IEEE P802.11
Wireless Access Method and Physical Layer Specifications

Title: New hopping sequences

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Abstract

The FCC would not approve BreezeCom's application for part 15.247 compliance because the hopping sequences defined by the IEEE 802.11 PHY are not pseudorandom. This is because the frequency increments between consecutive hops are constant (See the enclosed FCC response). The FCC would like to see pseudo-random intervals. A new set of hopping sequences, having pseudo-random increments, is suggested. This set also has the benefit of a minimal frequency difference between consecutive hops - an advantage in interference & multipath environment.

The article suggest the algorithm for generating the sequences, which was approved by FCC, and shows simulation results on the performance of these sequences with several Access Points operating in the same area. One of the three sets of hopping patterns for US/Europe is listed in Appendix A, and all the tree sets of hopping patterns for Japan are listed in Appendix B.

Hopping sequence derivation

BreezeNet's hopping sequences for US & Europe use 79 channels (labeled below as 2-80, corresponding to RF frequencies 2402-2480 MHz. The basic sequence was generated using the following algorithm:

1. A channel frequency is randomly chosen, using a uniform distribution pseudo-random number generator.
2. If the chosen frequency appears already in the sequence - it is discarded.
3. If the frequency difference between the chosen frequency and the previous frequency in the sequence is less than 6 MHz, it is discarded.
4. Otherwise, the chosen frequency is added to the sequence.
5. The process is repeated until a complete sequence of 79 frequencies is derived.

The benefit of this algorithm is the pseudo-random frequency increments between consecutive hops in the sequence, with an assured minimum hop size.

Deriving sequences for different cells

The basic sequence is used to generate hopping sequences for different cells. Sequences for neighboring cells are simply frequency shifts of the basic sequence. For example, the basic sequence begins with -

2, 25, 64, 10, 45, 18, ...

A sequence with an offset of 5 MHz is -

7, 30, 69, 15, 50, 23, ...

The shift is performed modulu 79, so that all sequences use the same 79 channels. In order to avoid multiple collisions frequency offsets which are multiple of 3 Mhz are used in each hopping pattern set.

Overlapping AP performance of the generated sequences

The performance of several APs clustered together was simulated. The assumption was that APs' hopping sequences have mutual random phases - no synchronization assumed. The sequences used were 3 MHz offsets of the basic sequence (3, 6, 9, ...). Any collision between two (or more) sequences was assumed to cause complete blockage of these hops - a worst case assumption.

Neighboring channels, up to a separation of ±2MHz, were also counted as collisions. The results give the maximum cell throughput vs the number of APs in the cell. The throughput is given relatively to the throughput of a single AP, rather than absolutely in Kbps. This is done to isolate the effects of the protocol, NOS, etc. The results are shown in Figure 1:

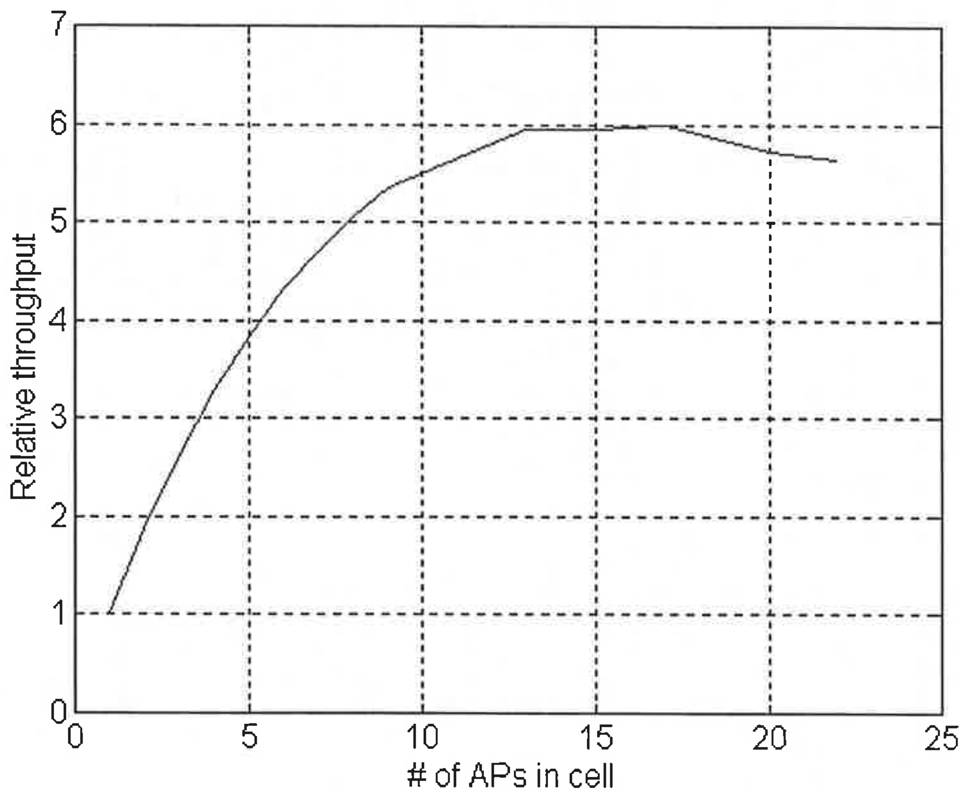

Fig. 1: Relative aggregate throughput of colocated APs

The aggregated throughput simulated above is comparable with the performance of the IEEE 802.11 sequences. This is true for almost any choice of basic sequence and frequency offsets, as long as the sequences are generated using the above algorithm.

A similar analysis was performed for the narrower frequency range in Japan. Because of the smaller number of channels the maximum number of co-located access points is 3-4. Therefore, only 3 sets of 4 sequences were derived for Japan. The Hopping Patterns obtained are listed in Appendix B.

Appendix A - First set of hopping sequences for US/Europe

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

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

Appendix B - The three sets of hopping sequences for Japan

73	79	85	91	74	80	86	92	75	81	87	93
84	90	73	79	85	91	74	80	86	92	75	81
95	78	84	90	73	79	85	91	74	80	86	92
85	91	74	80	86	92	75	81	87	93	76	82
75	81	87	93	76	82	88	94	77	83	89	95
90	73	79	85	91	74	80	86	92	75	81	87
81	87	93	76	82	88	94	77	83	89	95	78
93	76	82	88	94	77	83	89	95	78	84	90
77	83	89	95	78	84	90	73	79	85	91	74
94	77	83	89	95	78	84	90	73	79	85	91
89	95	78	84	90	73	79	85	91	74	80	86
74	80	86	92	75	81	87	93	76	82	88	94
92	75	81	87	93	76	82	88	94	77	83	89
78	84	90	73	79	85	91	74	80	86	92	75
91	74	80	86	92	75	81	87	93	76	82	88
76	82	88	94	77	83	89	95	78	84	90	73
83	89	95	78	84	90	73	79	85	91	74	80
88	94	77	83	89	95	78	84	90	73	79	85
82	88	94	77	83	89	95	78	84	90	73	79
87	93	76	82	88	94	77	83	89	95	78	84
80	86	92	75	81	87	93	76	82	88	94	77
86	92	75	81	87	93	76	82	88	94	77	83
79	85	91	74	80	86	92	75	81	87	93	76