Project: IEEE P802.15 WG for Wireless Personal Area Networks (WPANs)

Submission Title: [Frequency Hopping Mechanisms to Support 4g PHYs]
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Abstract: [Overview of reasons why frequency hopping additions are required and a summary of the proposed additions]
Purpose: [Provide an explanation of why frequency hopping additions are required and present an overview of the frequency hopping resolutions proposed in document 15-10-0258. Resolve frequency hopping related comments in the TG4g and TG4e letter ballots]

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Overview

- Considerations required to support PHYs that require frequency hopping
  - Review existing MAC interfaces to support network discovery, network formation, and network joining
  - Consider if these interfaces work with a PHY mode that requires frequency hopping
- Present an overview of the additions proposed to address the frequency hopping deficiencies
  - New MAC PIB attributes
  - New MLME and MAC commands to allow devices to "find" a device and exchange frequency hopping information

802.15.4 Mechanisms to Support Forming, Finding and Joining a Network

- The following MLME primitives result in the transmission of a MAC command frame:

MLME Primitive	Description	Transmitted MAC Command Frame	Mandatory/Optional
MLME-ASSOCIATE	Allows a device to attempt to request an association with (i.e. join) a coordinator	Association Request	Mandatory
MLME-SCAN			
Energy Detect	Used to detect energy on a list of specific channels (one channel at a time)	n/a	Mandatory for FFD; Optional for RFD
Active Scan	Device transmits Beacon Request Commands on a list of specific channels and waits for beacon (one channel at a time)	Beacon Request(s)	Mandatory for FFD; Optional for RFD
Passive Scan	Device listens for beacons on a list of specific channels (one channel at a time)	n/a	Mandatory
Orphan Scan	Device transmits Orphan Notification Commands on each listed channel (one channel at a time) until a Coordinator Realignment Command is received or all channels are attempted	Orphan Notification Command(s)	Mandatory

802.15.4 Mechanisms to Support Forming, Finding and Joining a Network

- Do these mechanisms work with a Frequency Hopping PHY?

MLME Primitive	Description	Transmitted MAC Command Frame	Mandatory/Optional	Works with FH PHY
MLME-SCAN				
Energy Detect	Used to detect energy on a list of specific channels (one channel at a time)	n/a	Mandatory for FFD; Optional for RFD	**NOT WELL** - Energy detect on a given channel may not accurately determine the presence of a frequency hopping PHY mode.
Active Scan	Device transmits Beacon Request Commands on a list of specific channels and waits for beacon (one channel at a time)	Beacon Request(s)	Mandatory for FFD; Optional for RFD	**NOT WELL** - Without knowing time and channel information to syncrhonize to target devices, the attempt is Device cannot transmit the command if it doesn't know FH parameters.
Passive Scan	Device listens for beacons on a list of specific channels (one channel at a time)	n/a	Mandatory	**NOT WELL** - Device cannot reliably receive a beacon if the FH parameters are not known unless it waits a considerable time or if beacons are transmitted very frequency on every channel in the hopping sequence.
Orphan Scan	Device transmits Orphan Notification Commands on each listed channel (one channel at a time) until a Coordinator Realignment Command is received or all channels are attempted	Orphan Notification Command(s)	Mandatory	**NO** - If the device is unsynchronized, it is not likely to be synchronized to the FH parameters necessary to transmit the message.
MLME-ASSOCIATE	Allows a device to attempt to request an association with (i.e. join) a coordinator	Association Request	Mandatory	**NO** - Device cannot transmit the command if it doesn't know FH parameters.

802.15.4 vs 802.15.4g PHY modes

- 802.15.4 prior to the 4g amendment allows two devices to exchange PPDUs ***only*** using PHY and MAC mechanisms (i.e. higher layer mechanisms are not required to exchange PPDUs)
- Without additional mechanisms added to 4e and/or 4g, 802.15.4g devices using PHY modes that require frequency hopping cannot synchronize and exchange PPDUs without higher layer coordination
- **Requirement** – Two devices shall be able to exchange PPDUs without requiring additional mechanisms defined only by higher layers
  - 802.15.4 prior to 4g amendment - YES
  - 802.15.4 with the 4g amendment - NO

Comment Resolution

- Document #0258 revision 2 proposes resolutions to the following comments:

  TG4g: 1637, 1799, 1804, 1805, 1806, 1808, 1814, 1815, 1816

  TG4e: 12, 13, 313, 314, 959, 960, 1009, 1010, 1028, 1029, 1041, 1042, 1172, 1173, 1198, 1340, 1341, 1474

- These change are summarized in this presentation

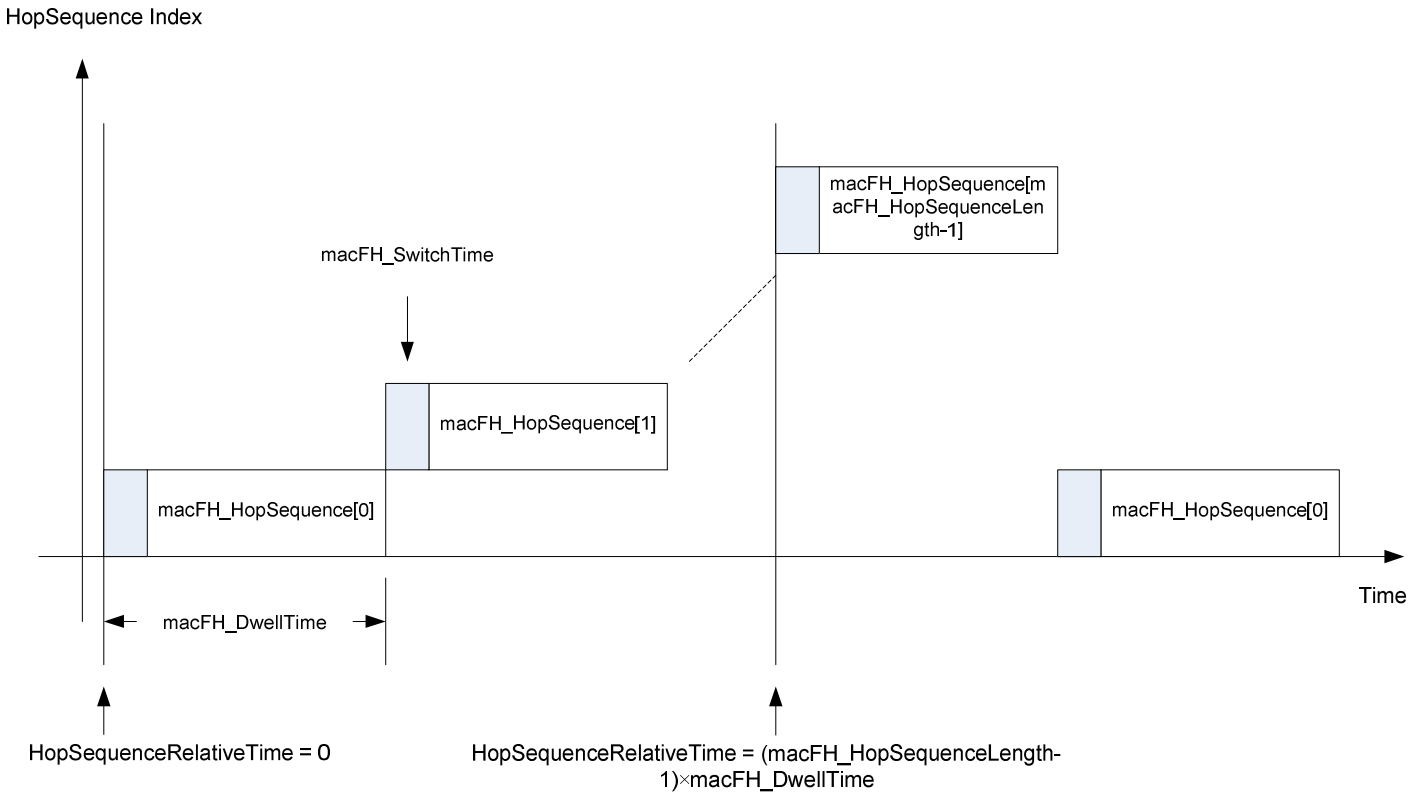
MAC PIB Attributes (1)

Attribute	Identifier	Type	Range	Description	Default
macSunFrequencyHopping	(increment the last value)	Boolean	TRUE or FALSE	TRUE if the device is operating in a frequency hopping mode and the macFH_ PIB attributes define the behavior FALSE if the system is not operating in a frequency hopping mode controlled by the macFH_ PIB attributes.	-
macFH_HopSequenceID	(increment the last value)	Integer	0x00 – 0xFFFF	An identifier used to assist in identifying the hopping sequence.	-
macFH_HopSequenceLength	(increment the last value)	Integer	2 – 511	Number of channels in the hop sequence.	-
macFH_HopSequence	(increment the last value)	Array	A 2 x {2-511} octet array (2 octet channel number, with an array size controlled by macFH_HopSequenceLength) .	This is the ordered sequence of channels that define the hopping sequence.	-

MAC PIB Attributes (2)

Attribute	Identifier	Type	Range	Description	Default
macFH_DwellTime	(increment the last value)	Integer	10 µsec – 655.35 msec	The total dwell time on each channel. A 16-bit field with a resolution of 10 µsec.	
macFH_SwitchTime	(increment the last value)	Integer	1 µsec – 1 msec	The time allocated for the PHY to change to a new frequency. When macSunFrequencyHopping = TRUE, the MAC shall change the PHY channel such that the PHY is stable at the start of the next channel in the hopping sequence. Note - The dwell time includes the hop time, therefore macFH_DwellTime must be greater than macFH_SwitchTime. macFH_SwitchTime is a 16-bit field with a resolution of 1 µsec.	

Hop Sequence Attributes



New MLME Primitives to Support FH

MLME-ACQUIRE-FH-INFO.request

7.1.x.1.2 Appropriate usage

The MLME-ACQUIRE-FH-INFO.request primitive is generated by the next higher layer and issued to its MLME **to initiate acquisition of frequency hopping information** within the POS of the querying device.

MLME-ACQUIRE-FH-INFO.request	(ChannelListSize, ChannelList, NumAttemptsPerChannel, TransmitInterval, TransmitRandomization, ResponseTime, ChannelListIterations, StopAfterFirstResponse)

MLME-ACQUIRE-FH-INFO.request (1)

Name	Type	Valid Range	Description
ChannelListSize	Integer	0x01–0x80	The number of elements in the channel list.
ChannelList	List of integers	—	The list of channels over which to acquire frequency hopping information. Note – ChannelList can be all of the available channels in the operating frequency band, the channels of a particular hop sequence in use by the targeted device/network, or a subset of either of these.
NumAttemptsPerChannel	Integer	0x0001–0xffff	The number of times to send frequency hopping acquisition request commands on each channel in ChannelList.
TransmitInterval	Integer	0x0001–0xffff	The time between frequency hopping acquisition request commands. Resolution is 1 ms.

MLME-ACQUIRE-FH-INFO.request (2)

Name	Type	Valid Range	Description
TransmitRandomization	Integer	0x00–0xff	Maximum random value that can be added to the TransmitInterval between two frequency hopping acquisition request commands. Resolution is 1 ms.
ResponseTime	Integer	0x0000–0xffff	The length of time to listen for frequency hopping acquisition response commands after sending a request. ResponseTime shall be less than TransmitInterval. A value of zero for ResponseTime indicates “listen until the next transmit interval.” Resolution is 1 ms.
ChannelListIterations	Integer	0x00-0xff	The number of times to iterate through ChannelList
StopAfterFirstResponse	Boolean	TRUE or FALSE	Indication of whether the frequency hopping information acquisition process should terminate after the first response has been received or if it should complete every attempt on every channel in the ChannelList.

MLME-ACQUIRE-FH-INFO.confirm

MLME-ACQUIRE-FH-INFO.confirm (
status,
ResultListSize,
FHDescriptorList
)

Name	Type	Valid Range	Description
Status	Enumeration	SUCCESS, LIMIT_REACHED, ACQUISITION_IN_PROGRESS, INVALID_PARAMETER	The status of the acquisition request.
ResultListSize	Integer	Implementation specific	The number of elements returned in the frequency hopping descriptor list.
FHDescriptorList	List of frequency hopping descriptor values	See Table T+1	The list of frequency hopping descriptors, one for each frequency hopping acquisition response command received during the acquisition process.

MLME-ACQUIRE-FH-INFO.request

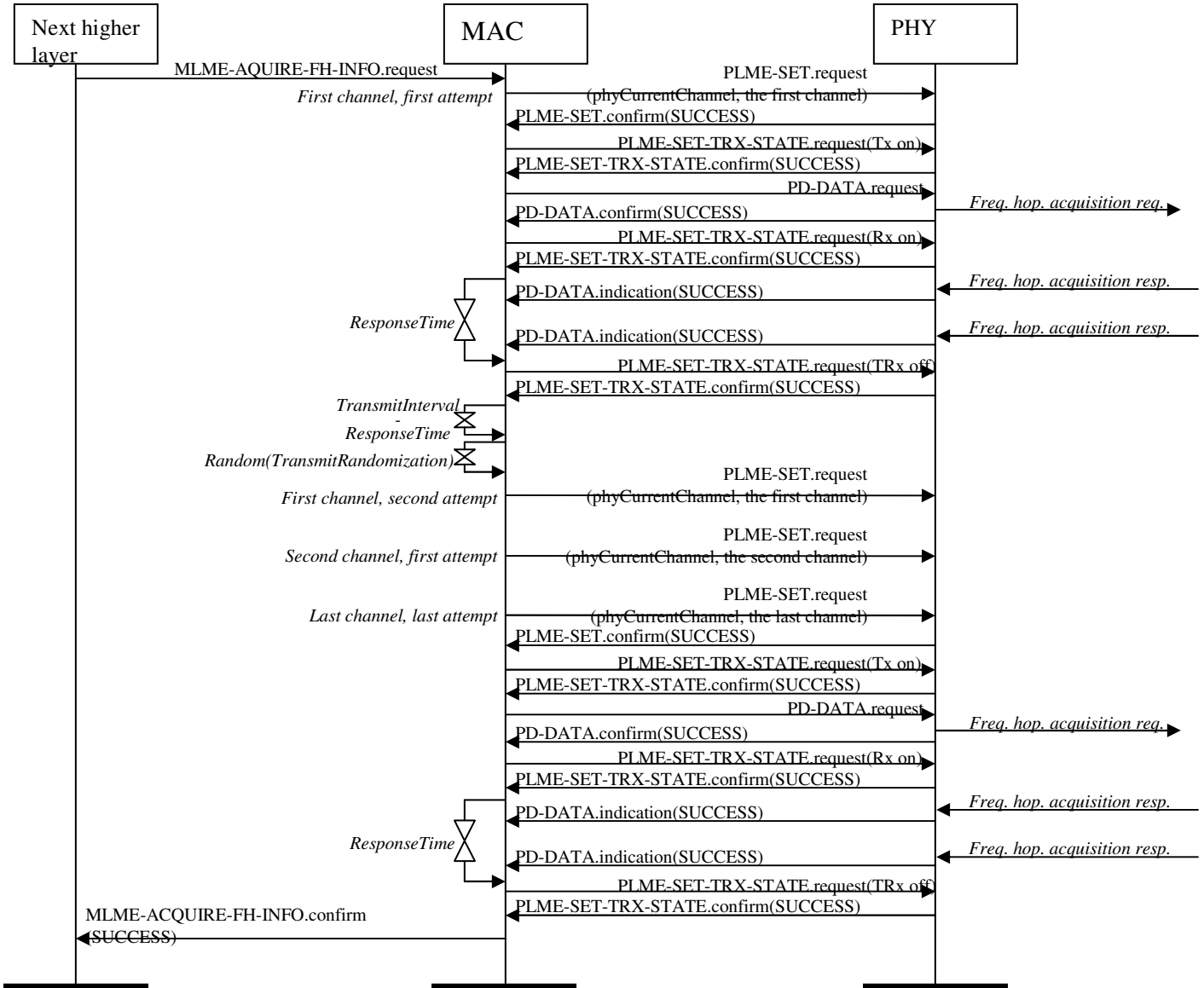
7.1.x.1.3 Effect on receipt

The MLME initiates acquisition across all channels specified in the ChannelList parameter.

The frequency hopping information acquisition is performed on each channel by the MLME first **sending a frequency hopping acquisition request command** (see 7.3.x). The MLME then enables the receiver for a duration given by the ResponseTime parameter. Information contained in frequency hopping acquisition response commands (see 7.3.y) during this period are recorded in a **frequency hopping descriptor structure** (see Table T+1 in 7.1.x.1.1).

The MLME will repeat this process on a channel NumAttemptsPerChannel times. The *n*th network information request command for a particular channel will be sent at the time ((*n* – 1) * TransmitInterval), plus a random value between 0 and TransmitRandomization, after the first information request command for the channel. Unless terminated as described in the following sections, the process repeats for ChannelListIterations.

Frequency hopping information acquisition sequence chart (refer to doc #258)



FH Descriptor Entries

Using information from the frequency hopping acquisition response command the MAC sublayer stores and maintains a list of FH Descriptors. The list of FH Descriptors are returned in the MLME-ACQUIRE-FH-INFO.confirm primitive. Each FH Descriptor contains the following parameters:

Name	Type	Valid Range	Description
PANId	Integer	0x0000–0xffff	The PAN ID of the device that sent the frequency hopping acquisition response command.
HopSequenceId	Integer	0x0000–0xffff	An implementation-specific value provided by the responding device to identify its hopping sequence.
HopSequenceLength	Integer	2–511	The number of elements in the hopping sequence.
HopSequence	List of integers	—	The repeating channel sequence the responding device uses for frequency hopping.
RelativeTime	**Integer**	**0x00000000–0xffffffff**	**Time measurement of how far the responding device is into its present hopping cycle. The MAC sublayer maintains the relative time from the start of the hop sequence (rolling around to a relative time of zero at the end of the hopping sequence and re-starting the relative timer). The MAC sublayer maintains this relative timer (see Section 7.1.x.1.3). Resolution is 1 μs.**
DwellTime	Integer	0x0001–0xffff	The length of time that any one HopSequence element is active (time spent listening on the channel *plus* time spent switching to the next channel in the sequence). Resolution is 10 μs.

Maintenance of FH Descriptors

7.1.x.1.3 Effect on receipt

:

:

The MAC sublayer maintains all entries in the frequency hopping descriptor list until a MLME-SET-SUN-FH-RELATIVE-TIME.request, a MLME-RESET.request or a MLME-ACQUIRE-FH-INFO.request primitive is received. **Maintenance of the frequency hopping descriptor list includes updating RelativeTime using HopSequenceLength, DwellTime, and the Hop Sequence Relative Time received in the Frequency hopping acquisition response**.

Selecting a FH Descriptor and Setting the Relative Time

The NHL selects one of the FH Descriptor entries

- Sets macFH_* PIB attributes
  - macFH_HopSequenceID
  - macFH_HopSequenceLength
  - macFH_HopSequence
  - macFH_DwellTime
- Selects or sets the FH relative time using MLME-SET-SUN-FH-RELATIVE-TIME.request

Table T+4 - SET-SUN-FH-RELATIVE-TIME.request parameters

Name	Type	Valid Range	Description
UseFHDescriptor	Boolean	TRUE or FALSE	If this value is TRUE, the device will set the SUN frequency hopping relative time to the value maintained by the MAC sublayer for the FHDescriptor identified by FHDescriptorIndex. If this value is FALSE, the device will set the SUN frequency hopping relative time to the value specified by RelativeTime.
FHDescriptorIndex	Integer	—	The index in the FHDescriptor array of the FHDescriptor-RelativeTime value to be used to set the SUN frequency hopping time
RelativeTime	Integer	0x00000000–0xffffffff	Relative time from the start of macFH_HopSequence. Resolution is 1 μs.

Annex N - Example of SUN Freq Hopping & Device Synchronization

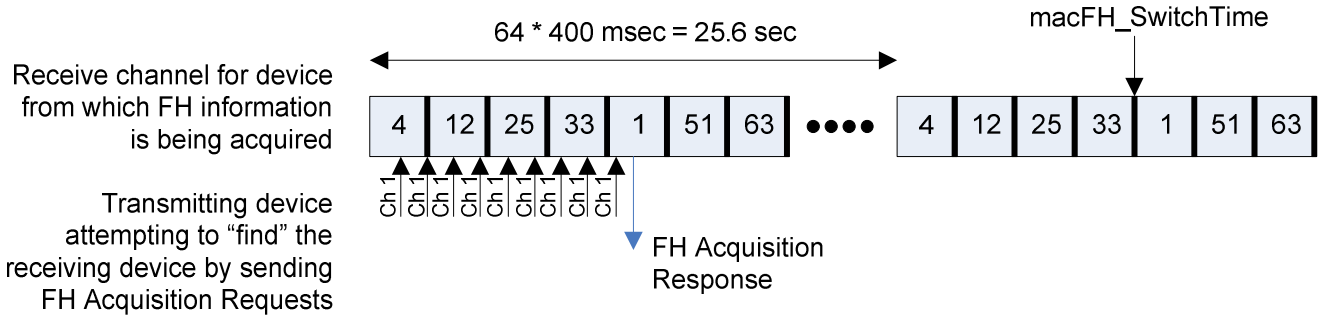
N.2 Example Synchronization Time Calculations

Assume the MAC PIB attributes for the network or device to which the device is attempting to synchronize are:

- *macFH_HopSequenceLength* = 64
- macFH_HopSequence = 4, 12, 25, 33, 1, 51, 63, …… (typically a pseudo-random sequence)
- *macFH_DwellTime* = 400 msec

Assume the following values are used for the MLME-ACQUIRE-FH-INFO primitive parameters:

- ChannelListSize = 32
- ChannelList = 1, 2, 3, 4, …… 32
- NumAttemptsPerChannel = 2 * *macFH_HopSequenceLength* + 1 = 129
- TransmitInterval = 199 msec
- TransmitRandomization = 0
- ResponseTime = 0 (listen until next transmit interval)
- ChannelListIterations = 0
- StopAfterFirstResponse = TRUE



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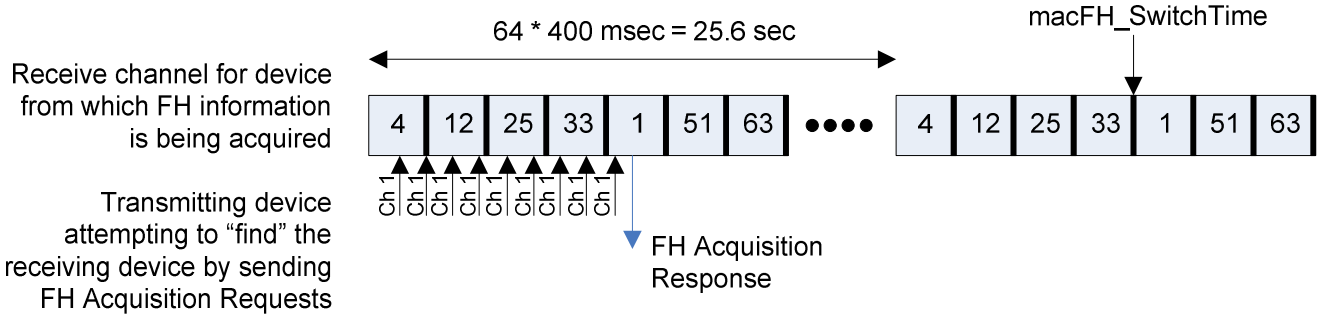

Estimation of time required to gain synchronization

Assuming there is not a packet error, the FH Acquisition Response would be received within a period of time equal to NumAttemptsPerChannel * TransmitInterval. For this example, this equates to: 129 * 199 msec = 25.7 seconds

Note that the actual time would often be less than this time because the alignment of the transmit channel (e.g. channel 1) and the receiver dwelling on channel 1, is likely to occur before this maximum time (as shown in the above figure).

The maximum response time would typically be controlled by the values of *macFH_HopSequenceLength* and *macFH_DwellTime*, and the time to receive a FH Acquisition Response would be reduced if these parameters were shorter in length.