IEEE 802.11
Wireless Access Method and Physical Specification

Title: **Proposal for New Frequency Hopping Patterns for USA**

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Introduction

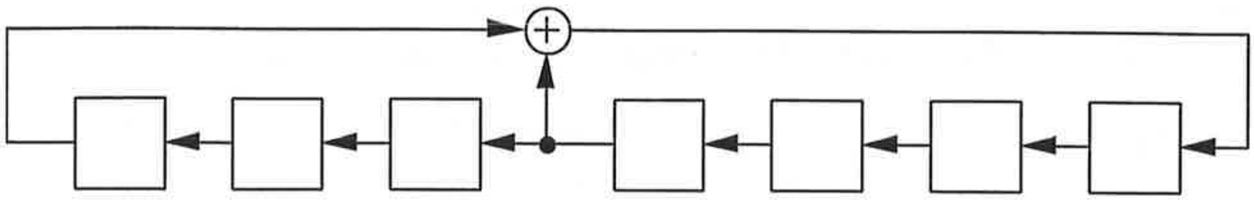
This submission proposes a new frequency hopping pattern for the US which has the following characteristics:

1) Certifiable by the FCC under 15.247 rules.
2) Provides a family of hopping patterns which is easily described and computed.
3) Performance approaches the more optimal hopping patterns in the current draft.
4) Simple modification to the current hopping pattern which allows maintaining the current hopping patterns for applicable countries in Europe and Asia.

Description of New Frequency Hopping Patterns

The new US frequency hopping pattern proposed is a pseudo-random sequence which selects one of 79 1 Mhz channels centered from 2402 to 2480 Mhz. Each channel is evenly utilized by selecting each channel once and only once in each cycle, and using identical dwells at each channel.

The hopping pattern is based on a pseudo-random sequence generated by a linear shift register with taps corresponding to the irreducible polynomial $x^7 + x^4 + 1$ as shown in the figure below. All registers are initialized with ones.



The contents of the registers form 7-bit words with values from 1 to 127. The left-most register in the figure above is the most significant bit; the right-most register is the least significant. The irreducible polynomial produces a maximal length sequence which mean that each value from 1 to 127 occurs once and only once in each cycle. Values less than 2 and greater than 80 are eliminated, leaving 79 values from 2 through 80 which corresponds to the frequencies 2402 through 2480.

A set of 78 hopping patterns are derived by permutations of the basic pseudo-random sequence. The permutations are derived by a sequential incrementing with modulo wrap-around through the basic pseudo-random sequence with an incremental delta from 1 to 78. Because the number of channels (79) in the hopping set is a prime number, a sequential incrementing through the base pseudo-random sequence using a delta from 1 to 78 will produce a unique sequence that is equally pseudo-random and evenly utilized as the basic pseudo-random sequence.

The permutations of the basic pseudo-random sequence uses the same algorithm as in the existing draft text. The difference is that the value f_X which is calculated by the equation

$$f_X(i) = [(i - 1) * x] \bmod (79) + 2$$

is now an index to the final frequency instead of the final frequency itself. The index points to the location within the pseudo-random sequence which could be implemented as a table lookup with 79 values or by a relatively simple hardware algorithm. The basic pseudo-random sequence and the first 8 permutations are shown in Table 1. A delta of 1 reproduces the basic pseudo-random sequence.

Index	Basic PRN Sequence	Delta= 2	Delta= 3	Delta= 4	Delta= 5	Delta= 6	Delta= 7	Delta= 8	Delta= 9
2	67	67	67	67	67	67	67	67	67
3	7	14	29	59	60	75	22	44	50
4	14	59	75	44	73	36	16	64	4
5	29	75	50	36	32	4	34	19	24
6	59	44	36	64	17	19	49	46	48
7	60	73	32	17	38	11	54	12	53
8	75	36	4	19	11	48	51	78	52
9	22	16	34	49	54	51	28	33	47
10	44	64	19	46	12	78	33	62	27
11	50	4	24	48	53	52	47	27	14
12	73	17	11	12	57	21	70	7	18
13	18	68	58	26	80	74	31	50	17
14	36	19	48	78	21	27	60	2	69
15	72	76	6	30	37	63	36	38	3
16	16	49	51	33	70	60	8	58	39
17	32	11	53	21	71	18	76	25	33
18	64	46	78	62	7	2	58	28	37
19	2	45	79	40	75	9	12	66	56
20	4	48	52	27	18	69	39	37	59
21	8	3	66	15	64	54	52	55	72
22	17	12	21	7	34	25	42	14	68
23	34	51	47	60	76	39	40	73	23
24	68	26	74	50	23	61	71	4	12
25	9	41	35	72	48	10	29	76	28
26	19	78	27	2	25	37	73	45	5
27	38	57	71	34	41	13	2	51	20
28	76	30	63	38	79	31	19	57	15
29	24	52	14	69	33	59	23	5	75
30	49	33	60	58	42	73	3	74	32
31	69	5	44	65	74	64	53	56	19
32	11	21	18	25	13	68	30	29	58
33	23	43	16	53	15	49	10	18	51
34	46	62	2	28	14	45	74	8	79
35	58	74	17	61	22	12	55	24	21
36	45	40	9	66	36	41	7	54	35
37	54	70	76	42	2	30	44	77	63
38	48	27	69	37	68	5	32	79	44
39	65	56	46	35	24	62	68	10	2
40	3	15	54	55	46	70	69	20	76
41	6	63	3	31	65	15	48	71	54
42	12	7	25	14	51	29	77	59	26
43	25	29	26	75	39	50	57	36	61
44	51	60	39	73	30	32	66	17	43
45	77	22	57	16	66	34	62	49	13
46	26	50	61	4	43	24	13	48	7
47	53	18	33	68	20	58	63	26	73
48	41	72	10	76	27	6	75	30	8
49	39	32	43	11	31	53	72	21	49
50	78	2	37	45	29	79	17	40	65
51	28	8	40	3	44	66	24	15	41

Table 1. Basic Pseudo-Random Sequence and Example Permutation Sequences

Index	Basic PRN Sequence	Delta= 2	Delta= 3	Delta= 4	Delta= 5	Delta= 6	Delta= 7	Delta= 8	Delta= 9
52	57	34	13	51	72	47	45	60	80
53	79	9	56	41	4	35	25	72	62
54	30	38	31	57	9	71	78	34	55
55	61	24	7	52	49	14	80	69	29
56	52	69	59	5	58	44	43	65	36
57	80	23	22	43	3	16	35	53	34
58	33	58	73	74	77	17	15	61	11
59	66	54	72	70	78	76	59	42	6
60	5	65	64	56	61	46	18	35	78
61	10	6	8	63	5	3	4	31	66
62	21	25	68	29	47	26	38	75	74
63	42	77	38	22	40	57	46	16	71
64	43	53	49	18	55	33	6	68	60
65	47	39	23	32	63	43	41	11	16
66	62	28	45	8	59	40	61	3	9
67	37	79	65	9	50	56	21	41	46
68	74	61	12	24	16	7	20	52	25
69	20	80	77	23	8	22	56	43	57
70	40	66	41	54	19	72	14	70	10
71	35	10	28	6	69	8	50	63	40
72	70	42	30	77	45	38	64	22	31
73	13	47	80	39	6	23	9	32	22
74	27	37	5	79	26	65	11	9	64
75	55	20	42	80	28	77	65	23	38
76	56	35	62	10	52	28	26	6	45
77	71	13	20	47	10	80	79	39	77
78	15	55	70	20	62	42	5	80	30
79	31	71	55	13	35	20	37	47	42
80	63	31	15	71	56	55	27	13	70

Table 1 (cont.). Basic Pseudo-Random Sequence and Example Permutation Sequences

Performance of New Hop Sequences

The key performance parameters of the hopping sequences were summarized in submission 92/84 by Krishna and Natarajan. The performance of the new hopping sequence is discussed below relative to these parameters.

1. Equal Use of Channels

No change. The new pattern uses each channel once per cycle.

2. Direct Hits

No change. There is only one direct hit per cycle between any two different hop patterns.

3. Adjacent Channel Interference

The number of adjacent channel hits between any two hop different hop patterns has an average value of two per cycle when averaged over the different phases of the hop sequences. This is the same as the old patterns. Unlike the old pattern, however, the value does vary over phase with a worst case number of adjacent channel hits of 10 per cycle.

4. Temporal Frequency Diversity

The new hop patterns cannot match the minimum hop distances in the old patterns. However, it is possible to select hop deltas to maximize the temporal frequency diversity.

5. Avoidance of Contiguous Bad Hops

The number of consecutive bad hops (direct or adjacent channel collision) between any two hop patterns has an average value less than 0.4 when averaged over the different phases of the hop sequences. This is slightly worse than the old hop patterns which had a value of zero. However, the maximum occurrences of contiguous bad hops over all phases is less than or equal to 6 occurrences for a small number of hop pattern combinations. The typical maximum over all phases between most hop patterns are 1 to 2 occurrences.

Summary of Changes to the Draft Text

MAC:

There are no changes to the MAC section of the draft text.

> Notes: There are some changes which affect operational parameters of the MAC, but not the MAC specification itself. Allowed patterns numbered from 1 to 78 instead of 7 to 72. Set 1 for US includes all patterns from 1 to 78. Sets 2 and 3 are unused for the US.
>
> The algorithm to select the next frequency index remains the same. The index is still passed across the MAC/PHY management interface. The PHY MIB already contains separate parameters for index (aCurrent_Index) and frequency (aCurrent_Channel_Nbr). The PHY would map the index to the correct frequency for the appropriate region/country.

FH-PHY:

US/Europe index vs frequency table are separated to result in three tables (US, Europe, and Japan). The PHY now maps index passed from the MAC LME to a frequency from the pseudo-randomly ordered list of hop frequencies for the US. The US table will now map index values (2, 3,..., 80) to the pseudo-randomly ordered frequencies (2467, 2407,..., 2463 MHz).

> Note: For Europe, the index is mapped one-for-one, e.g. 02 = 2402 MHz, resulting in no change in the hopping patterns for Europe relative to the D2.0 draft.

Specific Changes to D2.0 Draft Text

The specific changes proposed to the D2.0 802.11 draft text is presented below in revision mark format. Note that all changes are at the PHY level.

11.6.5 Operating Channel Center Frequency.

Channel #	Value	Channel #	Value	Channel #	Value
2	2.467	28	2.476	54	2.430
3	2.407	29	2.424	55	2.461
4	2.414	30	2.449	56	2.452
5	2.429	31	2.469	57	2.480
6	2.459	32	2.411	58	2.433
7	2.460	33	2.423	59	2.466
8	2.475	34	2.446	60	2.405
9	2.422	35	2.458	61	2.410
10	2.444	36	2.445	62	2.421
11	2.450	37	2.454	63	2.442
12	2.473	38	2.448	64	2.443
13	2.418	39	2.465	65	2.447
14	2.436	40	2.403	66	2.462
15	2.472	41	2.406	67	2.437
16	2.416	42	2.412	68	2.474
17	2.432	43	2.425	69	2.420
18	2.464	44	2.451	70	2.440
19	2.402	45	2.477	71	2.435
20	2.404	46	2.426	72	2.470
21	2.408	47	2.453	73	2.413
22	2.417	48	2.441	74	2.427
23	2.434	49	2.439	75	2.455
24	2.468	50	2.478	76	2.456
25	2.409	51	2.428	77	2.471
26	2.419	52	2.457	78	2.415
27	2.438	53	2.479	79	2.431
				80	2.463

Table 11-11a: USA Requirements

Channel #	Value	Channel #	Value	Channel #	Value
2	2.402	28	2.428	54	2.454
3	2.403	29	2.429	55	2.455
4	2.404	30	2.430	56	2.456
5	2.405	31	2.431	57	2.457
6	2.406	32	2.432	58	2.458
7	2.407	33	2.433	59	2.459
8	2.408	34	2.434	60	2.460
9	2.409	35	2.435	61	2.461
10	2.410	36	2.436	62	2.462
11	2.411	37	2.437	63	2.463
12	2.412	38	2.438	64	2.464
13	2.413	39	2.439	65	2.465
14	2.414	40	2.440	66	2.466
15	2.415	41	2.441	67	2.467
16	2.416	42	2.442	68	2.468
17	2.417	43	2.443	69	2.469
18	2.418	44	2.444	70	2.470
19	2.419	45	2.445	71	2.471
20	2.420	46	2.446	72	2.472
21	2.421	47	2.447	73	2.473
22	2.422	48	2.448	74	2.474
23	2.423	49	2.449	75	2.475
24	2.424	50	2.450	76	2.476
25	2.425	51	2.451	77	2.477
26	2.426	52	2.452	78	2.478
27	2.427	53	2.453	79	2.479
				80	2.480

Table 11-11b: ~~USA and~~ European Requirements

11.6.8 Hop Sequences

The hopping sequence of an individual PMD entity is used to co-locate multiple PMD entities in similar networks in the same geographic area and to enhance the overall efficiency and throughput capacity of each individual network. A frequency hopping pattern, Fx , consists of a permutation of all frequency channels defined in Tables 10-11 and 10-12. For a given pattern number, x, the hopping sequence can be written as:

$F_X = \{f_X(1), f_X(2), \ldots f_X(p)\}$

where,

$f_X(i)$ = channel number (as defined in 10.6.4) for i^{th} frequency in x^{th} hopping pattern
p = number of frequency channels in hopping pattern (79 for US/Europe, 23 for Japan)

Given the hopping pattern number, x, and the index for the next frequency, i, the channel number shall be defined to be:

$f_X(i) = [(i - 1) * x] \bmod (79) + 2$ in US and Europe
$= [(i - 1) * x] \bmod (23) + 73$ in Japan.

The channel number $f_X(i)$ is then used to look up the specific hopping frequency in the tables for the applicable regulatory region.

There is one set of 78 hopping patterns for the US. There are three sets of 22 hopping patterns each for Europe and three sets of 4 hopping patterns for Japan. The hopping pattern numbers are given in Table 11-12 for each region. There is an additional non-interoperable set, designated as Set 0, which is used for scanning prior to associating with a BSS. This set contains a single hopping pattern with a default value of 1.

Region	Set 1	Set 2	Set 3
USA	1 - 78	N/A	N/A
Europe	7, 10, 13, 16, 19, 22, 25, 28, 31, 34, 37, 40, 43, 46, 49, 52, 55, 58, 61, 64, 67, 70	8, 11, 14, 17, 20, 23, 26, 29, 32, 35, 38, 41, 44, 47, 50, 53, 56, 59, 62, 65, 68, 71	9, 12, 15, 18, 21, 24, 27, 30, 33, 36, 39, 42, 45, 48, 51, 54, 57, 60, 63, 66, 69, 72
Japan	6, 9, 12, 15	7, 10, 13, 16	8, 11, 14, 17

Table 11-12: Hopping Patterns per Region and Set

~~Each of the F_x contains each of the p frequency channels equally often. Given a pattern length of p and the criterion of minimal adjacent channel interference, the number of usable hopping sequences in a geographically co-located area that can be derived is:~~

$$\frac{(p - 1) - (2 * F)}{2k + 1} = \frac{(p - 13)}{2k + 1} = \text{22 patterns/set for US and Europe } (F = 6)$$

$$= \frac{(p - 11)}{2k + 1} = \text{4 patterns/set for Japan } (F = 5)$$

~~where k = the number of adjacent channel interferers on each side of the channel frequency and F is the minimum distance in frequency between contiguous hops. For the 802.11 compliant FHSS PMD in the USA and Europe, there are three sets of hopping sequences with 22 patterns per sequence that meet the criterion of one adjacent channel interferer on each side of the desired channel. The three sets of hopping sequences of 22 patterns each are listed Tables A, B, and C in the Annex. Similarly, there are three sets in Japan, except each set has four patterns as listed in Table D in the Annex. The channel numbers listed under each pattern refer to the actual frequency values listed in Tables 10-11 and 10-12.~~

11.8.2.1.33 aCurrent_Set.

The FHSS PHY contains up to 3 sets of hopping patterns depending on the aCurrent_Reg_Domain. ~~Each set contains up to 22 patterns and each pattern has some number of channels depending on the aCurrent_Reg_Domain. These channels are addressed through an Index.~~ The aCurrent_Set managed object for the FHSS PHY defines what set the station is using to determine the hopping pattern. Its value can be 0,1,2,3. The default is 0 which is used ~~to~~ when a node is probing for a WLAN. This MIB variable is managed by the PLME.

11.8.2.1.34 aCurrent_Pattern.

Each set in the~~The~~ FHSS PHY contains ~~3 set of hopping patterns. Each set contains~~ up to 78~~22~~ patterns ~~and each pattern has some number of channels~~ depending on the aCurrent_Reg_Domain. ~~These channels are addressed through an Index.~~ The aCurrent_Pattern managed object for the FHSS PHY defines what pattern the station is using to determine the hopping sequence. ~~Its value has various ranges depending on the aCurrent_Reg_Domain.~~ The default is 1~~0~~ which is used ~~to~~ when a node is scanning~~probing~~ for a WLAN. This MIB variable is managed by the PLME.

11.8.2.1.35 aCurrent_Index.

Each hopping pattern in the~~The~~ FHSS PHY contains ~~3 set of hopping patterns. Each set contains up to 22 patterns and each pattern has~~ up to 79 channels depending on the aCurrent_Reg_Domain. These channels are addressed through an Index. The aCurrent_Index managed object for the FHSS PHY defines what the current index is that the station is using to determine the next hop channel number. ~~Its value has various ranges depending on the aCurrent_Reg_Domain. When aCurrent_Set and aCurrent_Pattern are both set to 0, the value of the aCurrent_Index is equal to the value of the aCurrent_Channel_Nbr.~~ This MIB variable is managed by the PLME