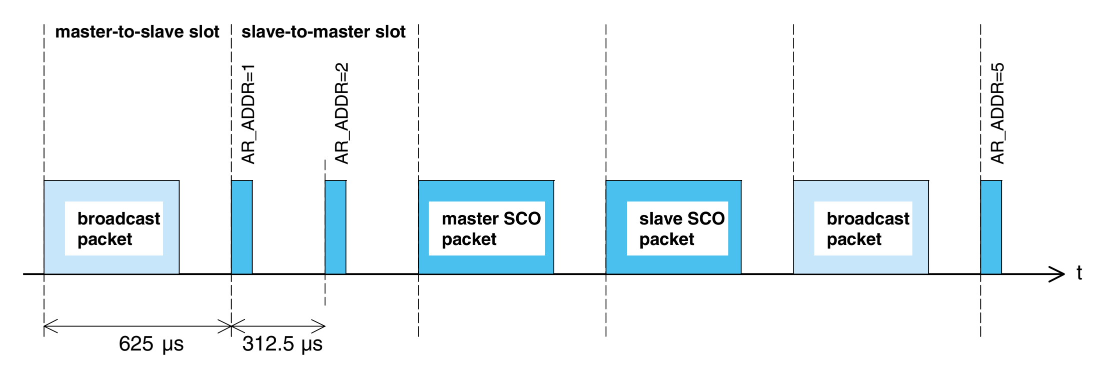


*Figure 8.16: Disturbance of access window by SCO traffic*

By default, the access window is always present. However, its activation depends on the master sending broadcast messages to the slave at the appropriate slots in the access window. A flag in a broadcast LMP message within the beacon slots may indicate that the access window(s) belonging to this instant will not be activated. This prevents unnecessary scanning of parked slaves that want to request access.

### 8.9.3 Parked slave synchronization

Parked slaves wake up periodically to re-synchronize to the channel. Any packet exchanged on the channel can be used for synchronization. Since master transmission is mandatory on the beacon slots, parked slaves will use the beacon train to re-synchronize. A parked slave may wake-up at the beacon instant to read the packet sent on the first beacon slot. If this fails, it may retry on the next beacon slot in the beacon train; in total, there are $N_B$ opportunities per beacon instant to re-synchronize. During the search, the slave may increase its search window, see also Section 2.2.5.2 on page 74. The separation between the beacon slots in the beacon train $\Delta_B$ shall be chosen such that consecutive search windows will not overlap.

The parked slave may not wake up at every beacon instant. Instead, a sleep interval may be applied which is longer than the beacon interval $T_B$, see Figure 8.17 on page 191. The slave sleep window shall be a multiple $N_{B\_sleep}$ of $T_B$.

The precise beacon instant the slave may wake up on shall be indicated by the master with $D_{B\_sleep}$ which indicates the offset (in multiples of $T_B$) with respect to the beacon instant ($0 < D_{B\_sleep} < N_{B\_sleep} - 1$). To initialize the wake-up period, the applicable equation shall be used:

$CLK_{27-1} \bmod (N_{B\_sleep} \bullet T_B) = D_B + D_{B\_sleep} \bullet T_B$ for initialization 1

$(\overline{CLK_{27}}, CLK_{26-1}) \bmod (N_{B\_sleep} \bullet T_B) = D_B + D_{B\_sleep} \bullet T_B$ for initialization 2

where initialization 1 shall be chosen by the master if the MSB in the current master clock is 0 and initialization 2 shall be chosen by the master if the MSB in the current master clock is 1.

When the master needs to send broadcast messages to the parked slaves, it may use the beacon slots for these broadcast messages. However, if $N_B < N_{BC}$, the slots following the last beacon slot in the beacon train shall be used for the remaining $N_{BC} - N_B$ broadcast packets. If $N_B > N_{BC}$, the broadcast message shall be repeated on all $N_B$ beacon slots.

A parked slave shall read the broadcast messages sent in the beacon slot(s) it wakes up in. If the parked slave wakes up, the minimum wake-up activity shall be to read the channel access code for re-synchronization and the packet header to check for broadcast messages.

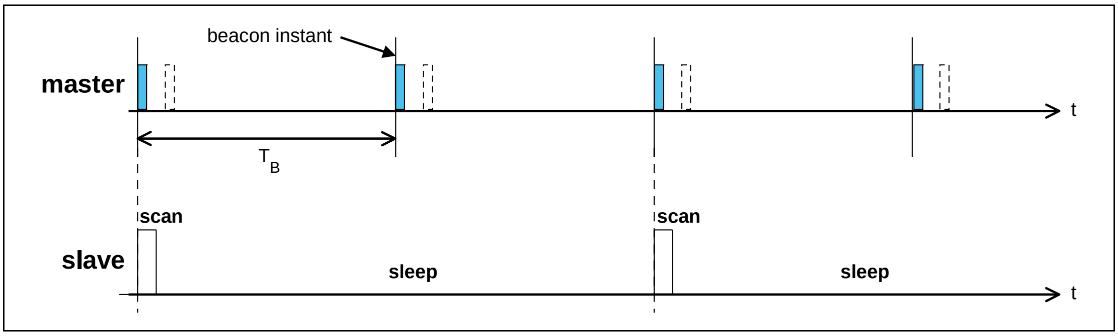


*Figure 8.17: Extended sleep interval of parked slaves.*

### 8.9.4 Parking

A master can park an active slave through the exchange of LMP commands. Before being put into park, the slave shall be assigned a PM_ADDR and an AR_ADDR. Every parked slave shall have a unique PM_ADDR or a PM_ADDR of 0. The AR_ADDR is not necessarily unique. The beacon parameters shall be given by the master when the slave is parked. The slave shall then give up its LT_ADDR and shall enter **PARK** state. A master can park only a single slave at a time. The park message is carried with a normal data packet and addresses the slave through its LT_ADDR.

### 8.9.5 Master-initiated unparking

The master can unpark a parked slave by sending a dedicated LMP unpark command including the parked slave's address. This message shall be sent in a broadcast packet on the beacon slots. The master shall use either the slave's PM_ADDR, or its BD_ADDR. The message also includes the logical transport address LT_ADDR the slave shall use after it has re-entered the piconet. The unpark message may include a number of slave addresses so that multiple slaves may be unparked simultaneously. For each slave, a different LT_ADDR shall be assigned.

After having received the unpark message, the parked slave matching the PM_ADDR or BD_ADDR shall leave the **PARK** state and enter the **CONNECTION** state. It shall keep listening to the master until it is addressed by the master through its LT_ADDR. The first packet sent by the master shall be a POLL packet. The return packet in response to the POLL packet confirms that the slave has been unparked. If no response packets from the slave is received for *newconnectionTO* number of slots after the end of beacon repetition period, the master shall unpark the slave again. The master shall use the same LT_ADDR on each unpark attempt until it has received a link supervision timeout for that slave or the unpark has completed successfully. If the slave does not receive the POLL packet for *newconnectionTO* number of slots after the end of beacon repetition period, it shall return to park, with the same beacon parameters. After confirming that the slave is in the **CONNECTION** state, the master decides in which mode the slave will continue.

When a device is unparked, the SEQN bit for the link shall be reset to 1 on both the master and the slave (see Section 7.6.2.1 on page 148).

### 8.9.6 Slave-initiated unparking

A slave can request access to the channel through the access window defined in section 8.9.2 on page 189. As shown in Figure 8.15 on page 189, the access window includes several slave-to-master half slots where the slave may send an access request message. The specific half slot the slave is allowed to respond in, corresponds to its access request address (AR_ADDR) which it received when it was parked. The order of the half slots (in Figure 8.15 the AR_ADDR numbers linearly increase from 1 to 5) is not fixed: an LMP command sent in the beacon slots may reconfigure the access window. When a slave desires access to the channel, it shall send an access request message in the proper slave-to-master half slot. The access request message of the slave is the **ID** packet containing the device access code (DAC) of the master (which is the channel access code without the trailer). The parked slave shall only transmit an access request message in the half slot, when in the preceding master-to-slave slot a broadcast packet has been received. This broadcast message may contain any kind of broadcast information not necessarily related to the parked slave(s). If no broadcast information is available, a broadcast **NULL** or broadcast **POLL** packet shall be sent.

After having sent an access request, the parked slave shall listen for an unpark message from the master. As long as no unpark message is received, the slave shall repeat the access requests in the subsequent access windows. After the last access window (there are $M_{access}$ windows in total, see Section 8.9.2 on page 189), the parked slave shall listen for an additional $N_{poll}$ time slots for an unpark message. If no unpark message is received within $N_{poll}$ slots after the end of the last access window, the slave may return to sleep and retry an access attempt after the next beacon instant.

After having received the unpark message, the parked slave matching the PM_ADDR or BD_ADDR shall leave the **PARK** state and enter the **CONNECTION** state. It shall keep listening to the master until it is addressed by the master through its LT_ADDR. The first packet sent by the master shall be a POLL packet. The return packet in response to the POLL packet confirms that the slave has been unparked. After confirming that the slave is in the **CONNECTION** state, the master decides in which mode the slave will continue. If no response packet from the slave is received for *newconnectionTO* number of slots after $N_{poll}$ slots after the end of the last access window, the master shall send the unpark message to the slave again. If the slave does not receive the POLL packet for *newconnectionTO* number of slots after $N_{poll}$ slots after the end of the last access window, it shall return to park, with the same beacon parameters.

When a device is unparked, the SEQN bit for the link shall be reset to 1 on both the master and the slave (see Section 7.6.2.1 on page 148).

### 8.9.7 Broadcast scan window

In the beacon train, the master can support broadcast messages to the parked slaves. However, it may extend its broadcast capacity by indicating to the parked slaves that more broadcast information is following after the beacon train. This is achieved by an LMP command ordering the parked slaves (as well as the active slaves) to listen to the channel for broadcast messages during a limited time window. This time window starts at the beacon instant and continues for the period indicated in the LMP command sent in the beacon train.

### 8.9.8 Polling in the park state

In the **PARK** state, parked slaves may send access requests in the access window provided a broadcast packet is received in the preceding master-to-slave slot. Slaves in the **CONNECTION** state shall not send in the slave-to-master slots following the broadcast packet, since they are only allowed to send if addressed specifically.

# 9 AUDIO

On the air-interface, either a 64 kb/s log PCM (Pulse Code Modulation) format (A-law or μ-law) may be used, or a 64 kb/s CVSD (Continuous Variable Slope Delta Modulation) may be used. The latter format applies an adaptive delta modulation algorithm with syllabic companding.

The voice coding on the line interface is designed to have a quality equal to or better than the quality of 64 kb/s log PCM.

Table 9.1 on page 195 summarizes the voice coding schemes supported on the air interface. The appropriate voice coding scheme is selected after negotiations between the Link Managers.

| **Voice Codecs** | |
|---|---|
| linear | CVSD |
| 8-bit logarithmic | A-law |
| | μ-law |

*Table 9.1: Voice coding schemes supported on the air interface.*

## 9.1 LOG PCM CODEC

Since the synchronous logical transports on the air-interface can support a 64 kb/s information stream, a 64 kb/s log PCM traffic can be used for transmission. Either A-law or μ-law compression may be applied. In the event that the line interface uses A-law and the air interface uses μ-law or vice versa, a conversion from A-law to μ-law shall be performed. The compression method shall follow ITU-T recommendations G. 711.

## 9.2 CVSD CODEC

A more robust format for voice over the air interface is delta modulation. This modulation scheme follows the waveform where the output bits indicate whether the prediction value is smaller or larger then the input waveform. To reduce slope overload effects, syllabic companding is applied: the step size is adapted according to the average signal slope. The input to the CVSD encoder shall be 64 ksamples/s linear PCM (typically 16 bits, but actual value is implementation specific). Block diagrams of the CVSD encoder and CVSD decoder are shown in Figure 9.1 on page 196, Figure 9.2 on page 196 and Figure 9.3 on page 196. The system shall be clocked at 64 kHz.

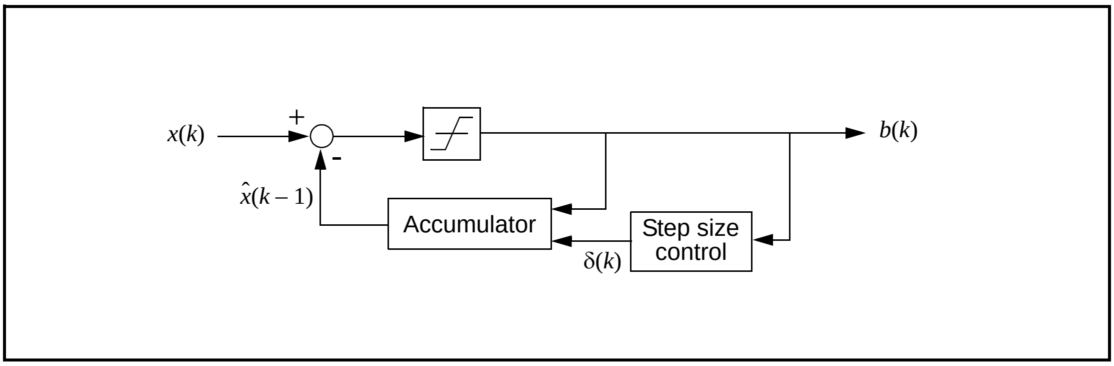


*Figure 9.1: Block diagram of CVSD encoder with syllabic companding.*

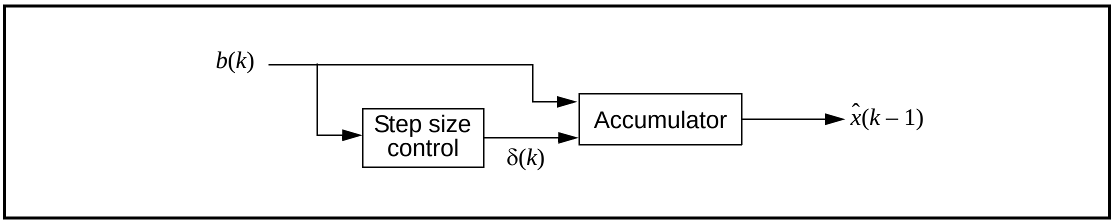


*Figure 9.2: Block diagram of CVSD decoder with syllabic companding.*

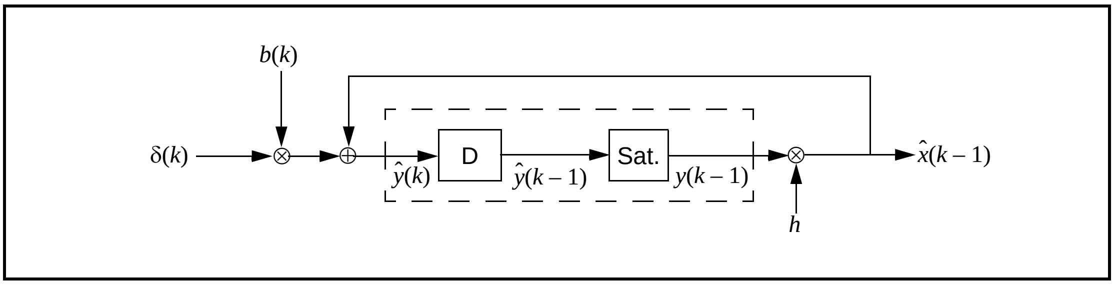


*Figure 9.3: Accumulator procedure.*

Let $\text{sgn}(x) = 1$ for $x \geq 0$, otherwise $\text{sgn}(x) = -1$. On air these numbers shall be represented by the sign bit; i.e. negative numbers are mapped on “1” and positive numbers are mapped on “0”.

Denote the CVSD encoder output bit $b(k)$, the encoder input $x(k)$, the accumulator contents $y(k)$, and the step size $\delta(k)$. Furthermore, let *h* be the decay factor for the accumulator, let $\beta$ denote the decay factor for the step size, and, let $\alpha$ be the syllabic companding parameter. The latter parameter monitors the slope by considering the *K* most recent output bits

Let

$$\hat{x}(k) = hy(k). \qquad \text{(EQ 13)}$$

Then, the CVSD encoder internal state shall be updated according to the following set of equations:

$$b(k) = \operatorname{sgn}\{x(k) - \hat{x}(k-1)\}, \quad \text{(EQ 14)}$$

$$\alpha = \begin{cases} 1, & \text{if } J \text{ bits in the last } K \text{ output bits are equal,} \\ 0, & \text{otherwise,} \end{cases} \quad \text{(EQ 15)}$$

$$\delta(k) = \begin{cases} \min\{\delta(k-1) + \delta_{min}, \delta_{max}\}, & \alpha = 1, \\ \max\{\beta\delta(k-1), \delta_{min}\}, & \alpha = 0, \end{cases} \quad \text{(EQ 16)}$$

$$y(k) = \begin{cases} \min\{\hat{y}(k), y_{max}\}, & \hat{y}(k) \geq 0. \\ \max\{\hat{y}(k), y_{min}\}, & \hat{y}(k) < 0. \end{cases} \quad \text{(EQ 17)}$$

where

$$\hat{y}(k) = \hat{x}(k-1) + b(k)\delta(k). \quad \text{(EQ 18)}$$

In these equations, $\delta_{min}$ and $\delta_{max}$ are the minimum and maximum step sizes, and, $y_{min}$ and $y_{max}$ are the accumulator's negative and positive saturation values, respectively. Over air, the bits shall be sent in the same order they are generated by the CVSD encoder.

For a 64 kb/s CVSD, the parameters as shown in Table 9.2 shall be used. The numbers are based on a 16 bit signed number output from the accumulator. These values result in a time constant of 0.5 ms for the accumulator decay, and a time constant of 16 ms for the step size decay

| **Parameter** | **Value** |
|---|---|
| $h$ | $1 - \frac{1}{32}$ |
| $\beta$ | $1 - \frac{1}{1024}$ |
| $J$ | 4 |
| $K$ | 4 |
| $\delta_{min}$ | 10 |
| $\delta_{max}$ | 1280 |
| $y_{min}$ | $-2^{15}$ or $-2^{15} + 1$ |
| $y_{max}$ | $2^{15} - 1$ |

*Table 9.2: CVSD parameter values. The values are based on a 16 bit signed number output from the accumulator.*

## 9.3 ERROR HANDLING

In the DV, HV3, EV3, EV5, 2-EV3, 3-EV3, 2-EV5 and 3-EV5 packets, the voice is not protected by FEC. The quality of the voice in an error-prone environment then depends on the robustness of the voice coding scheme and, in the case of eSCO, the retransmission scheme. CVSD, in particular, is rather insensitive to random bit errors, which are experienced as white background noise. However, when a packet is rejected because either the channel access code, the HEC test was unsuccessful, or the CRC has failed, measures have to be taken to “fill” in the lost speech segment.

The voice payload in the **HV2** and **EV4** packets are protected by a 2/3 rate FEC. For errors that are detected but cannot be corrected, the receiver should try to minimize the audible effects. For instance, from the 15-bit FEC segment with uncorrected errors, the 10-bit information part as found before the FEC decoder should be used. The **HV1** packet is protected by a 3 bit repetition FEC. For this code, the decoding scheme will always assume zero or one-bit errors. Thus, there exist no detectable but uncorrectable error events for **HV1** packets.

## 9.4 GENERAL AUDIO REQUIREMENTS

### 9.4.1 Signal levels

For A-law and $\mu$-law log-PCM encoded signals the requirements on signal levels shall follow the ITU-T recommendation G.711.

Full swing at the 16 bit linear PCM interface to the CVSD encoder is defined to be 3 dBm0.

### 9.4.2 CVSD audio quality

For Bluetooth audio quality the requirements are put on the transmitter side. The 64 ksamples/s linear PCM input signal should have negligible spectral power density above 4 kHz. The power spectral density in the 4-32 kHz band of the decoded signal at the 64 ksample/s linear PCM output, should be more than 20 dB below the maximum in the 0-4 kHz range.

# 10 LIST OF FIGURES

# 11 LIST OF TABLES

# APPENDIX A: GENERAL AUDIO RECOMMENDATIONS

## MAXIMUM SOUND PRESSURE

It is the sole responsibility of each manufacturer to design their audio products in a safe way with regards to injury to the human ear. The Bluetooth Specification doesn't specify maximum sound pressure from an audio device.

## OTHER TELEPHONY NETWORK REQUIREMENTS

It is the sole responsibility of each manufacturer to design the Bluetooth audio product so that it meets the regulatory requirements of all telephony networks that it may be connected to.

## AUDIO LEVELS FOR BLUETOOTH

Audio levels shall be calculated as Send Loudness Rating, SLR, and Receive Loudness Rating, RLR. The calculation methods are specified in ITU-T Recommendation P.79.

The physical test set-up for Handsets and Headsets is described in ITU-T Recommendation P.51 and P.57

The physical test set-up for speakerphones and "Vehicle handsfree systems" is specified in ITU-T Recommendation P.34.

A general equation for computation of loudness rating (LR) for telephone sets is given by ITU-T recommendations P.79 and is given by

$$LR = -\frac{10}{m}\log_{10}\left(\sum_{i=N_1}^{N_2} 10^{m(s_i - w_i)/10}\right), \qquad \text{(EQ 19)}$$

where

$m$ is a constant (~ 0.2).

$w_i$ = weighting coefficient (different for the various LRs).

$S_i$ = the sensitivity at frequency $F_i$, of the electro-acoustic path

$N_1$,$N_2$, consecutive filter bank numbers (Art. Index: 200-4000 Hz)

(EQ 19) on page 204 is used for calculating the (SLR) according to Figure 12.1 on page 205, and (RLR) according to Figure 12.2 on page 205. When calculating LRs one must only include those parts of the frequency band where an actual signal transmission can occur in order to ensure that the additive property of LRs is retained. Therefore ITU-T P.79 uses only the frequency band 200-4000 Hz in LR computations.

## MICROPHONE PATH

### SLR measurement model

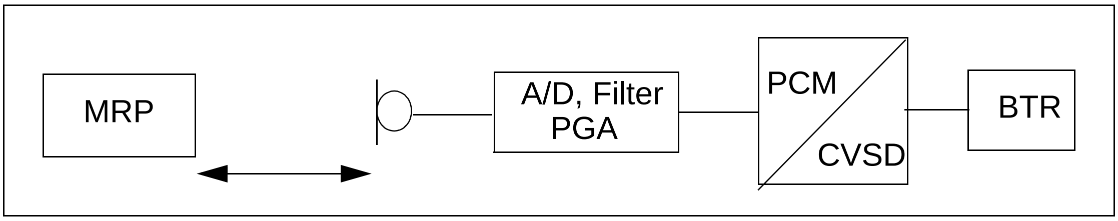


*Figure 12.1: SLR measurement set-up.*

## LOUDSPEAKER PATH

### RLR measurement model

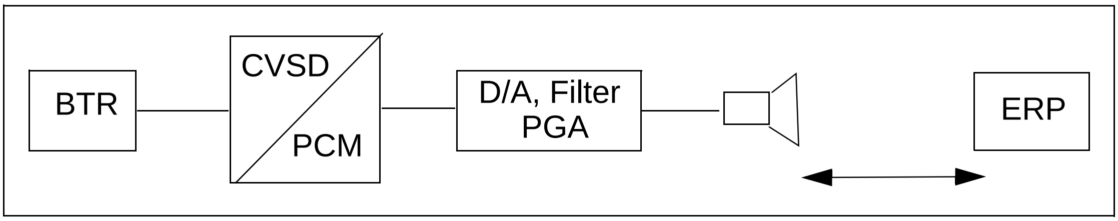


*Figure 12.2: RLR measurement set-up.*

## BLUETOOTH VOICE INTERFACE

The specification for the Bluetooth voice interface should follow in the first place the *ITU-T Recommendations P.79*, which specifies the loudness ratings for telephone sets. These recommendations give general guidelines and specific algorithms used for calculating the loudness ratings of the audio signal with respect to Ear Reference Point (ERP).

For Bluetooth voice interface to the different cellular system terminals, loudness and frequency recommendations based on the cellular standards should be used. For example, GSM 03.50 gives recommendation for both the loudness ratings and frequency mask for a GSM terminal interconnection with Bluetooth.

1- The output of the CVSD decoder are 16-bit linear PCM digital samples, at a sampling frequency of 8 ksample/second. Bluetooth also supports 8-bit log PCM samples of A-law and μ-law type. The sound pressure at the ear reference point for a given 16-bit CVSD sample, should follow the sound pressure level given in the cellular standard specification.

2- A maximum sound pressure which can be represented by a 16-bit linear PCM sample at the output of the CVSD decoder should be specified according to the loudness rating, in ITU P.79 and at PGA value of 0 dB. Programmable Gain Amplifiers (PGAs) are used to control the audio level at the terminals by the user. For conversion between various PCM representations: A-law, μ-law and linear PCM, ITU-T G.711, G.712, G.714 give guidelines and PCM value relationships. Zero-code suppression based on ITU-T G.711 is also recommended to avoid network mismatches.

## FREQUENCY MASK

For interfacing a Bluetooth terminal to a digital cellular mobile terminal, a compliance of the CVSD decoder signal to the frequency mask given in the cellular standard, is recommended to guarantee correct function of the speech coders. A recommendation for a frequency mask is given in the Table 12.1 below. The Figure 12.3 below shows a plot of the frequency mask for Bluetooth (solid line). The GSM frequency mask (dotted line) is shown in Figure 12.3 for comparison.

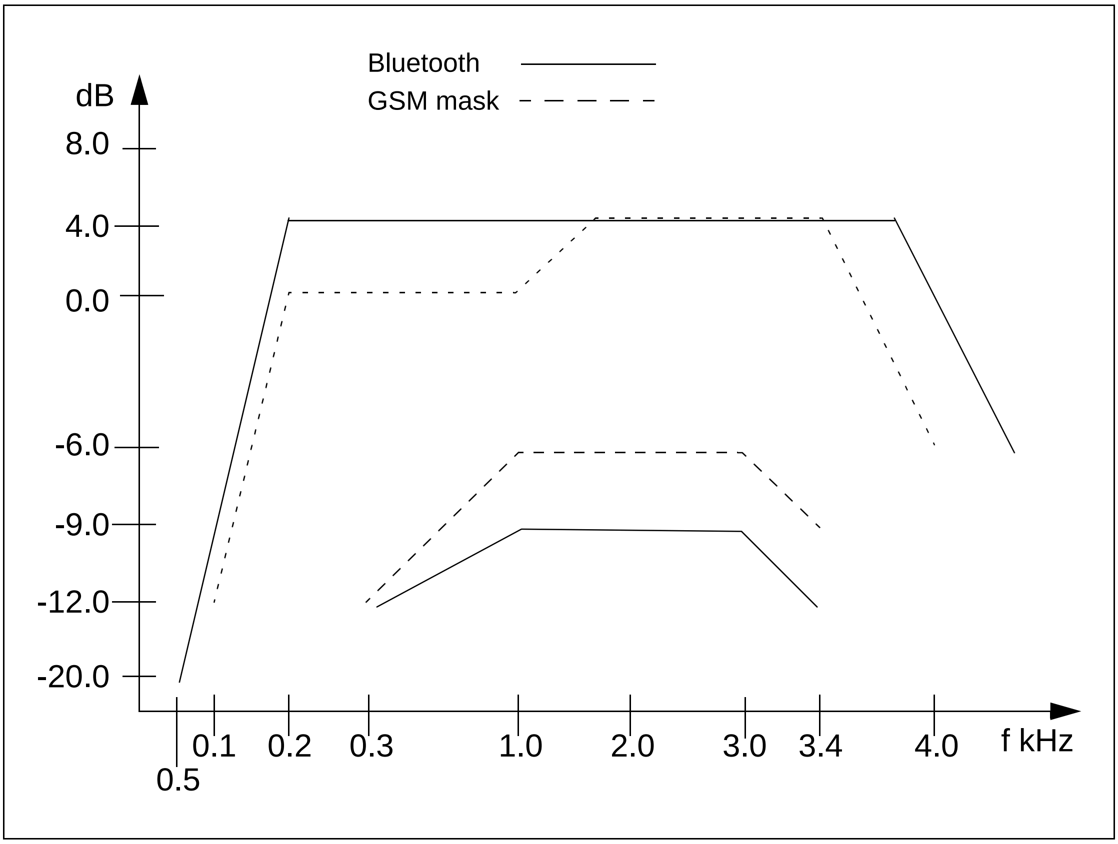


*Figure 12.3: Plot of recommended frequency mask for Bluetooth. The GSM send frequency mask is given for comparison (dotted line)*

| Frequency (Hz) | Upper Limit (dB) | Lower Limit (dB) |
|---|---|---|
| 50 | -20 | - |
| 300 | 4 | -12 |
| 1000 | 4 | -9 |
| 2000 | 4 | -9 |
| 3000 | 4 | --9 |
| 3400 | 4 | -12 |
| 4000 | 0 | - |

*Table 12.1: Recommended Frequency Mask for Bluetooth*

# APPENDIX B: TIMERS

This appendix contains a list of Baseband timers related to inactivity timeout defined in this specification. Definitions and default values of the timers are listed below

All timer values are given in slots.

## LIST OF TIMERS

### inquiryTO

The *inquiryTO* defines the number of slots the **inquiry** substate will last. The timer value may be changed by the host. HCI provides a a command to change the timer value.

### pageTO

The *pageTO* defines the number of slots the **page** substate can last before a response is received. The timer value may be changed by the host. HCI provides a a command to change the timer value.

### pagerespTO

In the slave, it defines the number of slots the slave awaits the master's response, FHS packet, after sending the page acknowledgment ID packet. In the master, *pagerespTO* defines the number of slots the master should wait for the FHS packet acknowledgment before returning to **page** substate. Both master and slave units should use the same value for this timeout, to ensure common page/scan intervals after reaching *pagerespTO*.

The *pagerespTO*value is 8 slots.

### newconnectionTO

Every time a new connection is started through paging, scanning, role switch or unparking, the master sends a POLL packet as the first packet in the new connection. Transmission and acknowledgment of this POLL packet is used to confirm the new connection. If the POLL packet is not received by the slave or the response packet is not received by the master for *newconnectionTO* number of slots, both the master and the slave will return to the previous substate.

*newconnectionTO* value is 32 slots.

### supervisionTO

The *supervisionTO* is used by both the master and slave to monitor link loss. If a device does not receive any packets that pass the HEC check and have the proper LT_ADDR for a period of *supervisionTO*, it will reset the link. The supervision timer keeps running in hold mode, sniff mode and park state.

The *supervisionTO* value may be changed by the host. HCI provides a a command to change the timer value. At the baseband level a default value that is equivalent to 20 seconds will be used.

# APPENDIX C: RECOMMENDATIONS FOR AFH OPERATION IN PARK, HOLD AND SNIFF

The three possible AFH operation modes for an AFH capable slave in park, hold and sniff are the same three AFH operation modes used during **CONNECTION** state:

- *Enabled* (using the same AHS as slaves in the **CONNECTION** state)
- *Enabled* (using AHS(79))
- *Disabled*

The master may place an AFH capable slave in any of the three AFH operating modes.

## Operation at the Master

A master that has one or more slaves in park, hold or sniff and decides to update them simultaneously shall schedule an *AFH_Instant* for a time that allows it to update all these slaves (as well as its active slaves) with the new adaptation.

A master that has multiple slaves with non-overlapping “wake” times (e.g. slaves in sniff mode with different timing parameters) may keep them *enabled* on the same adaptation provided that its scheduling of the *AFH_Instant* allows enough time to update them all.

This timing is summarized in the figure below. In this example the master decides that a hop sequence adaptation is required. However it cannot schedule an *AFH_Instant* until it has informed its active slave, its slave in hold, its slave in sniff, and had time to un-park its parked slaves.

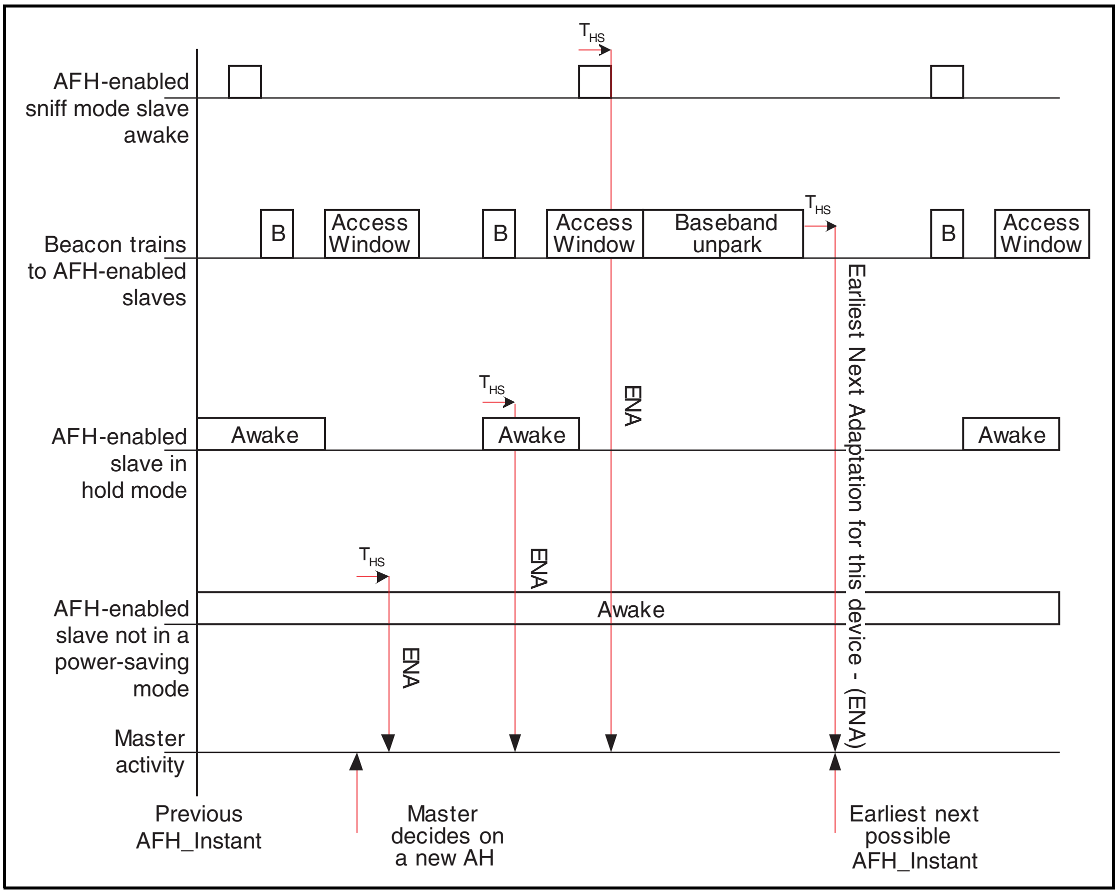


*Figure 12.4: Timing constraint on AFH_Instant with slaves in park, hold and sniff*

## Operation in park

A slave that is in the Park state cannot send or receive any AFH LMP messages. Once the slave has left the Park state the master may subsequently update the slave's adaptation.

## AFH Operation in Sniff

Once a slave has been placed in sniff mode, the master may periodically change its AHS without taking the slave out of sniff mode.

## AFH Operation in Hold

A slave that is in hold mode cannot send or receive any LMP messages. Once the slave has left hold mode the master may subsequently update the slave's adaptation.

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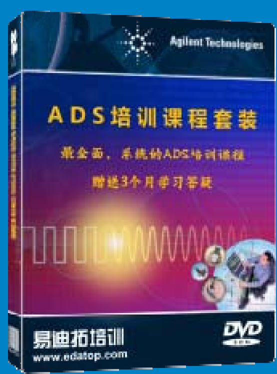



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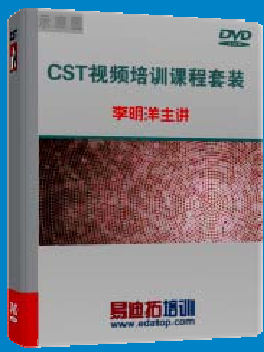


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