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Title	**802.16m DL Control Structure: Preamble Design**
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Re:	Call for Contributions on Project 802.16m System Description Document (SDD) (IEEE 802.16m-08/016) - DL Control Structures (Preambles)
Abstract	This contribution addresses preamble design in 802.16m to improve system acquisition performance
Purpose	Discuss as part of SDD call for contributions and consider for adoption
Notice	
Release	
Patent Policy	

802.16m DL Control Structure: Preamble Design

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1 Introduction

A key requirement in the 802.16m SRD [1] is to support the ability to synchronize frame timing across an entire system in a given geographic area, including synchronization among all BSs and MSs operating on the same or on different carrier frequencies and among neighboring 802.16m systems. This is a critical requirement for the coexistence of TDD systems.

Frame timing is addressed by the use of an effective preamble in a frame. The preamble sequence must be sufficiently distinct to enable fast detection for quick system acquisition. In this contribution, we address preamble design in view of previous proposals made in 802.16 and also proposed in other competing systems, such as LTE.

In [2]-[3] Constant Amplitude Zero Auto-Correlation (CAZAC) sequences were previously proposed for use in 802.16. These sequences have the following attractive properties

a. They enable fast cell search due to their unique correlation structure
b. Sequence matching can be easily done in the frequency domain using efficient algorithms
c. Low PAPR due to their constant amplitude feature

More recently, a class of CAZAC sequences, known as Zadoff-Chu sequences [4] (also see Appendix and references in [2] for the mathematical properties of these sequences) have been considered by LTE for preamble design showing attractive results. In this contribution we propose a preamble design based on these sequences and indicate some of the advantages for 802.16m

2 Downlink Preambles

The 802.16m preamble is partitioned into two parts, the primary preamble and the secondary preamble.

The primary preamble is used by the MS to identify frame timing. It occupies subcarriers[1] -48 to 48 in symbol 2 of slot time 0 within a frame (all parameters are in accordance with our proposal for DL Physical Resource Unit [5]) . Of these 96 subcarriers, only subcarriers -41 to 41 are occupied, the other subcarriers within these subchannels having no energy placed upon them (the DC subcarrier is also vacant). The occupied subcarriers are modulated with a frequency domain Zadoff-Chu sequence based on

$p_u(x)=\exp(-j\pi u x(x+1)/83)$ for $x = 0,1,\ldots,82$. The mapping of $p_u(x)$ onto subcarriers is given by:

$$\text{Subcarrier}(m) = \begin{cases} p_1(m+41) & \text{if } -41 \le m < 0 \text{ or } 0 < m \le 41 \\ 0 & \text{Otherwise} \end{cases}$$

The secondary preamble is used to allow the mobile to identify particular sectors. Each sector is assigned

[1] For algorithmic convenience, negative and positive subcarrier indexing is used, with subcarrier index 0 corresponding to DC. Conversion to indexing using positive subcarrier numbers is straightforward.

an identity from 0 to 511[2], and transmits a frequency domain Zadoff-Chu sequence based on that ID. In particular, the secondary preamble occupies subcarriers -48 to 48 in symbol 3 of slot time 0 within a frame. Of these 96 subcarriers, only subcarriers -41 to 41 are occupied, the other subcarriers having no energy placed upon them. Of course, the DC subcarrier is also vacant. Let $N_{\text{cell}}^{\text{ID}}$ represent the cell identity. The subcarrier modulation is provided by:

$$\text{Subcarrier}(m) = \begin{cases} p_u([m+41+S]\bmod 83) & \text{if } -41 \le m < 0 \text{ or } 0 < m < 41 \\ 0 & \text{Otherwise} \end{cases}$$

where the parameters u and S are derived from $N_{\text{cell}}^{\text{ID}}$ as given in Table 1.

Table 1. Mapping of $N_{\text{cell}}^{\text{ID}}$ to preamble parameters.

$N_{\text{cell}}^{\text{ID}}$	u	S	$N_{\text{cell}}^{\text{ID}}$	u	S	$N_{\text{cell}}^{\text{ID}}$	u	S	$N_{\text{cell}}^{\text{ID}}$	u	S
0	2	0	128	18	0	256	34	0	384	50	0
1	2	48	129	18	7	257	34	4	385	50	16
2	2	53	130	18	26	258	34	8	386	50	32
3	2	58	131	18	33	259	34	29	387	50	33
4	2	63	132	18	45	260	34	33	388	50	49
5	2	68	133	18	52	261	34	37	389	50	65
6	2	73	134	18	64	262	34	58	390	50	66
7	2	78	135	18	71	263	34	62	391	50	82
8	3	0	136	19	0	264	35	0	392	51	0
9	3	11	137	19	11	265	35	11	393	51	11
10	3	21	138	19	29	266	35	22	394	51	22
11	3	32	139	19	40	267	35	35	395	51	33
12	3	42	140	19	47	268	35	46	396	51	47
13	3	52	141	19	58	269	35	59	397	51	58
14	3	63	142	19	65	270	35	70	398	51	69
15	3	73	143	19	76	271	35	81	399	51	80
16	4	0	144	20	0	272	36	0	400	52	0
17	4	24	145	20	38	273	36	13	401	52	3
18	4	29	146	20	39	274	36	26	402	52	6
19	4	34	147	20	40	275	36	32	403	52	9
20	4	39	148	20	41	276	36	45	404	52	12
21	4	68	149	20	80	277	36	58	405	52	15
22	4	73	150	20	81	278	36	64	406	52	18
23	4	78	151	20	82	279	36	77	407	52	21
24	5	0	152	21	0	280	37	0	408	53	0
25	5	69	153	21	3	281	37	34	409	53	1
26	5	71	154	21	6	282	37	41	410	53	2
27	5	73	155	21	9	283	37	48	411	53	28
28	5	75	156	21	43	284	37	55	412	53	29
29	5	77	157	21	46	285	37	62	413	53	30
30	5	79	158	21	49	286	37	69	414	53	56
31	5	81	159	21	52	287	37	76	415	53	57
32	6	0	160	22	0	288	38	0	416	54	0

[2] This large number of cell IDs makes for a simple assignment of IDs

N_{cell}^{ID}	*u*	*S*	N_{cell}^{ID}	*u*	*S*	N_{cell}^{ID}	*u*	*S*	N_{cell}^{ID}	*u*	*S*
33	6	16	161	22	27	289	38	20	417	54	11
34	6	21	162	22	35	290	38	29	418	54	15
35	6	26	163	22	43	291	38	38	419	54	30
36	6	47	164	22	51	292	38	47	420	54	45
37	6	52	165	22	59	293	38	56	421	54	49
38	6	73	166	22	67	294	38	65	422	54	64
39	6	78	167	22	75	295	38	74	423	54	79
40	7	0	168	23	0	296	39	0	424	55	0
41	7	9	169	23	1	297	39	4	425	55	7
42	7	18	170	23	14	298	39	8	426	55	14
43	7	27	171	23	15	299	39	12	427	55	30
44	7	46	172	23	28	300	39	16	428	55	37
45	7	55	173	23	42	301	39	20	429	55	44
46	7	64	174	23	56	302	39	24	430	55	60
47	7	73	175	23	70	303	39	28	431	55	67
48	8	0	176	24	0	304	40	0	432	56	0
49	8	12	177	24	4	305	40	19	433	56	8
50	8	17	178	24	13	306	40	20	434	56	23
51	8	34	179	24	26	307	40	40	435	56	38
52	8	39	180	24	39	308	40	41	436	56	53
53	8	56	181	24	48	309	40	61	437	56	61
54	8	61	182	24	61	310	40	62	438	56	68
55	8	78	183	24	74	311	40	82	439	56	76
56	9	0	184	25	0	312	41	0	440	57	0
57	9	7	185	25	15	313	41	17	441	57	41
58	9	14	186	25	32	314	41	20	442	57	47
59	9	21	187	25	47	315	41	37	443	57	53
60	9	45	188	25	49	316	41	40	444	57	59
61	9	52	189	25	64	317	41	57	445	57	65
62	9	59	190	25	66	318	41	60	446	57	71
63	9	66	191	25	81	319	41	80	447	57	77
64	10	0	192	26	0	320	42	0	448	58	0
65	10	76	193	26	6	321	42	3	449	58	2
66	10	77	194	26	12	322	42	23	450	58	17
67	10	78	195	26	18	323	42	26	451	58	19
68	10	79	196	26	24	324	42	43	452	58	34
69	10	80	197	26	30	325	42	46	453	58	36
70	10	81	198	26	36	326	42	63	454	58	51
71	10	82	199	26	42	327	42	66	455	58	68
72	11	0	200	27	0	328	43	0	456	59	0
73	11	3	201	27	7	329	43	1	457	59	9
74	11	19	202	27	15	330	43	21	458	59	22
75	11	35	203	27	22	331	43	22	459	59	35
76	11	51	204	27	30	332	43	42	460	59	44
77	11	54	205	27	45	333	43	43	461	59	57
78	11	67	206	27	60	334	43	63	462	59	70
79	11	70	207	27	75	335	43	64	463	59	79

N_{cell}^{ID}	*u*	*S*	N_{cell}^{ID}	*u*	*S*	N_{cell}^{ID}	*u*	*S*	N_{cell}^{ID}	*u*	*S*
80	12	0	208	28	0	336	44	0	464	60	0
81	12	8	209	28	16	337	44	55	465	60	13
82	12	13	210	28	23	338	44	59	466	60	27
83	12	26	211	28	39	339	44	63	467	60	41
84	12	39	212	28	46	340	44	67	468	60	55
85	12	52	213	28	53	341	44	71	469	60	68
86	12	65	214	28	69	342	44	75	470	60	69
87	12	78	215	28	76	343	44	79	471	60	82
88	13	0	216	29	0	344	45	0	472	61	0
89	13	1	217	29	4	345	45	9	473	61	8
90	13	12	218	29	19	346	45	18	474	61	16
91	13	24	219	29	34	347	45	27	475	61	24
92	13	36	220	29	38	348	45	36	476	61	32
93	13	48	221	29	53	349	45	45	477	61	40
94	13	60	222	29	68	350	45	54	478	61	48
95	13	72	223	29	72	351	45	63	479	61	56
96	14	0	224	30	0	352	46	0	480	62	0
97	14	9	225	30	26	353	46	7	481	62	31
98	14	23	226	30	27	354	46	14	482	62	34
99	14	32	227	30	53	355	46	21	483	62	37
100	14	46	228	30	54	356	46	28	484	62	40
101	14	55	229	30	55	357	46	35	485	62	74
102	14	69	230	30	81	358	46	42	486	62	77
103	14	78	231	30	82	359	46	49	487	62	80
104	15	0	232	31	0	360	47	0	488	63	0
105	15	23	233	31	62	361	47	6	489	63	1
106	15	25	234	31	65	362	47	19	490	63	2
107	15	27	235	31	68	363	47	25	491	63	3
108	15	52	236	31	71	364	47	38	492	63	42
109	15	54	237	31	74	365	47	51	493	63	43
110	15	79	238	31	77	366	47	57	494	63	44
111	15	81	239	31	80	367	47	70	495	63	45
112	16	0	240	32	0	368	48	0	496	64	0
113	16	6	241	32	3	369	48	2	497	64	7
114	16	17	242	32	14	370	48	13	498	64	18
115	16	28	243	32	25	371	48	24	499	64	25
116	16	39	244	32	36	372	48	37	500	64	36
117	16	50	245	32	50	373	48	48	501	64	43
118	16	61	246	32	61	374	48	61	502	64	54
119	16	72	247	32	72	375	48	72	503	64	72
120	17	0	248	33	0	376	49	0	504	65	0
121	17	8	249	33	1	377	49	21	505	65	12
122	17	16	250	33	17	378	49	25	506	65	19
123	17	33	251	33	18	379	49	46	507	65	31
124	17	41	252	33	34	380	49	50	508	65	38
125	17	58	253	33	50	381	49	54	509	65	50
126	17	66	254	33	51	382	49	75	510	65	57

N_{cell}^{ID}	u	S	N_{cell}^{ID}	u	S	N_{cell}^{ID}	u	S	N_{cell}^{ID}	u	S
127	17	74	255	33	67	383	49	79	511	65	76

Since a time delay corresponds to a frequency shift in the Zadoff-Chu sequence, the parameters in this formula have been selected so that sectors can be uniquely identified in the case of expected time of arrival differences between BSs.

The cross-correlation between any two different Zadoff-Chu sequences, after puncturing for a DC subcarrier, is still approximately -9 dB below the correlation peak, even against shifts in frequency.

3 Performance Results

The preambles can be used to perform five different functions:

a. System detection.
b. Symbol timing detection.
c. Frame/Superframe timing detection.
d. System selection and identification during initial acquisition.
e. System selection and identification for handover.

Our initial simulation efforts are centered on the fourth of these functions. Some current implementations of the first three functions rely on algorithms that are largely independent of the choice of sequence, e.g., autocorrelation of the cyclic prefix of the received waveform. For implementations that utilize the preamble for the first three applications, performance is largely dependent on the energy received, rather than on the specific properties of the signal. Further, only the primary preamble is used. Therefore, as long as the waveform used is wide enough in frequency to provide diversity, the sequence used for the primary preamble has good auto and cross-correlation properties, and it provides a good peak to average ratio, we would expect one preamble sequence to perform roughly as well as another. Since the waveform and the CAZAC sequences chosen for the primary preamble are optimum in all respects, we expect them to meet or exceed the performance of all other proposals.

Of the remaining two functions, system selection and identification during initial acquisition is the more challenging, as the mobile station cannot narrow the search to a known set of preambles in use. A preamble that performs well in this case should also excel in handover scenarios. This, therefore, is where we have chosen to focus our efforts. We demonstrate the efficacy of the proposed preamble structure to provide sector/cell ID for two scenarios:

a. Acquisition performance in an isolated cell
b. Acquisition performance in a cell with interference from adjacent cells/sectors

As a starting point for the simulations, we assume that symbol timing (to within a cyclic prefix) is already known. We use the primary preamble to identify the timing of each of the waveforms arising from multipath and from neighboring cells. We then use that time alignment to detect the secondary waveform. An acquisition is successful if it correctly identifies a base station that is actually transmitting a preamble.

3.1 Isolated Cell Performance

The results in this sub-section address proper system acquisition in an isolated cell environment, i.e., how well the preamble scheme does at reliably identifying a system signal broadcast by the BS and how long it takes in doing so. We assume a preamble (both primary and secondary on adjacent symbols) is present at the beginning of each frame (or superframe).

The decision algorithm for this simulation is shown in Figure 1. The primary symbol is correlated against all possible circular shifts in frequency of the preamble sequence, producing 83 candidates for the arrival of the waveform. This process is repeated over four preamble transmissions, and the energies detected are summed to produce a decision matrix. The frequency bin with the largest sum is chosen as the correct one, and this offset is then translated into a time offset that is used to align the secondary preamble acquisition. The secondary preamble samples are saved for each of the symbols used by the primary acquisition. The primary time offset is used to align the FFT for the secondary preamble search, and the received tones are correlated against all possible secondary waveforms. The result is a 64 x 8 matrix, representing the 64 different values of u from Table 1, along with all possible circular shifts of those waveforms. Again, the largest entry in the matrix is chosen as the identified signal, and it is mapped to the closest possible entry in Table 1. If the result differs from the ID of the transmitting base station, a bad detection is declared. The simulation runs for 10000 iterations, or 100 error events, whichever occurs first.

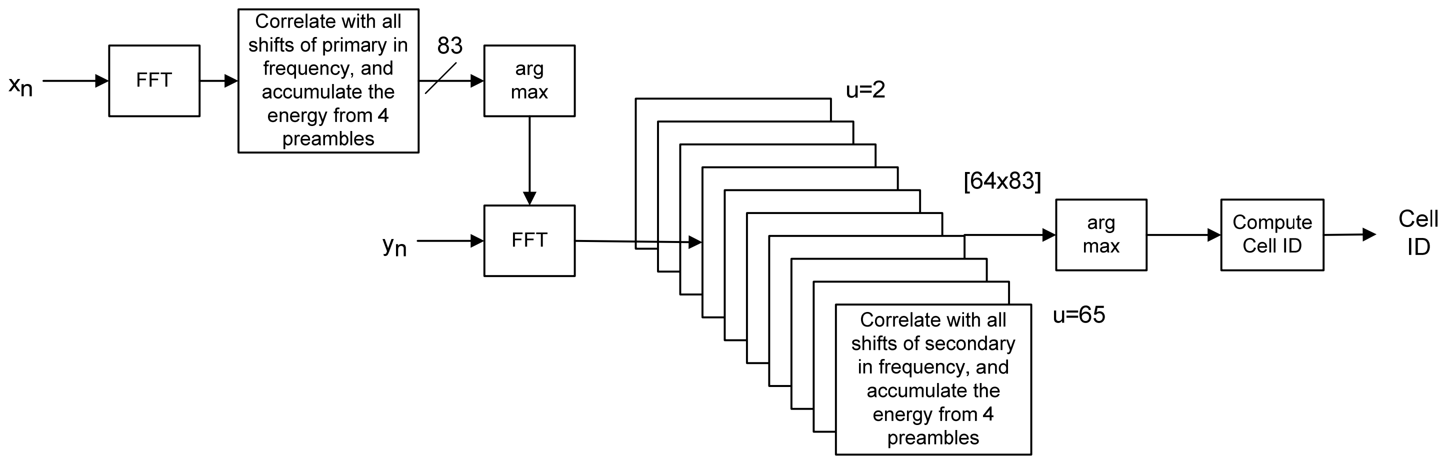

Figure 1 Initial acquisition algorithm for the isolated cell case

This algorithm was tested for a signal transmitted over the Pedestrian-B and Vehicular-A channel models considered in the 802.16m Evaluation Methodology (both the 6-tap and modified 24-tap ITU channel models have been considered [5]), at varying received signal levels. The parameters used are shown in Table 2**.** Because the preambles are separated in time by at least 5ms, each preamble was faded independently. The performance of this system is shown in Figure 2. Results are relatively insensitive both to the channel chosen and to the velocity of the mobile. The correct system is identified 99% of the time at an SNR of approximately -5.5 dB per subcarrier. This represents a 20 ms acquisition time if the preamble is transmitted every frame, and 80 ms if it is transmitted every superframe. These results are considered adequate, but can be improved if desired by increasing the number of incoherent sums at the expense of longer acquisition time.

Table 2 Channels used in performance simulation.

Channel	Velocity (km/h)
Pedestrian-B	3
Modified Pedestrian-B	

Vehicular A	30/120
Modified Vehicular A	

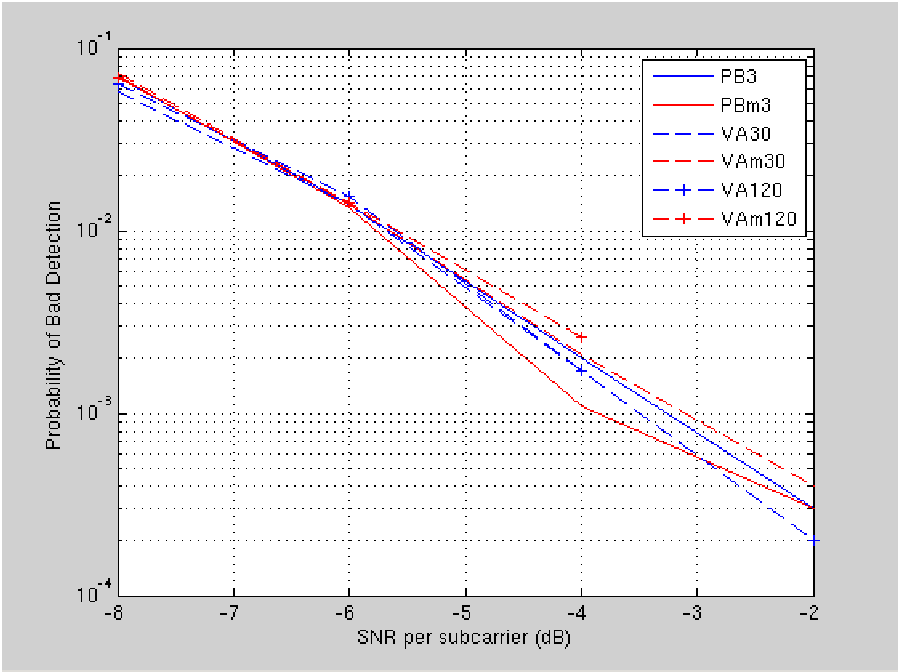

Figure 2. Isolated cell acquisition performance.

3.2 Performance with Interference

In this sub-section we address acquisition performance in a cell with interference from adjacent cells/sectors. As described in Section 2, the secondary preamble sequence is constructed based on the cell/sector ID mapping shown in Table 1. For this scenario, we consider two equal strength BSs experiencing identical channels arriving within a 5 μs window at the mobile.

The acquisition algorithm is modified from the first simulation to cope with multiple base stations. The modified algorithm is shown in Figure 3. The metrics for the primary preamble are computed as in the isolated cell case, but we want to detect all arriving base stations. Therefore, we identify all primary peaks that are above a threshold. If no peak exceeds the threshold, we chose the largest peak. For each identified peak, we align a DFT with its offset on the secondary symbol, and again compute a 64 x 83 matrix of alternatives, summing the energy over 4 attempts. This is used to identify the value of *u* that was transmitted in the secondary. Having identified *u*, we consider the metrics corresponding to each primary peak and that *u*, and chose the offset that is closest to an allowable offset. This is then converted to a cell ID. If it matches one of the transmitted cell IDs, the acquisition is considered successful. Otherwise, a bad detection is declared. As in the previous section, the simulation is allowed to run for 10000 iterations, or 100 error events, whichever occurs first.

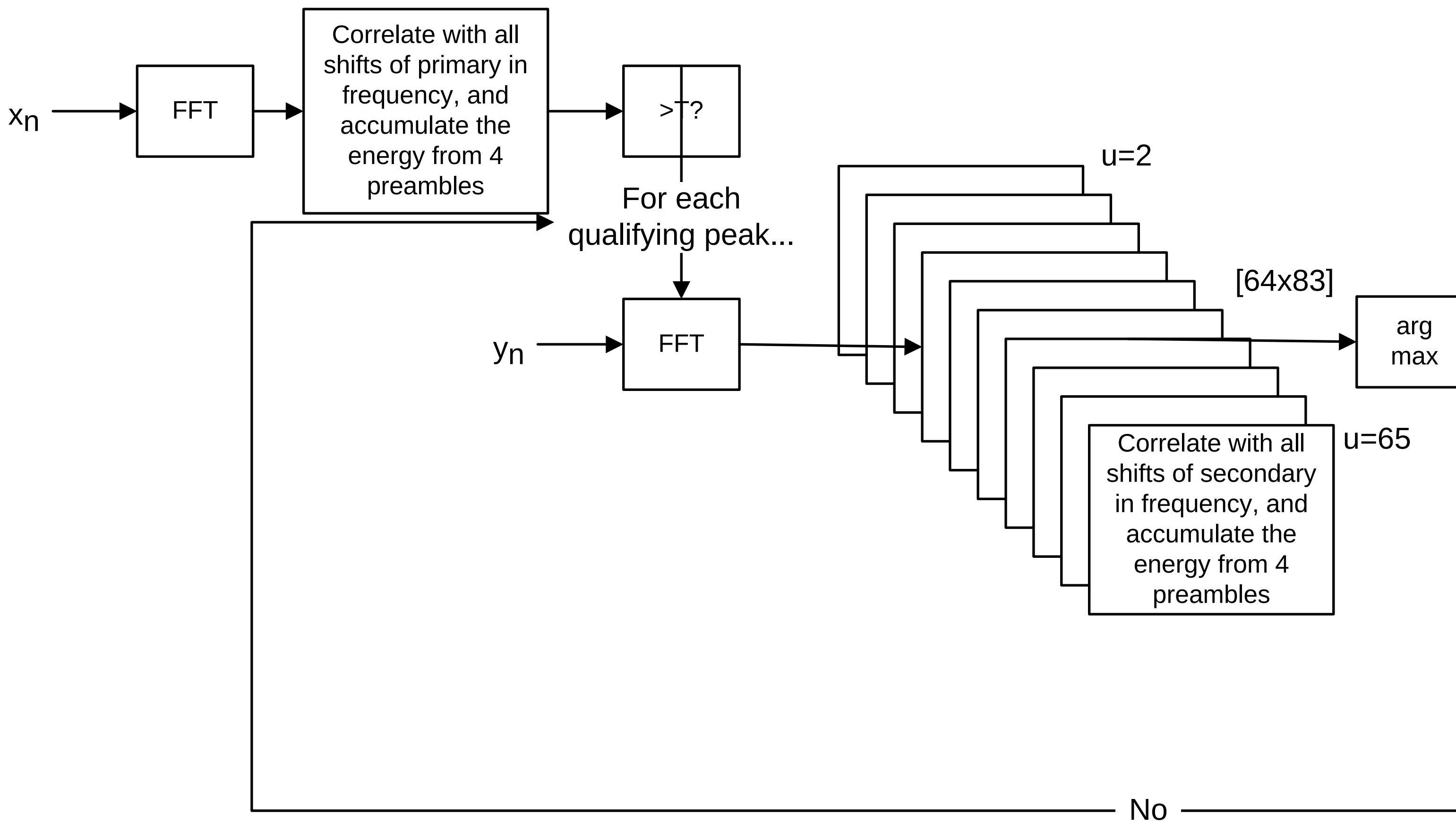

Figure 3 Initial acquisition algorithm for multiple cells

Figure 4 shows the acquisition performance for this scenario. The channels in Table 2 provide test cases. Again, the results are largely insensitive to both the channel chosen and the velocity of the mobile. Because both base stations arrive at equal strength, and because the mobile succeeds if it identifies either correctly, performance has improved from the isolated cell case. A correct base station is identified 99% of the time at an SNR of only -8 dB per subcarrier.

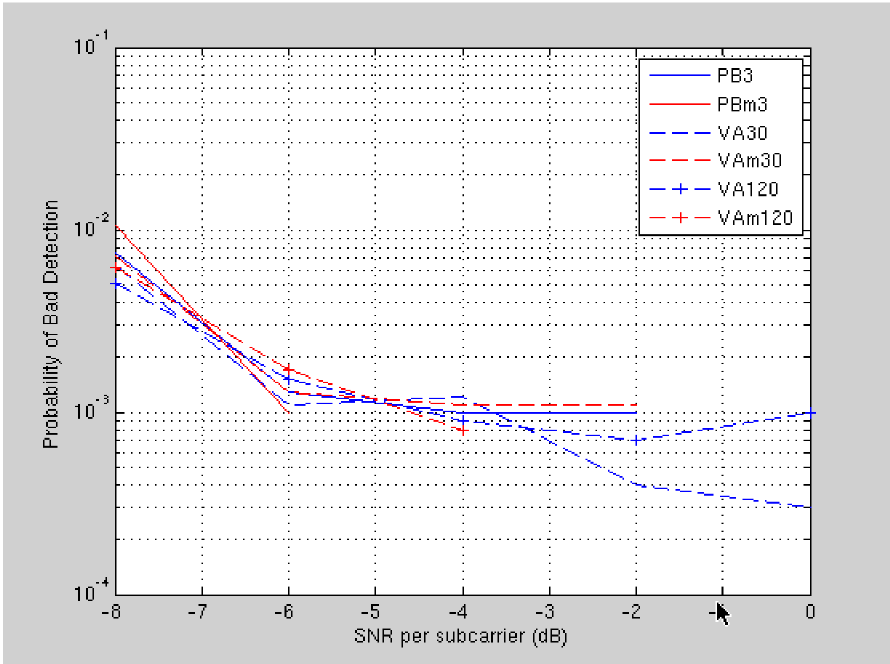

Figure 4 Acquisition performance in a cell with interference.

4 Summary of the Contribution

We have presented a preamble design for 802.16m, which offers the following attractive features

a. It enables fast cell search and system acquisition due to the unique correlation structure of Zadoff-Chu sequences (a special class of CAZAC sequences)
b. Primary and secondary preamble searches can be run in parallel to speed up system timing acquisition
c. No multipliers are needed to perform correlation because Zadoff-Chu sequences are complex roots of unity and cordic techniques can be used instead [2]
d. This scheme reduces preamble overhead relative to 802.16e
e. This scheme enables system acquisition without knowledge of the channel bandwidth
f. Simple acquisition algorithms provide good performance even in the presence of fading and interference.

5 References

[1] IEEE 802.16m-07/002r4. See Section 8.2.

[2] J. Hou et al (ZTE), “Preamble Sequence For Fast Cell Search, Low Computational Complexity, and Low PAPR” (IEEE C802.16e-04/265r1), 28 August 2004.

[3] J. Zhuang et al. (Motorola), “Generalized Chirp-Like-based preamble design for 1024,512 and 128 FFT sizes in the OFDMA PHY layer,” (IEEE C80216e-04/241r1), 29 August 2004.

[4] Ericsson, “Comparison of Zero Cross-Correlation Sequences and Zadoff-Chu Sequences for E-UTRA RACH,” TSG-RAN WG1 LTE AdHoc R1-061869, Cannes, France, June 27–30, 2006.

[5] G. Marsh et al. (NextWave), “Proposal for Downlink Physical Resource Allocation Unit,” C80216m-08_189

[6] IEEE 802.16m-08/004r1 (See Tables 22 and 23 in Section 3.2.9, Mandatory Channel Model).