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Wireless LANs

Effects of WBFH Power Reduction and Hop Rate

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Abstract

In a recent NPRM (ET Docket 99-231), the FCC proposed to amend the rules for Frequency Hopping Spread Spectrum (FHSS) radios operating in the 2.45 GHz ISM band. Proposed rule changes include reduced transmit power levels and faster hop rates for Wide Band Frequency Hopping (WBFH) radios operating on 3 MHz or 5 MHz wide channels. The impact of proposed power reductions is discussed. An analysis demonstrating that increasing the required minimum hop rate for WBFH radios actually increases interference to other users is presented.

1.0 Summary

Intersil opposes changes in the operating rules governing operation of FHSS radios in the 2.45 GHz band as proposed by the HomeRF Working Group in a November, 1998 petition for rule making. In that petition, HomeRF sought an increase in the FHSS occupied channel width. This increase would allow FHSS radios to operate with channel widths of 1, 3, or 5 MHz. Systems employing 3 MHz wide channels or 5 MHz wide channels are collectively referred to as Wide Band Frequency Hopping (WBFH) radios.

HomeRF asserted that the interference resulting from the wider channel widths could be offset by a combination of power reduction in proportion with the expansion in channel width, and an increase in the hop rate. The rules for the three variations of FHSS channel width are summarized in Table 1.0-1.

Channel Width	Max Power	Max Dwell Time	Minimum # Hops
1 MHz	30 dBm	400 msec	75
3 MHz	25 dBm	50 msec	75
5 MHz	23 dBm	20 msec	75

Table 1.0-1 Proposed FHSS Channel Parameters

In the subsequent NPRM (ET Docket 99-231), the Office of Engineering and Technology (OET) indicated that it was of the opinion that the proposed rule changes would not result in increased interference to Direct Sequence Spread Spectrum (DSSS) systems. However, OET specifically sought comment on whether the reduction in power and increase in hop rate as described above would, in fact, preclude any increase in interference to DSSS systems.

Due to the fact that nearly all portable FHSS and DSSS radios operating in accordance with Part 15, Section 247 of the Commission's Rules transmit at 20 dBm (100 mW) or less, the power reductions suggested by HomeRF appear to offer little or no protection to existing users of the 2.45 GHz ISM band. In addition, it is shown by simple analysis that increasing the hop rate as suggested by HomeRF will actually result in an increase in interference to existing DSSS and FHSS systems.

2.0 Power Reduction

The reduction in power as proposed by HomeRF is not adequate to ensure that existing users of the band, including both FHSS and DSSS radios, will not suffer adverse effects. The reason is simple. The reduced power levels shown in Table 1.0-1 are above the transmit power levels of nearly all portable devices on the market today. The vast majority of IEEE 802.11 WLAN devices transmit at 100 mw (+20 dBm) or less. Most Bluetooth devices will radiate at only 1 mW (0 dBm).

These systems use transmit power levels far below the limit permitted under Section 15.247 of the Commission's Rules in order to maximize battery life in portable computing devices. Technologies such as Bluetooth and IEEE 802.11 WLANs are intended to facilitate wireless mobile computing. Battery life is therefore a paramount consideration in these types of devices.

Based on HomeRF's presentation to the FCC on Feb. 25, 1999 [1] it is clear that the intended modulation scheme is 4FSK. Delivery of 10 Mbps data rates using this form of modulation in a 5 MHz wide channel will require a very low index of modulation index (h) of about 0.15. This is an extremely inefficient modulation technique as demonstrated by the Eb/No curves shown in Figure 2.0-1.

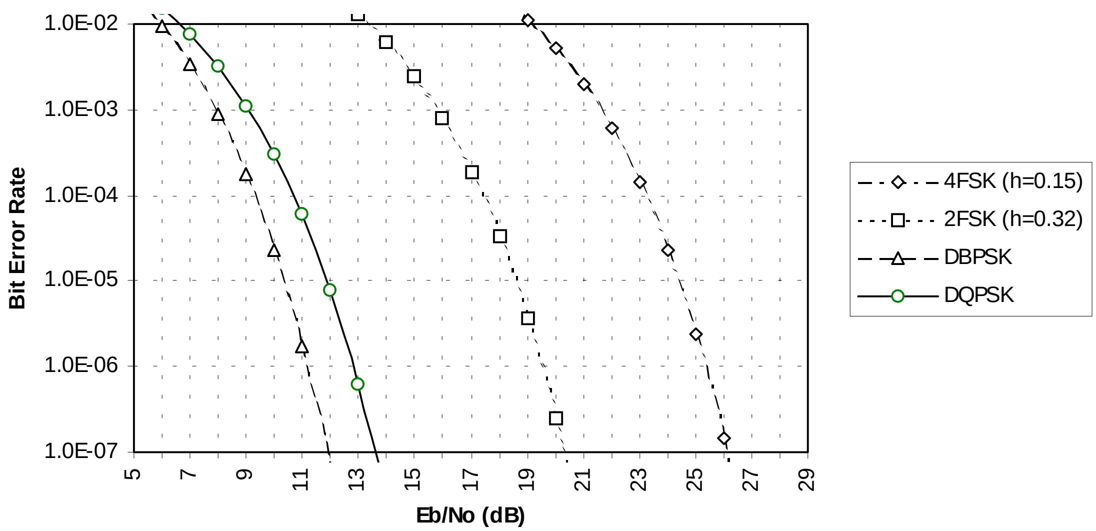

Figure 2.0-1 Eb/No vs. BER for FSK and PSK Waveforms

In addition, the 4FSK waveform is also highly susceptible to multipath. Due to the inefficiency of the 4 FSK waveform and susceptibility to multipath, WBFH radios will be required to operate at or near the maximum allowable transmit power (+23 dBm). Even at this power level, it is doubtful that a WBFH system as proposed by HomeRF could provide a Quality of Service (QoS) adequate to support the types of multimedia applications described in their letter to the Commission of November 11, 1998.

2.1 Previous Rulings

The power reductions proposed by HomeRF are linear in relation to the increase in channel width. In a previous ruling on a similar proposal by Symbol (FCC 96-36), the Commission commented on the potential interference to both authorized services and other Part 15 devices:

"While this increase in interference potential could be partially offset by a reduction in the output power of the frequency hopping transmitters, we are not convinced that a linear power reduction alone is sufficient to offset this interference potential."

The Symbol proposal differed from the HomeRF proposal in that it called for a decrease in the number of FHSS hopping channels in proportion to the increase in channel width. In this sense, the Symbol proposal was technically superior to the HomeRF proposal. The use of overlapping channels will actually increase the collision rate among WBFH systems, and in no way reduces interference to other Part 15 devices.

In a proceeding relating to the reduction of the number of channels in the 915 MHz band (FCC 97-147), the Commission granted the request to reduce the number of hopping channels to allow FHSS systems operating in that band to avoid interfering with other services. However, the Commission recognized that such a reduction hopping channels would result in an increase in collisions among FHSS systems in the 915 MHz band.

In order to offset the potential for increased interference, the Commission adopted rules which required systems using fewer hopping channels to reduce power *in proportion to the square of the reduction in the number of hopping channels.* This conclusion was based on comments submitted by TIA Wireless[2]. In the 915 MHz ISM band, systems using 50 hopping channels are permitted to transmit at up to 1 Watt, while systems using fewer channels (but not fewer than 25) are limited to 250 mW.

The use of overlapping channels obscures this issue to some extent. However, in a previous submission to OET in this proceeding [3], the adverse impact of allowing overlapping FHSS channels has been demonstrated. The number of overlapping FHSS channels is largely irrelevant. Collision rates among FHSS systems can be reduced only by increasing the number of *orthogonal* (non-overlapping) channels. In this sense, the HomeRF proposal contains the same number of orthogonal channels as the earlier proposal by Symbol. It should therefore become more apparent that the linear power reduction proposed by HomeRF is inadequate to offset the increased potential for interference to other users of the 2.45 GHz band.

3.0 Hop Rate

In its letter to the Commission of Nov. 11, 1999, HomeRF indicated that the reduction in time of occupancy is an effective means of reducing interference between WBFH and other users of the spectrum. It must be pointed out that a reduction in occupancy time requires a corresponding increase in hop rate. However, even neglecting the expansion in bandwidth, when averaged over a 30 second period the time of occupancy on any single channel is unchanged. The net result of the proposed increase in hop rate is therefore more frequent collisions of a shorter duration.

Increasing the hop rate of an FHSS system is *NOT* a means of reducing interference with either DSSS or other FHSS systems. In fact, increasing the hop rate for an FHSS system *increases* the risk of interference to other users. A model for predicting the collision rate with an FHSS system has been proposed [4]. The model can be used to determine the rate of collision between a DSSS system and an FHSS system, or between two FHSS systems.

In the event of a collision, any bit error will cause the Cyclic Redundancy Code (CRC) of a packet transmission to fail, and the packet will be lost. The model estimates the probability of collision based on:

1.) Hop rate of the interfering signal (HR)
2.) Probability that FHSS interfering signal hops into passband of desired signal (P_{hop})
3.) Probability that FHSS system actively transmits while on any given hop (P_{tx})
4.) Packet length (in time) of desired signal transmission (L_{packet})

The effect of hop rate can be shown by studying the example of a DSSS system operating at 1 Mbps in the presence of a nearby FHSS system. The bandwidth of a DS signal is roughly 20 MHz. Therefore the probability that the FHSS system will hop into the DSSS passband is 20/79, or about 25%. In this example, all parameters are held constant with the exception of hop rate. In the first case, the FHSS system is 128 hops per sec, which results in an FHSS dwell period (t_{dwell}) on any given channel of 7812 usec.

Case 1:

HR	=	128 hops/sec
P_{hop}	=	25%
P_{tx}	=	100 %
L_{packet}	=	8370 usec

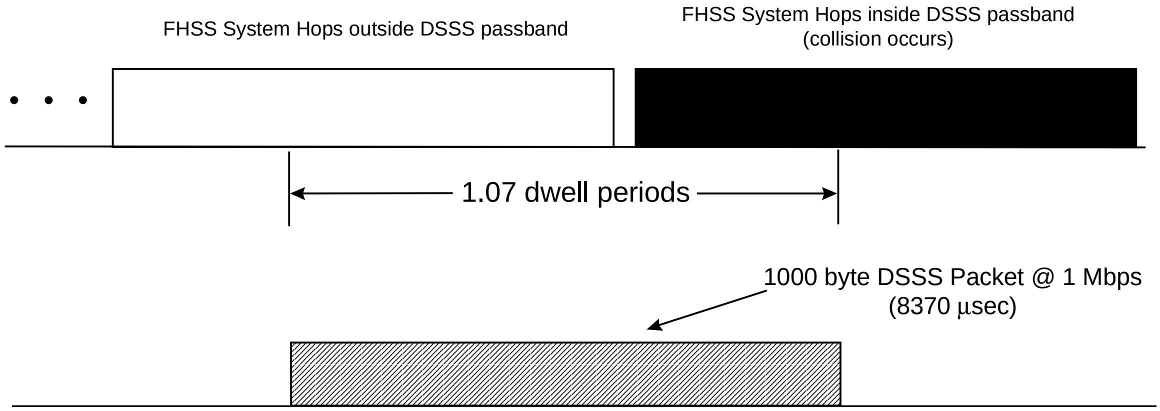

Figure 3.0-1 Probability of Collision Depends on Hop Rate (FHSS System @ 128 hops/sec)

The number of dwell periods overlapped is a function of packet length and the Start-of-Transmission (SOT) time. SOT is a uniform random variable with a range of 0 to t_{dwell}. Based on these considerations and the FHSS system load factor (P_{tx}), the probability of collision for the single DSSS packet under consideration can be computed:

Probability FHSS system hops into DSSS passband (P_{hop}):	25%
Probability of overlapping 2 FHSS dwells ($P_{2\text{-slot}}$):	92.9%
Probability of overlapping 3 FHSS dwells ($P_{3\text{-slot}}$):	7.1%
Probability of FHSS transmission (P_{tx}):	100%

Probability of collision with n slot overlap ($P_{coll}(n)$) $= 1 - (1 - (P_{hop} * P_{tx}))^n = 1 - (0.75)^n$ (1)

Overall Probability of collision (P_{tot}) $= (P_{2\text{-slot}} * P_{coll}(2)) + (P_{3\text{-slot}} * P_{coll}(3))$ (2)

$= ((0.929 * 0.4375) + (0.071 * 0.5781))$

$= 44.7\ \%$

Consider the same situation, with the exception that hop rate is increased to 512 hops/sec:

Case 2:

HR	=	512 hops/sec
P_{hop}	=	25%
P_{tx}	=	100 %
L_{packet}	=	8370 usec

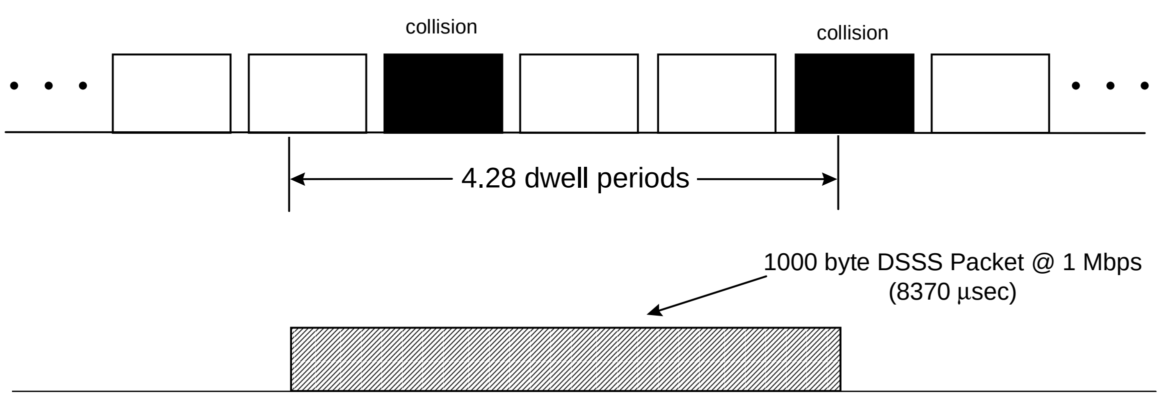

Figure 3.0-2 Increasing Hop Rate Increases Probability of Collision (FHSS System @ 512 hops/sec)

Note that the higher hop rate increases the number of dwell periods overlapped by the DSSS packet. In this situation, the DSSS packet overlaps either five dwell periods or six dwell periods, depending on the start-of-transmission time. The probability of collision for the single DSSS packet under consideration can be computed:

Probability FHSS system hops into DSSS passband (P_{hop}):	25%
Probability of overlapping 5 FHSS dwells ($P_{4\text{-slot}}$):	72%
Probability of overlapping 6 FHSS dwells ($P_{5\text{-slot}}$):	28%
Probability of FHSS transmission (P_{tx}):	100%

Overall Probability of collision (P_{tot}) $= (P_{5\text{-slot}} * P_{coll}(5)) + (P_{6\text{-slot}} * P_{coll}(6))$ (3)

$= ((0.72 * 0.684) + (0.28 * 0.76))$

$= 77.9\ \%$

All parameters in Cases 1 and 2 are held constant, except for hop rate. As hop rate is increased, the collision rate increases as well. Therefore, increasing hop rate does not mitigate interference to DSSS users in the 2.45 GHz ISM band. The Probability of Collision is plotted as a function of hop rate for the stated conditions in Figure 3.0-3. Note that as hope rate is increased, the collision rate increases monotonically. There is no point on the curve at which the Probability of Collision *decreases* as hop rate *increases*. This result also holds true when *both* the victim and the jammer are FHSS systems.

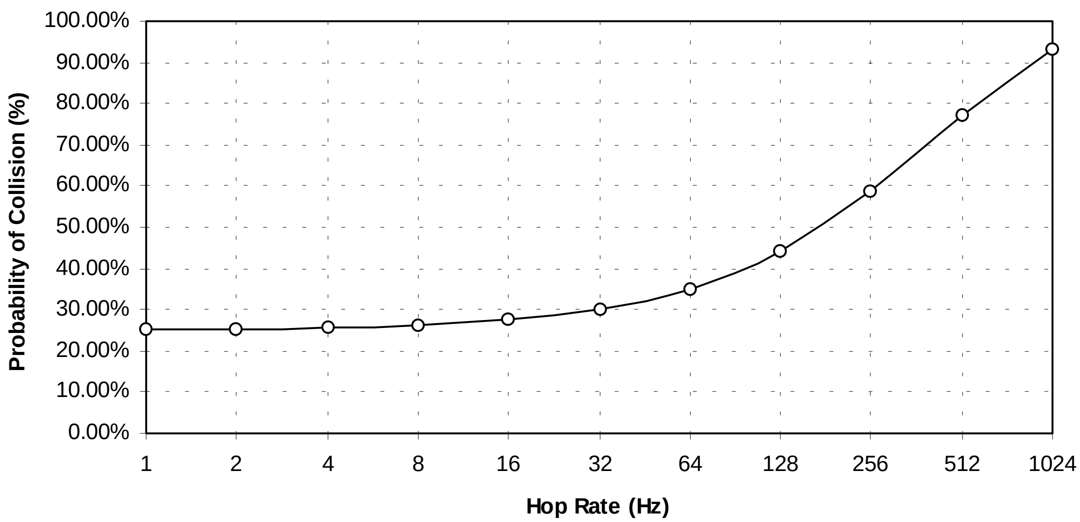

Figure 3.0-3 DSSS Probability of Collision as a Function of FHSS Hop Rate (1000 byte DSSS Packets)

3.1 Impact of Higher Hop Rate on Throughput

In general, in FHSS systems which deal with packet data can deliver higher throughput with a slower hop rate. Increasing hop rate reduces throughput mainly via two mechanisms: more down time due to channel switching, and lost time at the end of a dwell period.

Current FHSS systems require about 200 - 300 usec to switch channels. Therefore, hopping faster results in more time spent switching between channels. Assuming a 250 usec channel switching time, a system hopping at 10 Hz would lose 0.025% throughput due to channel switching (2500 usec / sec). By comparison, the same FHSS system hopping at 1000 Hz would lose 25% throughput due to time lost in channel switching (250,000 usec / sec).

There is another effect which can be of significance for systems which employ Carrier Sense Multiple Access / Collision Avoidance (CSMA/CA) medium access methods. This is one form of a "listen before talk" medium sharing method. IEEE 802.11, HomeRF, and Open Air radios are among those employing this mechanism. Because the timing of traffic is somewhat random, time can be lost at the end of a dwell time if there is insufficient time remaining to transmit a packet of some arbitrary length before switching channels.

In either case, increasing hop rate actually decreases throughput for FHSS networks. Bluetooth radios hop at 1600 hops/sec. However, they can increase throughput by using multiple time slot packets. In this mode, a Bluetooth radio can dwell on one channel for up to 5 time slots. As a result of using longer dwell periods, the hop rate in this mode is lower. In other words, Bluetooth radios actually reduce hop rate in order to increase throughput.

3.2 So Why Do Some FHSS Radios Use Higher Hop Rates?

Channel distortion and interference are the two main mechanisms by which communications in FHSS systems are disrupted. Regardless of which mechanism is at work, increasing the hop rate increases the number of disruptions, but reduces the duration of each disruption by a corresponding amount. This characteristic can be exploited where Quality of Service (QoS) is more important than peak throughput.

Recall from the previous section that increasing the hop rate decreases throughput for an FHSS system. However, for many services such as toll grade voice, throughput requirements are relatively modest (full duplex @ $\leq$ 64 kbps). When supporting telephony, timing of delivery of the digitized voice and reliability of reception are paramount.

Consider the case of a Bluetooth piconet which is supporting a two way voice conversation. Bluetooth features packet structures which support both data and isochronous voice services. In order to deliver robust voice services, Bluetooth uses three different types of voice packets. The most robust packet format uses 1/3 rate Forward Error Correction (FEC) to support Continuous Variable Slope Delta (CVSD) voice encoding. When using this level of FEC, upstream and downstream traffic are sent on alternating time slots as shown in Figure 3.2.1.

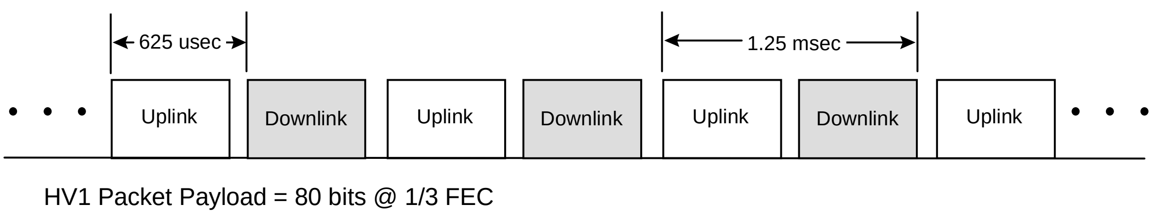

Figure 3.2.1 Bluetooth Piconet TDMA Scheme for Delivery of Voice via 1/3 Rate FEC

When delivering voice services, Bluetooth radios change channels at 1600 hops/sec. If a single voice packet is corrupted in this mode, only 1.25 msec of voice is lost. This is imperceptible to the listener. Assuming that the radio hops to a subsequent channel which is not distorted or jammed, the user will perceive no disruption or degradation of voice quality. If Bluetooth hopped at a slower rate, the amount of voice lost due to a corrupted packet would be correspondingly longer. At some point, a single lost voice packet could become perceptible to the listener. This example is illustrative because Bluetooth trades throughput in this mode to provide extremely robust voice transmission capable of maintaining very high QoS.

4.0 Conclusions

The power reductions proposed by HomeRF are inadequate to ensure that other users of the band will not encounter increased levels of interference. Expansion in the occupied channel width reduces the number of orthogonal (non-overlapping) channels in the band. In a ruling regarding operation of FHSS radios in the 915 MHz band, the Commission concluded that linear power reduction in proportion to the reduction in the number of channels was inadequate to protect other users. In addition, the proposed limits for WBFH radios would allow transmission at power levels which are higher than those used by the vast majority of radios currently operating in the band.

The analysis presented in this paper demonstrates that increasing hop rate does not reduce interference to other Part 15 users. In fact, increasing hop rate actually increases the rate of collision with other users. It is reasonable to conclude that authorized users will suffer a similar impact. It has further been shown that increasing hop rate reduces throughput for FHSS systems. Due to the higher hop rate, periods of interference with other users such as DSSS radios or conventional FHSS radios are more frequent, but of a shorter duration. In applications where QoS is of greater importance than peak throughput, this property can be exploited to provide services such as telephony.

Under current regulations, manufacturers of FHSS equipment have the latitude to select a hop rate suited to their particular application. If maximum throughput is desired, the hop rate can be set as low as 2.5 Hz. If TDMA support of isochronous services is sought, a higher hop rate can be selected. Therefore, there should be no regulatory prohibition against use of faster hopping, nor should the FCC *require* faster hop rates due to the fact that this will increase interference to other users of the spectrum.

The proposal put forward by HomeRF is similar to an earlier proposal to widen FHSS channel widths which was rejected by the Commission (ET Docket 96-8). The only salient differences are that the HomeRF scheme calls for the use of overlapping channels and a higher hop rate. Both measures have been shown to increase interference to other users in the band. In addition, due to susceptibility to multipath, WBFH systems will not be able to provide sufficient throughput to deliver the benefits to consumers claimed by its proponents. The HomeRF proposal should therefore be rejected.

References

1. HomeRF Working Group Technical Committee, "*Technical Material in Support of the Wider Channel Bandwidth Proposal for 2.4 GHz Frequency Hopping Regulations*", presented to OET, Feb. 25, 1999
2. Padgett, J., "*The Effect of System Parameters on the Interference Potential of Frequency Hopping Systems in the ISM Bands*", Submission to OET (ET Docket 96-8), June 14, 1996.
3. Zyren and Gandolfo, "*Analysis and Simulation of Overlapped Frequency Hopping Channels*", Submission to OET (ET Docket 99-231), Sept. 1999.
4. Ennis, "*Impact of Bluetooth on 802.11 Direct Sequence Wireless LANs*", Doc.: IEEE802.11-98/319a, Sept. 1998.