**IEEE P802.19**

**Wireless Coexistence**

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| Title | **Contribution for 9.1.1 Frequency Hopping** | |
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| Re: | [Draft Development] | |
| Abstract | Contains background and recommendations for Frequency Hopping use of 802.15.4 SUN FSK (15.4g) | |
| Purpose | [] | |
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# IEEE 802.11ah and IEEE 802.15.4g coexistence recommendations

## Distributed coexistence

### Frequency hopping

#### Overview

Frequency hopping is a coexistence method in which all devices perform channel hopping according to hopping sequences. Hopping refers to varying frequency over time. The primary goal of the frequency hopping is to improve reliability by mitigating interference impact and adapting to environment. Frequency hopping is a popular technique to improve reliability of wireless systems in licensed exempt spectrum, especially for narrow band systems where a large number of channels can be available. Hopping is commonly used with the 802.15.4 SUN FSK, and do to the narrow channels is required in some regions to meet regulatory requirements, as described in [Clause 6].

Document 19-19-0083-00-0003 provides some background frequency hopping commonly used with the 802.15.4g FSK PHY. It shows the benefits that can be achieved with the use of channel diversity in high density environments. The primary goal of spreading transmissions across a set of channels is to enhance reliability by reducing the probability of collisions and reducing the impacts of frequency selective impairments. The primary gain from channel diversity is reducing the effective duty cycle per channel and reducing aggregate occupation of a given channel. This also provides coexistence benefits for non-participating systems by reducing the effective interference footprint of the hopping systems. For the hopping system, when a dissimilar system occupies part of the band, hopping “around” can mitigate the impact of interfering systems.

The value increases with the number of available channels. The available number of channels may be limited in some regions in the Sub-1 GHz bands. It depends on the probability that not all available channels are blocked all the time, which of course increases with the number of channels. In some regions the available spectrum may not allow significant diversity and thus may not improve coexistence in the presence of 802.11ah devices.

Some methods of frequency hopping can add significant latency depending on implementation choices. It may be necessary to defer a transmission opportunity until the next hop, and typically retransmissions following failed attempts should be attempted on a different channel than the initial attempt, which can add to the latency of each retransmission attempt.

Specific methods are discussed in this sub-clause. This clause deals with methods that switch among a defined channel set, termed Channel Hopping and also sometimes referred to as Channel Diversity.

#### Control Methods

Some characteristics of popular hopping schemes are provided in this sub-clause.

Two commonly used control methods are listener directed and transmitter directed scheduling. In listener directed, each participating devices determines ises a channel sequence and schedule it will follow for reception. This information is shared with devices that will communicate with the device. The sender is responsible for determining the correct channel at a given time to send to the targeted device. This is typically used for unicast exchanges. In transmitter directed scheduling, the sending device determines a schedule for transmission and makes this known to peer devices; each device that intends to receive transmission is responsible for listening on the right channel at a given time. This is typically used for broadcast exchanges.

The time which is spent on a particular channel is termed dwell duration. When the dwell duration is less than the duration of a PHY protocol data unit (PPDU) this is termed fast hopping. When the dwell duration is equal to or greater than the duration of a PPDU, this is termed slow hopping.

802.15.4w is an example of fast hopping: the PPDU is dived into multiple fragments each sent on a different channel at a different time. In this example, forward error correction with interleaving is used so that the redundant coded information is transmitted on different channels. In this case frequency diversity is inherent in the PHY.

Application of hopping over 802.15.4 SUN FSK uses slow hopping, where one or more PPDUs are transmitted on a channel. With fixed dwell duration, the channel switch always occurs at the end of the dwell duration; If transmission cannot complete by end of dwell interval, the transmitter will wait for next dwell interval. This approach provides predictable timing. Dynamic dwell duration is commonly used also. In this approach a nominal dwell duration is known, but the time on the channel may be extended to complete a packet, packet and acknowledgment, or multiple packet exchange. Timing in this case is less predictable.

Some systems (e.g. TSCH) use a centralized or zone-wise control method, in which global synchronization is required and a global schedule is available. Once a device acquires the global time, it can join a schedule.

#### Hopping Sequence Selection

In effect, distributing transmission attempts dynamically over multiple channels improves the ‘luckiness” by reducing effective duty cycle per channel and thus collision probability. To achieve this it is important that the method for generating sequences has a high probability that each participating device is using a unique pseudo-random channel sequence.

“Hopping” is a form of random channel access. Key to the effectiveness is a good approximation of Randomness. The method used to generate sequences should produce a large number of unique sequences with a low probability that two participating devices will select the same channel for transmission at the same time. The sequence generated should provide balanced distribution of transmission attempts across the available channels over a period of time.

Another quality of a good sequence generation scheme is that it avoids unintended synchronization. The method to generate device unique sequences should produces a large number of orthogonal sequences, i.e. sequences that have few overlaps as the phase of the sequence is rotated. This property is improved by having a sequence generator that produces sequences much longer than the number of available channels.

#### Hopping Sequence Adaptation

Another consideration is adaptation to actual channel conditions. Many impairments in the RF environment may be frequency selective. Most schemes will thus include the ability to not use channels determined to be poor. Adaptive frequency hopping should be used when the number of available channels in the band is sufficient to allow for a large enough channel set.

Implementation of adaptive hopping should include consideration of the following:

* Evaluation of channel conditions based on repeatable metrics. Common metrics include packet failure rates. Dynamic evaluation is highly desirable: many times the environment varies over time, and a previously ‘bad’ channel may improve.
* Hysteresis to avoid too rapid abandonment of a channel: infrequent failure is likely in interference limited environment and/or when operating at low link margin.

#### Channel Access

Access of an individual channel can use CSMA-CA, ALOHA, or hybrid techniques. Hopping lowers the effective duty cycle; With low effective duty cycle per channel, ALOHA may be most efficient (ALOHA threshold ~18% effective channel load).

When higher channel load CSMA-CA can improve performance. In some schemes, some channels may be more likely to exceed ALOHA threshold, such as when transmission channel is not random and/or when multiple nodes share transmission schedules for discovery, control and management functions. Implementation of broadcast is an example of when it is necessary for multiple transmitters to use the same channel at the same time. When multiple transmitters are expected to target the same channel/time schedule with sufficient frequency to raise the effective channel loading, CSMA-CA should be used.