**Question #9**

**1.**

## Adaptive Frequency Hopping

The purpose of using frequency hopping in a radio system is to provide diversity that allows data throughput to be maintained even if interfering radio systems or the physical environment (e.g. multipath fading) render some RF channels unusable. In the 2.4 GHz ISM band, the sheer amount of radio systems and the severity and dynamic nature of indoor fading phenomena in typical operating environments require the use of this kind of diversity if a minimum data throughput is to be assured (as audio streaming requires).

Frequency hopping systems can either implement a fixed sequence of channel hops or adapt its hopping sequence dynamically to the changing environment it operates in. In order to maximize its own chances of delivering audio data in time and to co-exist amicably with other fixed-frequency or adaptive frequency hopping systems, PurePath Wireless uses an adaptive frequency hopping (AFH) scheme that adapts to changing conditions within tens of milliseconds.

PurePath Wireless divides the 2.4 GHz band into 18 RF channels with 4 MHz bandwidth. The protocol master controls the adaptive frequency hopping scheme for the audio network, and maintains a table with an entry for each RF channel and an associated quality-of-service (QoS) estimate for each. Each time an RF channel is used the QoS estimate is updated based on what happens during the timeslot.

The frequency hopping algorithm separates the 18 RF channels into two sets:

- A set of 4 *active channels*
- A set of 14 *trial channels*

The active channel set contains the preferred RF channels that have proven that they provide sufficiently good quality-of-service. The trial channel set contains the remaining RF channels that are only evaluated occasionally in order to be able to maintain an accurate picture of their quality-of-service. If the QoS estimate of an RF channel in the active set goes beyond a minimum threshold this channel is swapped out with the RF channel in the trial channel set that has the best QoS estimate. Other factors play in when selecting a new RF channel to the active channel set, such as trying to maintain a certain minimum distance in frequency between the different active channels.

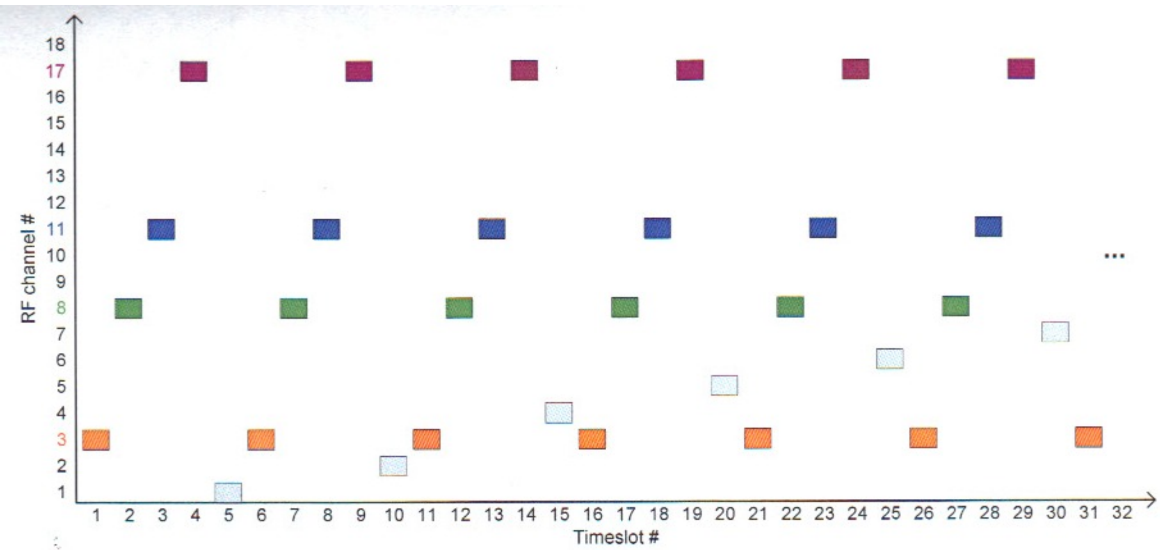


**Figure 36 – Example of AFH hop sequence (active set in color, trial set in black/gray)**

The frequency hopping algorithm, when using all 18 channels and no swaps between the active and trial channel sets occur, goes through a sequence of 70 hops over the course of which every RF channel has been used.

This 70-hop *macrosequence* consists of 14 repetitions of a

- o 5-hop *microsequence* during which
  - Each of the four active RF channels are used once
  - One of the trial RF channels is used once
    (cycling through all trial channels over the course of a macrosequence)

Figure 36 illustrates this concept. This gives an average steady-state RF channel usage of:

- Each of the four active channels are used 20% of the time
- Each trial channel is used 1.43% of the time

**2. and 3.**

## Anatomy of a Timeslot

PurePath Wireless divides time into so-called timeslots, during which all nodes in the audio network operate on the same RF channel and each node transmits one packet. The duration of a timeslot is nominally 2.5 ms, but this parameter depends on the protocol master's configuration.

To achieve robustness against interferers and frequency-selective fading, each successive timeslot is transmitted at a different RF channel following a deterministic sequence. See section 2.4.3 for further details.

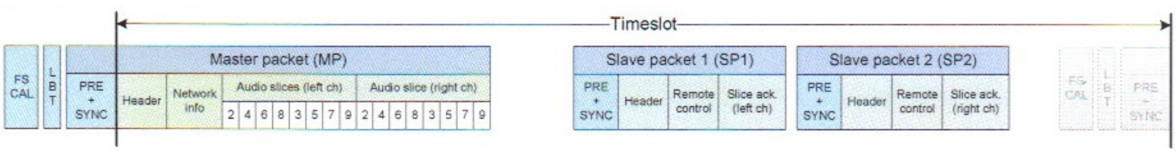


**Figure 35 - Anatomy of a timeslot with two protocol slaves, network full (not drawn to scale)**

The start of a timeslot is defined as the point in time when the protocol master has just transmitted its packet synchronization sequence. The protocol master dictates the timing within each timeslot and informs the protocol slaves if and when they may transmit and when the next timeslot will start. The sequence of events during a timeslot is illustrated in Figure 35 and summarized below for a three-node audio network:

- **Frequency synthesizer calibration** is performed just prior to the start of the timeslot
- The protocol master performs an **energy measurement** in the RF channel to see whether it is already in use
- If the energy is below a threshold, the **protocol master transmits its packet**. This marks the start of the timeslot. The protocol master packet contains:
  - o Information about the audio network
  - o Data side-channel datagram to a single protocol slave, if any
  - o Audio slice acknowledgments for each audio channel the protocol master consumes
  - o Audio slices for each active audio channel that the protocol master produces
- Following the protocol master packet is the **slave join packet slot**. This is reserved for protocol slaves that wish to join the audio network. If the audio network has the maximum number of supported protocol slaves, this slot is removed.
- Then each of the **protocol slaves transmits their packets** at the time offset in the timeslot announced by the protocol master in its packet. Each protocol slave packet contains:
  - o Remote control information
  - o Data side-channel datagram to the protocol master, if any
  - o Audio slice acknowledgments for each audio channel the protocol slave consumes
  - o Audio slices for each active audio channel that the protocol slave produces.