Synchronization Channel for IEEE 802.16m Amendment

Document Number: IEEE C802.16m-09/0272r1
Date Submitted: 2009-01-07

Source:

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MediaTek Inc.

Venue:

IEEE 802.16m-08/053r1, “Call for Comments and Contributions on Project 802.16m Amendment Working Document”.

- DL PHY control structure

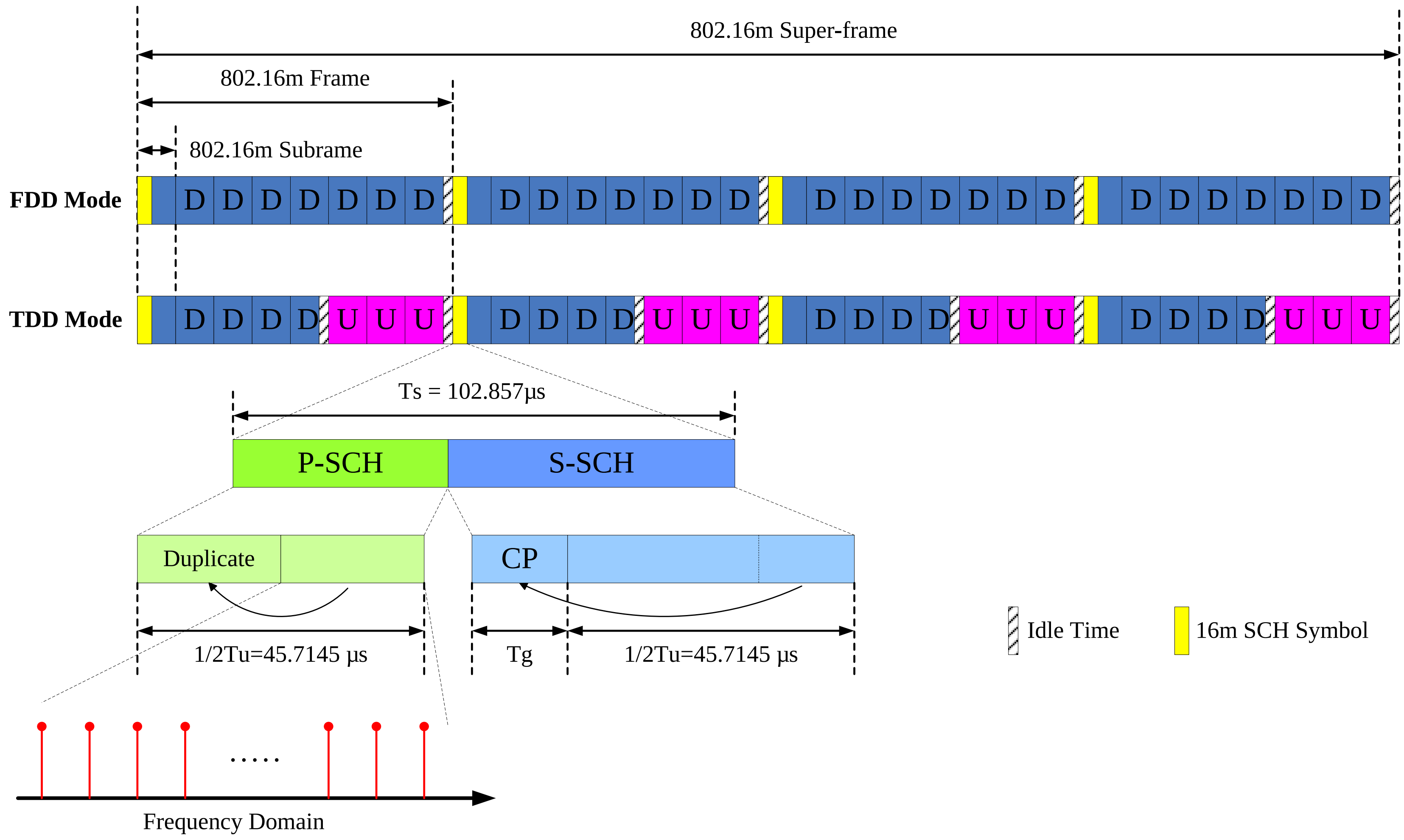
Base Contribution:

This is base contribution.

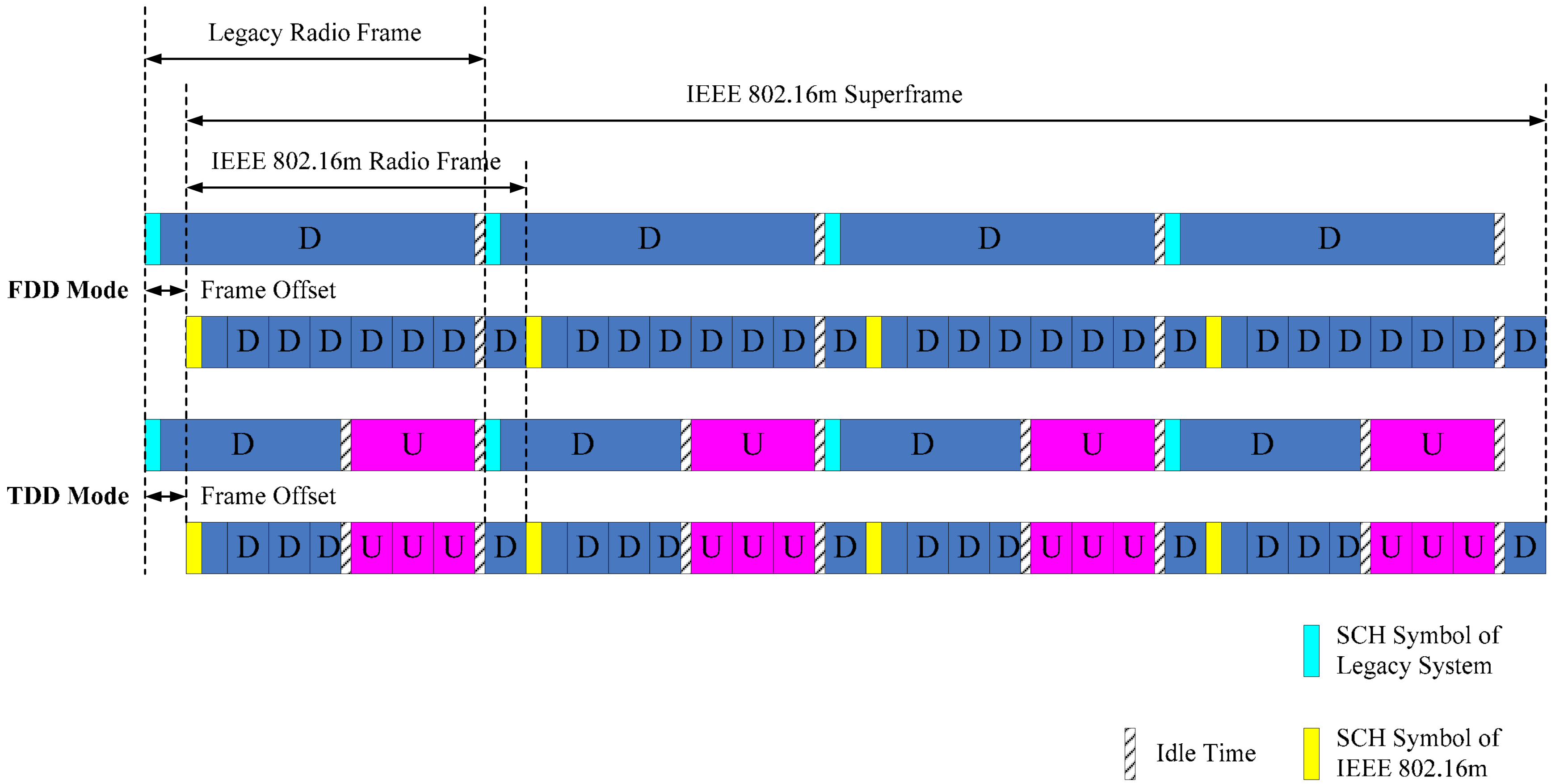
Purpose:

Propose to be discussed and adopted by TGm for IEEE 802.16m Amendment.

SCH Architecture for 802.16m



Legacy Support



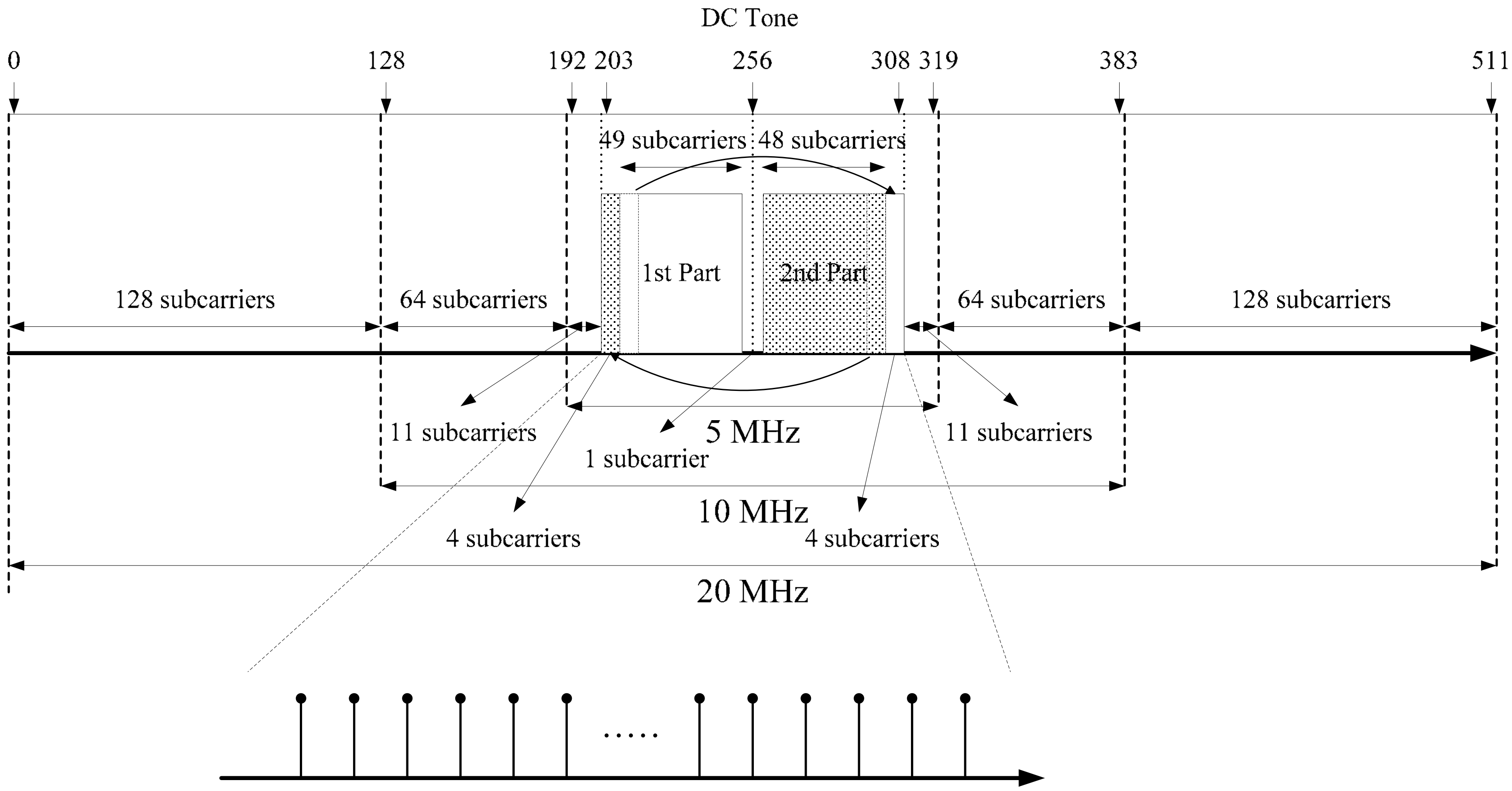
P-SCH Structure (1/2)

- Subcarrier spacing is four times larger than that of regular data OFDM symbols
- Useful subcarrier number is 106
- Binary code with code length 97 is suggested
  - 3 code sequences for different channel bandwidths (512-FFT, 1024-FFT, 2048-FFT) for sector #1
  - 3 code sequences for different channel bandwidths (512-FFT, 1024-FFT, 2048-FFT) for sector #2
  - 3 code sequences for different channel bandwidths (512-FFT, 1024-FFT, 2048-FFT) for sector #3
  - 1 code sequence for non-fully configured carrier
  - Total number of code sequences: 10

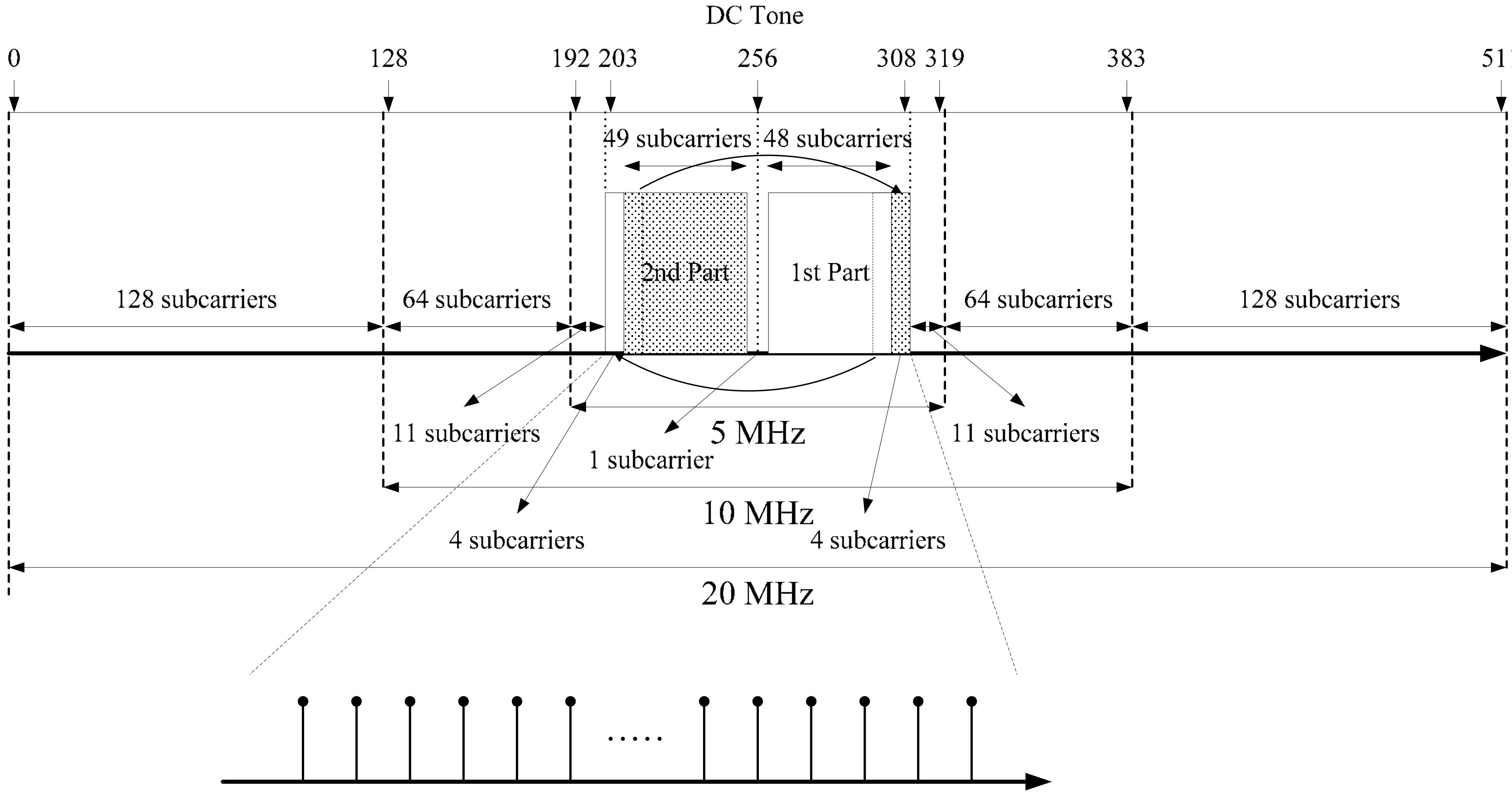
P-SCH Structure (1/2)

- Guard chips are applied to provide better cross-correlation property for code sequence detection
  - Left guard chip: 4 subcarriers
  - Right guard chip: 4 subcarriers
- Code sequence is divided into two parts
  - Different ordering of two parts can be used to differentiate regular frame header from superframe header
- There is 2-period time-domain structure in P-SCH

Frequency-Domain Illustration for Regular Frame



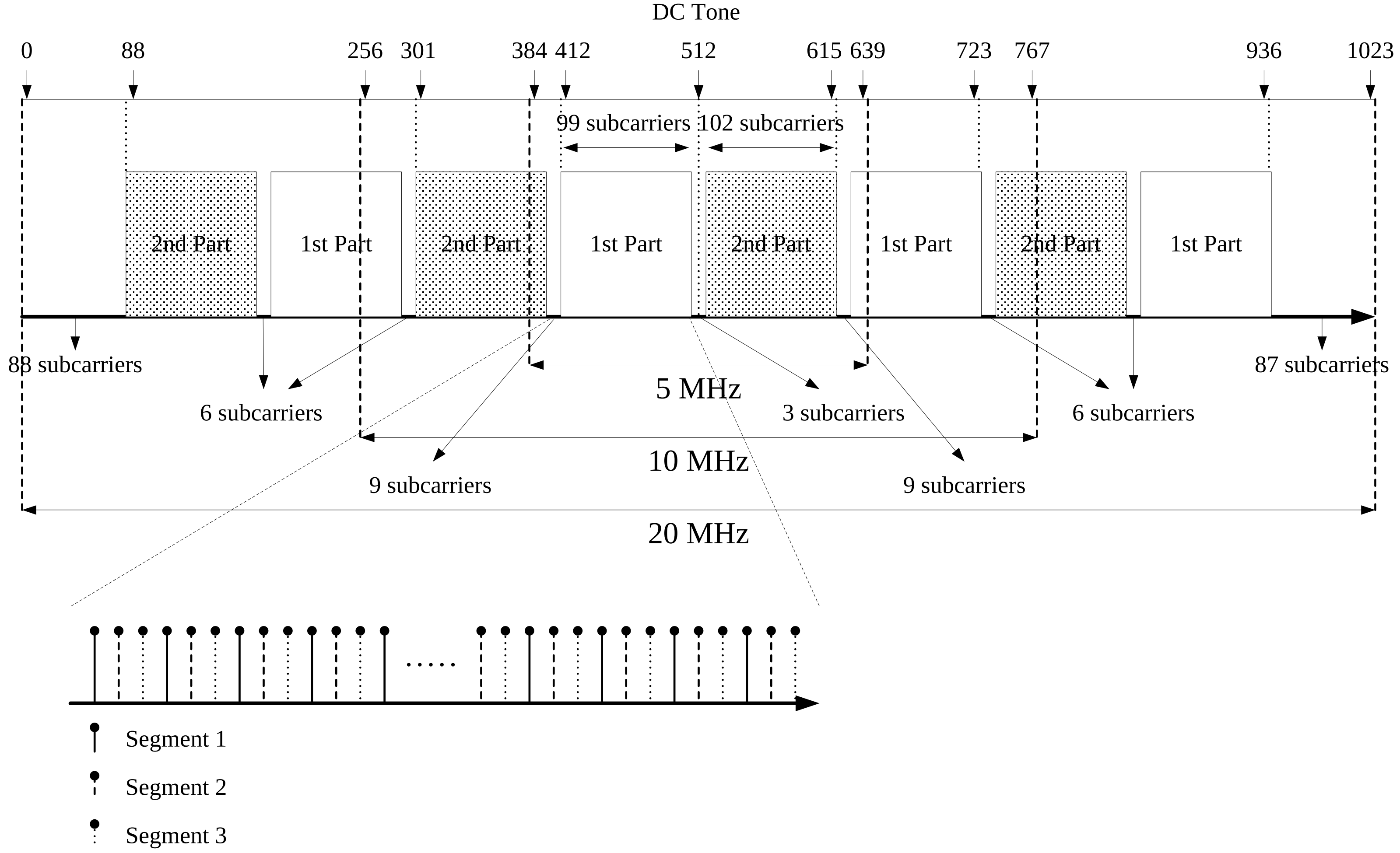
Frequency-Domain Illustration for Superframe



S-SCH Structure

- Subcarrier spacing is two times larger than that of regular data OFDM symbols
- Useful subcarrier number is 204
- Zadoff-Chu or binary code sequences are suggested
  - Since integer frequency offset is already compensated in P-SCH, there is no need to consider it in code sequence design
- Full cell ID information is carried in 5 MHz channel bandwidth
- The code sequence is repeated outside 5 MHz bandwidth if larger channel bandwidth is applied
  - Allow to exploit frequency diversity to alleviate orthogonality destruction effect on code sequences due to frequency selectivity
- There is 3-period time-domain structure in S-SCH
  - Since S-SCH is only half time length of a regular OFDM symbol, there won't be confusion with legacy preamble for legacy MS

Frequency-Domain Illustration



Frequency Reuse Pattern for S-SCH

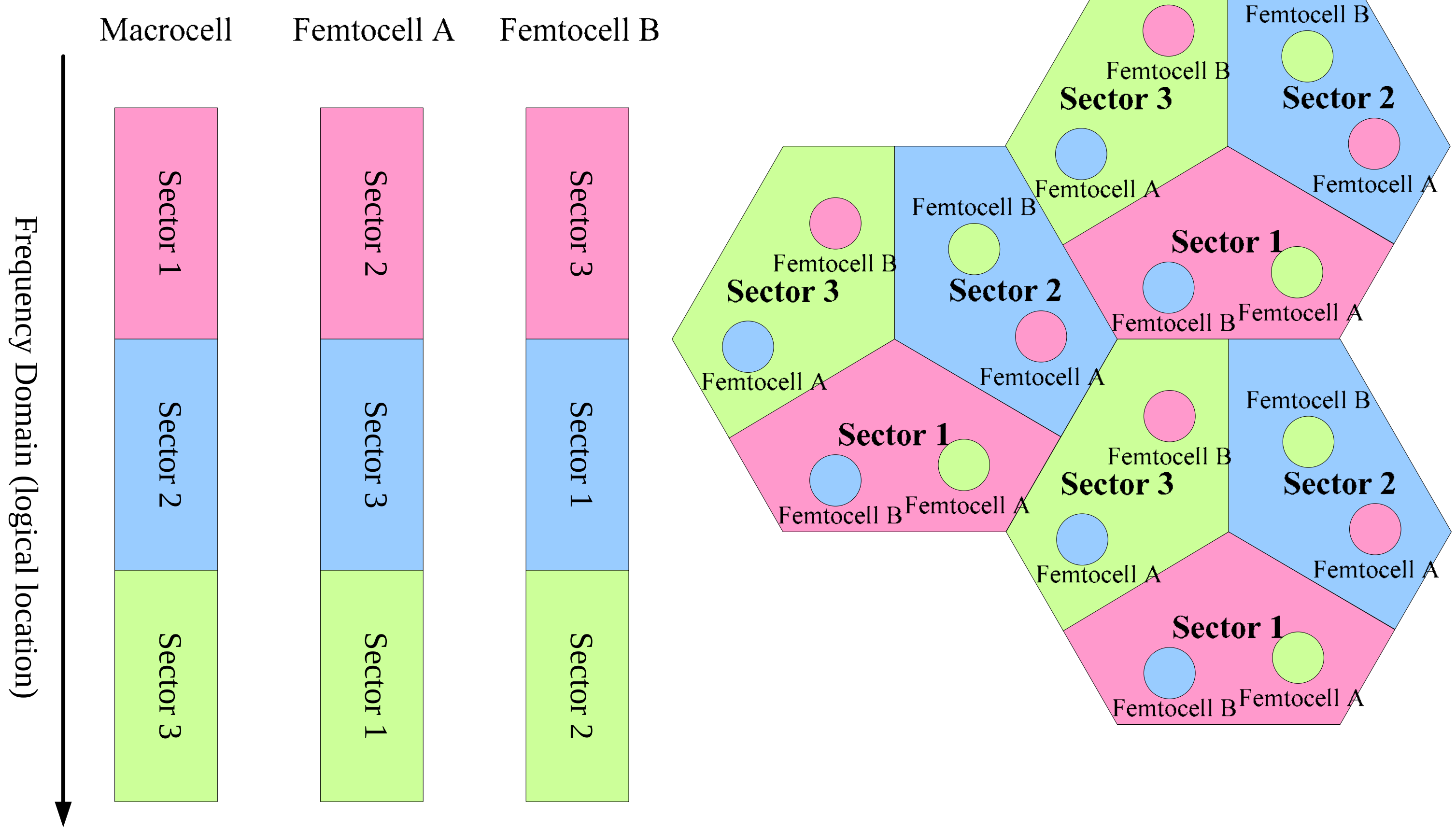
- Different frequency reuse patterns are applied to femtocells and macrocells to reduce interferences between them

- Femtocell can choose the best frequency reuse pattern for itself but it has to be paired with corresponding P-SCH code sequence

- BS-type information can also be obtained by the combination of segment information carried by P-SCH and frequency reuse pattern applied to S-SCH for fast cell ID search

Frequency Reuse Patterns

S-SCH Frequency Reuse Pattern



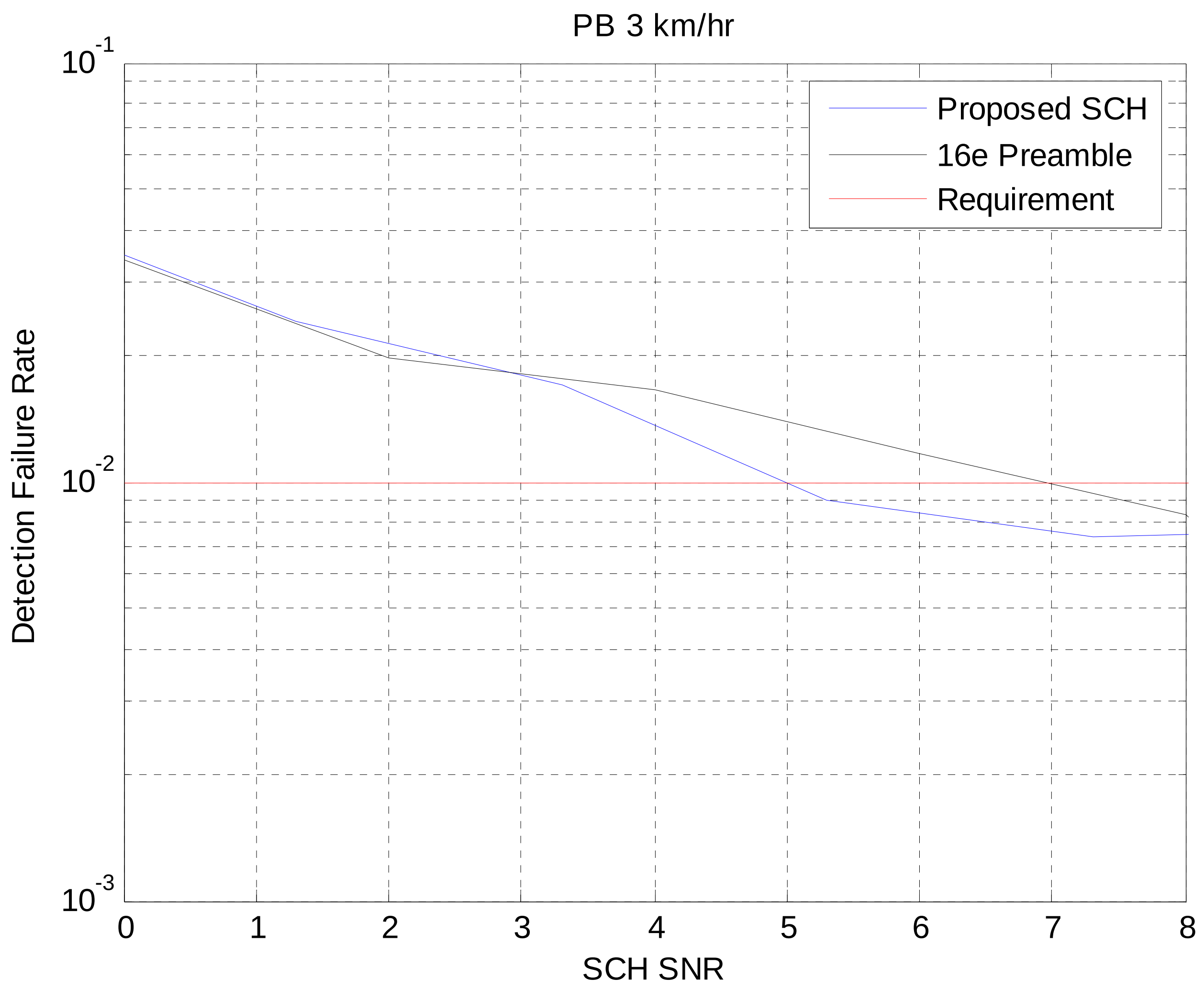
Mapping Table for BS-Type Information

S-SCH \ P-SCH	Code for Sector 1	Code for Sector 2	Code for Sector 3
Frequency Partition Pink	Macrocell	Femtocell A	Femtocell B
Frequency Partition Blue	Femtocell B	Macrocell	Femtocell A
Frequency Partition Green	Femtocell A	Femtocell B	Macrocell

Simulation Assumptions

- SISO case
- 3 cells with SIR = 6 dB
- ITU-R PB 3 km/hr multipath fading channel model
- Frequency offset = 4.8 x 10.9375 KHz
- Timing is assumed imperfect
- Binary code sequences for P-SCH
  - 10 code sequences from 16e preamble code sequences for 128-FFT
- Zadoff-Chu code sequences for S-SCH
  - 520 code sequences
- SNR value is based on SCH time-domain power over noise power

Simulation Results



Conclusion

- A detailed SCH structure is proposed in this contribution
- Even with 520 cell ID for detection, proposed SCH structure is still competitive to 16e preamble
- The performance of proposed SCH can be further improved by optimizing both applied code sequences and detection algorithm
- Text proposal is in the following slides

Text Proposal

---Start of the Text---

[*Add the following into the TGm Amendment Document*]

15.3.7.2.1 Synchronization Channel (SCH)

The synchronization channel (SCH) is a DL physical channel which provides a reference signal for time, frequency, and frame synchronization, RSSI estimation, channel estimation, and BS identification.

Two levels of synchronization hierarchy exist. These are called the primary synchronization channel (P-SCH) and secondary synchronization channel (S-SCH).

The P-SCH transmits one of [10] unique identifications to support the acquisition of physical cell/sector identifications transmitted in S-SCH.
The S-SCH transmits one of [520] complete physical cell/sector identifications.

There are 4 OFDM symbols located every 5 ms for P-/S-SCH in a single superframe and the P-SCH and S-SCH shall share one OFDM symbol in time length as shown in Figure X-1. P-SCH and S-SCH are multiplexed by TDM inside the OFDM symbol. Each pair of P-SCH and S-SCH is located in the first DL subframe of the frame and occupies the 1st symbol position within a subframe.

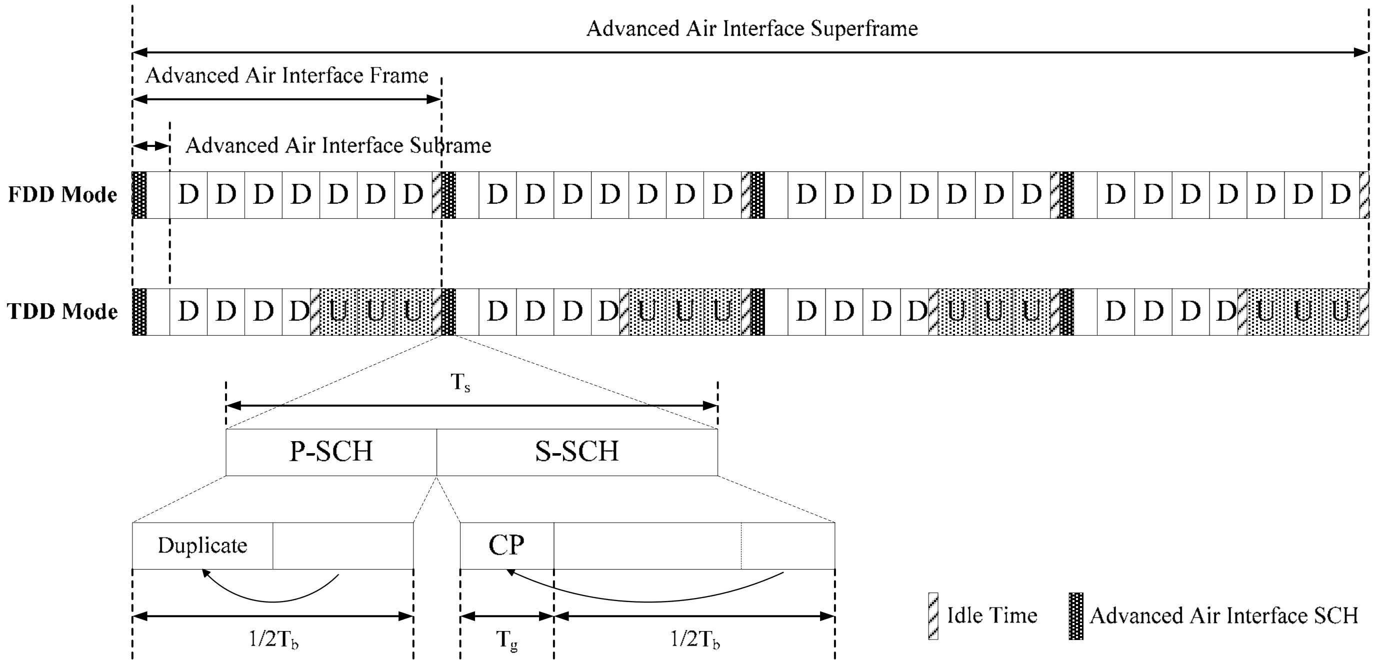


Figure X-1 Advanced Air Interface SCH Architecture

15.3.7.2.1.1 Primary Synchronization Channel (P-SCH)

In P-SCH, frequency reuse 1 shall be applied. The time length of P-SCH is $\frac{1}{2}T_b$ and the occupied channel bandwidth is 5 MHz. The P-SCH is used for initial acquisition, superframe synchronization, channel estimation, and sending additional information.

15.3.7.2.1.1.1 P-SCH Modulation Series

The length of each P-SCH modulation series is [97]. The modulation and power boosting of P-SCH is FFS. The P-SCH series depends on the sector information, system bandwidth, and carrier information.

The series (W_k) used for the P-SCH modulation is defined in Table X-1. Table X-1 includes a set of series in a hexadecimal format. The value of the P-SCH modulation series is obtained by converting the series (W_k) to a binary sequence and mapping the converted sequence starting from the MSB of each symbol to the LSB. (0 mapped to +1 and 1 mapped to –1. For example, W_k = 110000010010..., and the mapping shall follow: –1 –1 +1 +1 +1 +1 +1 –1 +1 +1 –1 +1 ...)

The equation (X-1) defines the mapping rule of the sector information, system bandwidth, and carrier information into P-SCH index, ID_{P-SCH} as follows:

$$ID_{P-SCH} = \begin{cases} N_{Sector} + 3 \cdot N_{BW}, & \text{if } N_{Carrier} = 0 \\ 9 & \text{, if } N_{Carrier} = 1 \end{cases}, \quad \text{(X-1)}$$

where

- N_{Sector} denotes the sector index with 0, 1, and 2.
- N_{BW} denotes the bandwidth indication with 0, 1, and 2, and thus, the indices 0, 1, and 2 represent 512-FFT, 1024-FFT, and 2048-FFT, respectively.
- $N_{Carrier}$ represents the carrier type whether this carrier is a fully-configured carrier, i.e., $N_{Carrier} = 0$, or a partially-configure carrier, i.e., $N_{Carrier} = 1$.

Table X-1 P-SCH modulation series [TBD]

ID_{P-SCH}	Series to modulate (W_k)
0	…
1	…
2	…
3	…
4	…
5	…
6	…
7	…
8	…
9	…

15.3.7.2.1.1.2 Transmission of P-SCH Series

The subcarrier spacing of P-SCH is four times larger than that of a regular data OFDM symbol. Each subcarrier is modulated using a boosted BPSK modulation with a specific series defined in 15.3.7.2.1.1.1. After inverse FFT, the time domain samples are duplicated into two copies to form one P-SCH. In other words, the P-SCH in the time domain has two repeated waveform.

In regular frame header, the subcarrier modulation for P-SCH is provided by the following equation (X-2)

$$Subcarrier(x)_{P-SCH} = \begin{cases} W_k(x - offset + 97), \text{ if } x \geq offset - 4 \text{ and } x \leq offset - 1 \\ W_k(x - offset), \text{ if } x \geq offset \text{ and } x \leq offset + 48 \\ W_k(x - offset - 1), \text{ if } x \geq offset + 50 \text{ and } x \leq offset + 97 \\ W_k(x - offset - 98), \text{ if } x \geq offset + 98 \text{ and } x \leq offset + 101 \\ \text{nulled, otherwise} \end{cases} , \quad \text{(X-2)}$$

where $Subcarrier(x)_{P\text{-}SCH}$ represents the subcarrier with running index x and $W_k(l)$ represents the lth digit of the modulated P-SCH series. x ranges from 0 to 127 and *offset* is equal to 15 for the channel bandwidth of 5 MHz; x ranges from 0 to 255 and *offset* is equal to 79 for the channel bandwidth of 7, 8.75 and 10 MHz; x ranges from 0 to 511 and *offset* is equal to 207 for the channel bandwidth of 20 MHz. Figure X-2 illustrates an example of P-SCH frequency domain structure in regular frame header for channel bandwidths of 5, 10 and 20 MHz.

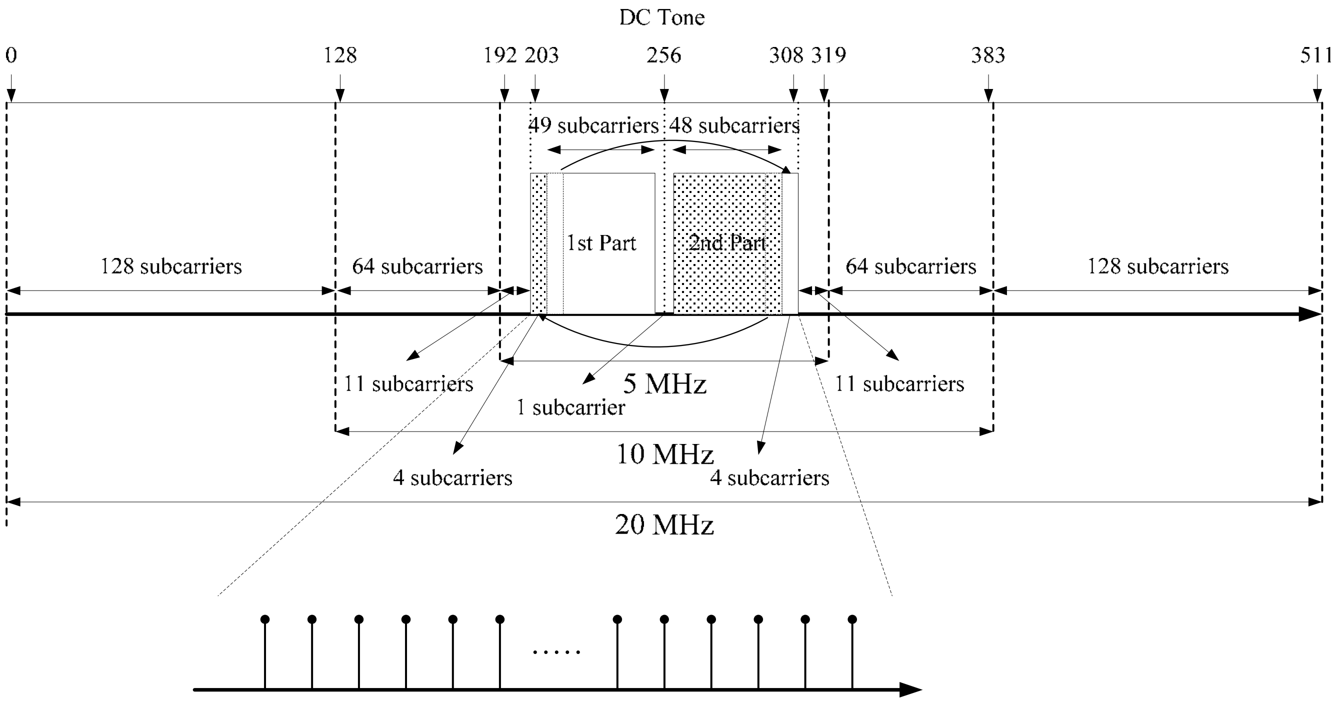


Figure X-2 Example of P-SCH Frequency Domain Structure in Regular Frame Header

In superframe header, the subcarrier modulation for P-SCH is provided by the following equation (X-3)

$$Subcarrier(x)_{P-SCH} = \begin{cases} W_k(x - offset + 4), \text{ if } x \geq offset - 4 \text{ and } x \leq offset - 1 \\ W_k(x - offset + 48), \text{ if } x \geq offset \text{ and } x \leq offset + 48 \\ W_k(x - offset - 50), \text{ if } x \geq offset + 50 \text{ and } x \leq offset + 97 \\ W_k(x - offset - 5), \text{ if } x \geq offset + 98 \text{ and } x \leq offset + 101 \\ \text{nulled, otherwise} \end{cases}, \quad \text{(X-3)}$$

where $Subcarrier(x)_{P\text{-}SCH}$ represents the subcarrier with running index x and $W_k(l)$ represents the lth digit of the modulated P-SCH series. x ranges from 0 to 127 and *offset* is equal to 15 for the channel bandwidth of 5 MHz; x ranges from 0 to 255 and *offset* is equal to 79 for the channel bandwidth of 7, 8.75 and 10 MHz; x ranges from 0 to 511 and *offset* is equal to 207 for the channel bandwidth of 20 MHz. Figure X-3 illustrates an example of P-SCH frequency domain structure in superframe header for channel bandwidths of 5, 10 and 20 MHz.

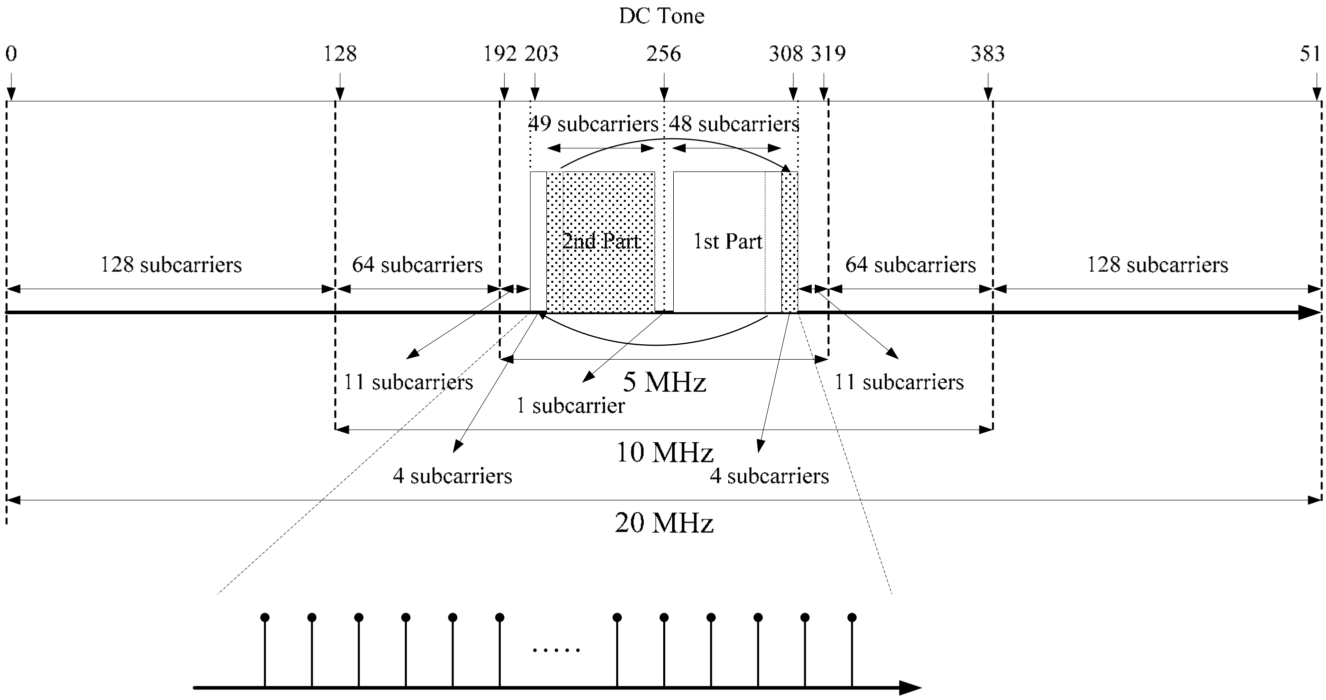


Figure X-3 Example of P-SCH Frequency Domain Structure in Superframe Header

15.3.7.2.1.2 Secondary Synchronization Channel (S-SCH)

In S-SCH, frequency reuse 3 shall be applied. The time length of S-SCH is $T_g + \frac{1}{2}T_b$ and S-SCH occupies full bandwidth. The S-SCH is used for fine synchronization, RSSI measurement, and cell/sector identification (ID).

15.3.7.2.1.2.1 S-SCH Modulation Series

The length of each S-SCH modulation series is [67] for any channel bandwidth. Full cell ID information shall be carried inside the minimal supported channel bandwidth – 5 MHz. The modulation and power boosting of S-

SCH is FFS.

The S-SCH series modulating the subcarriers is generated from Zadoff-Chu sequences with parameters *u* and *S* defined in Table X-2.1~2.4, where Table X-2.4 is for femtocells only.

Table X-2.1 S-SCH modulation series [FFS]

Cell ID	Segment	u	S	Cell ID	Segment	u	S	Cell ID	Segment	u	S
0	0	1	0	60	0	9	0	120	0	17	0
1	1	1	5	61	1	9	5	121	1	17	5
2	2	1	10	62	2	9	10	122	2	17	10
3	0	1	15	63	0	9	15	123	0	17	15
4	1	1	20	64	1	9	20	124	1	17	20
5	2	1	25	65	2	9	25	125	2	17	25
6	0	1	30	66	0	9	30	126	0	17	30
7	1	1	35	67	1	9	35	127	1	17	35
8	2	1	40	68	2	9	40	128	2	17	40
9	0	1	45	69	0	9	45	129	0	17	45
10	1	1	50	70	1	9	50	130	1	17	50
11	2	1	55	71	2	9	55	131	2	17	55
12	0	2	0	72	0	10	0	132	0	18	0
13	1	2	5	73	1	10	5	133	1	18	5
14	2	2	10	74	2	10	10	134	2	18	10
15	0	2	15	75	0	10	15	135	0	18	15
16	1	2	20	76	1	10	20	136	1	18	20
17	2	2	25	77	2	10	25	137	2	18	25
18	0	2	30	78	0	10	30	138	0	18	30
19	1	2	35	79	1	10	35	139	1	18	35
20	2	2	40	80	2	10	40	140	2	18	40
21	0	2	45	81	0	10	45	141	0	18	45
22	1	2	50	82	1	10	50	142	1	18	50
23	2	2	55	83	2	10	55	143	2	18	55
24	0	3	0	84	0	12	0	144	0	21	0
25	1	3	5	85	1	12	5	145	1	21	5
26	2	3	10	86	2	12	10	146	2	21	10
27	0	3	15	87	0	12	15	147	0	21	15
28	1	3	20	88	1	12	20	148	1	21	20
29	2	3	25	89	2	12	25	149	2	21	25
30	0	3	30	90	0	12	30	150	0	21	30
31	1	3	35	91	1	12	35	151	1	21	35

32	2	3	40	92	2	12	40	152	2	21	40
33	0	3	45	93	0	12	45	153	0	21	45
34	1	3	50	94	1	12	50	154	1	21	50
35	2	3	55	95	2	12	55	155	2	21	55
36	0	4	0	96	0	14	0	156	0	22	0
37	1	4	5	97	1	14	5	157	1	22	5
38	2	4	10	98	2	14	10	158	2	22	10
39	0	4	15	99	0	14	15	159	0	22	15
40	1	4	20	100	1	14	20	160	1	22	20
41	2	4	25	101	2	14	25	161	2	22	25
42	0	4	30	102	0	14	30	162	0	22	30
43	1	4	35	103	1	14	35	163	1	22	35
44	2	4	40	104	2	14	40	164	2	22	40
45	0	4	45	105	0	14	45	165	0	22	45
46	1	4	50	106	1	14	50	166	1	22	50
47	2	4	55	107	2	14	55	167	2	22	55
48	0	7	0	108	0	16	0	168	0	24	0
49	1	7	5	109	1	16	5	169	1	24	5
50	2	7	10	110	2	16	10	170	2	24	10
51	0	7	15	111	0	16	15	171	0	24	15
52	1	7	20	112	1	16	20	172	1	24	20
53	2	7	25	113	2	16	25	173	2	24	25
54	0	7	30	114	0	16	30	174	0	24	30
55	1	7	35	115	1	16	35	175	1	24	35
56	2	7	40	116	2	16	40	176	2	24	40
57	0	7	45	117	0	16	45	177	0	24	45
58	1	7	50	118	1	16	50	178	1	24	50
59	2	7	55	119	2	16	55	179	2	24	55

Table X-2.2 S-SCH modulation series [FFS]

Cell ID	Segment	u	S	Cell ID	Segment	u	S	Cell ID	Segment	u	S
180	0	26	0	240	0	34	0	300	0	43	0
181	1	26	5	241	1	34	5	301	1	43	5
182	2	26	10	242	2	34	10	302	2	43	10
183	0	26	15	243	0	34	15	303	0	43	15
184	1	26	20	244	1	34	20	304	1	43	20
185	2	26	25	245	2	34	25	305	2	43	25
186	0	26	30	246	0	34	30	306	0	43	30
187	1	26	35	247	1	34	35	307	1	43	35

188	2	26	40	248	2	34	40	308	2	43	40
189	0	26	45	249	0	34	45	309	0	43	45
190	1	26	50	250	1	34	50	310	1	43	50
191	2	26	55	251	2	34	55	311	2	43	55
192	0	28	0	252	0	35	0	312	0	45	0
193	1	28	5	253	1	35	5	313	1	45	5
194	2	28	10	254	2	35	10	314	2	45	10
195	0	28	15	255	0	35	15	315	0	45	15
196	1	28	20	256	1	35	20	316	1	45	20
197	2	28	25	257	2	35	25	317	2	45	25
198	0	28	30	258	0	35	30	318	0	45	30
199	1	28	35	259	1	35	35	319	1	45	35
200	2	28	40	260	2	35	40	320	2	45	40
201	0	28	45	261	0	35	45	321	0	45	45
202	1	28	50	262	1	35	50	322	1	45	50
203	2	28	55	263	2	35	55	323	2	45	55
204	0	30	0	264	0	37	0	324	0	46	0
205	1	30	5	265	1	37	5	325	1	46	5
206	2	30	10	266	2	37	10	326	2	46	10
207	0	30	15	267	0	37	15	327	0	46	15
208	1	30	20	268	1	37	20	328	1	46	20
209	2	30	25	269	2	37	25	329	2	46	25
210	0	30	30	270	0	37	30	330	0	46	30
211	1	30	35	271	1	37	35	331	1	46	35
212	2	30	40	272	2	37	40	332	2	46	40
213	0	30	45	273	0	37	45	333	0	46	45
214	1	30	50	274	1	37	50	334	1	46	50
215	2	30	55	275	2	37	55	335	2	46	55
216	0	32	0	276	0	39	0	336	0	49	0
217	1	32	5	277	1	39	5	337	1	49	5
218	2	32	10	278	2	39	10	338	2	49	10
219	0	32	15	279	0	39	15	339	0	49	15
220	1	32	20	280	1	39	20	340	1	49	20
221	2	32	25	281	2	39	25	341	2	49	25
222	0	32	30	282	0	39	30	342	0	49	30
223	1	32	35	283	1	39	35	343	1	49	35
224	2	32	40	284	2	39	40	344	2	49	40
225	0	32	45	285	0	39	45	345	0	49	45
226	1	32	50	286	1	39	50	346	1	49	50
227	2	32	55	287	2	39	55	347	2	49	55

228	0	33	0	288	0	41	0	348	0	50	0
229	1	33	5	289	1	41	5	349	1	50	5
230	2	33	10	290	2	41	10	350	2	50	10
231	0	33	15	291	0	41	15	351	0	50	15
232	1	33	20	292	1	41	20	352	1	50	20
233	2	33	25	293	2	41	25	353	2	50	25
234	0	33	30	294	0	41	30	354	0	50	30
235	1	33	35	295	1	41	35	355	1	50	35
236	2	33	40	296	2	41	40	356	2	50	40
237	0	33	45	297	0	41	45	357	0	50	45
238	1	33	50	298	1	41	50	358	1	50	50
239	2	33	55	299	2	41	55	359	2	50	55

Table X-2.3 S-SCH modulation series [FFS]

Cell ID	Segment	u	S	Cell ID	Segment	u	S	Cell ID	Segment	u	S
360	0	51	0	380	2	53	40	400	1	57	20
361	1	51	5	381	0	53	45	401	2	57	25
362	2	51	10	382	1	53	50	402	0	57	30
363	0	51	15	383	2	53	55	403	1	57	35
364	1	51	20	384	0	55	0	404	2	57	40
365	2	51	25	385	1	55	5	405	0	57	45
366	0	51	30	386	2	55	10	406	1	57	50
367	1	51	35	387	0	55	15	407	2	57	55
368	2	51	40	388	1	55	20	408	0	58	0
369	0	51	45	389	2	55	25	409	1	58	5
370	1	51	50	390	0	55	30	410	2	58	10
371	2	51	55	391	1	55	35	411	0	58	15
372	0	53	0	392	2	55	40	412	1	58	20
373	1	53	5	393	0	55	45	413	2	58	25
374	2	53	10	394	1	55	50	414	0	58	30
375	0	53	15	395	2	55	55	415	1	58	35
376	1	53	20	396	0	57	0	416	2	58	40
377	2	53	25	397	1	57	5	417	0	58	45
378	0	53	30	398	2	57	10	418	1	58	50
379	1	53	35	399	0	57	15	419	2	58	55

Table X-2.4 S-SCH modulation series for femtocells [FFS]

Cell ID	Segment	u	S	Cell ID	Segment	u	S	Cell ID	Segment	u	S
420	0	60	0	454	1	64	50	488	2	14	60
421	1	60	5	455	2	64	55	489	0	16	60
422	2	60	10	456	0	65	0	490	1	17	60
423	0	60	15	457	1	65	5	491	2	18	60
424	1	60	20	458	2	65	10	492	0	21	60
425	2	60	25	459	0	65	15	493	1	22	60
426	0	60	30	460	1	65	20	494	2	24	60
427	1	60	35	461	2	65	25	495	0	26	60
428	2	60	40	462	0	65	30	496	1	28	60
429	0	60	45	463	1	65	35	497	2	30	60
430	1	60	50	464	2	65	40	498	0	32	60
431	2	60	55	465	0	65	45	499	1	33	60
432	0	63	0	466	1	65	50	500	2	34	60
433	1	63	5	467	2	65	55	501	0	35	60
434	2	63	10	468	0	66	0	502	1	37	60
435	0	63	15	469	1	66	5	503	2	39	60
436	1	63	20	470	2	66	10	504	0	41	60
437	2	63	25	471	0	66	15	505	1	43	60
438	0	63	30	472	1	66	20	506	2	45	60
439	1	63	35	473	2	66	25	507	0	46	60
440	2	63	40	474	0	66	30	508	1	49	60
441	0	63	45	475	1	66	35	509	2	50	60
442	1	63	50	476	2	66	40	510	0	51	60
443	2	63	55	477	0	66	45	511	1	53	60
444	0	64	0	478	1	66	50	512	2	55	60
445	1	64	5	479	2	66	55	513	0	57	60
446	2	64	10	480	0	1	60	514	1	58	60
447	0	64	15	481	1	2	60	515	2	60	60
448	1	64	20	482	2	3	60	516	0	63	60
449	2	64	25	483	0	4	60	517	1	64	60
450	0	64	30	484	1	7	60	518	2	65	60
451	1	64	35	485	2	9	60	519	0	66	60
452	2	64	40	486	0	10	60				
453	0	64	45	487	1	12	60				

15.3.7.2.1.2.2 Transmission of S-SCH Series

The subcarrier spacing of S-SCH is two times larger than that of a regular data OFDM symbol. Every third subcarrier is modulated using a boosted value with a specific series defined in 15.3.7.2.1.2.1. The subcarrier modulation for S-SCH is provided by the following equations, which are FFS. DC tone shall be nulled.

Figure X-4 illustrates an example of S-SCH frequency domain structure for channel bandwidths of 5, 10 and 20 MHz.

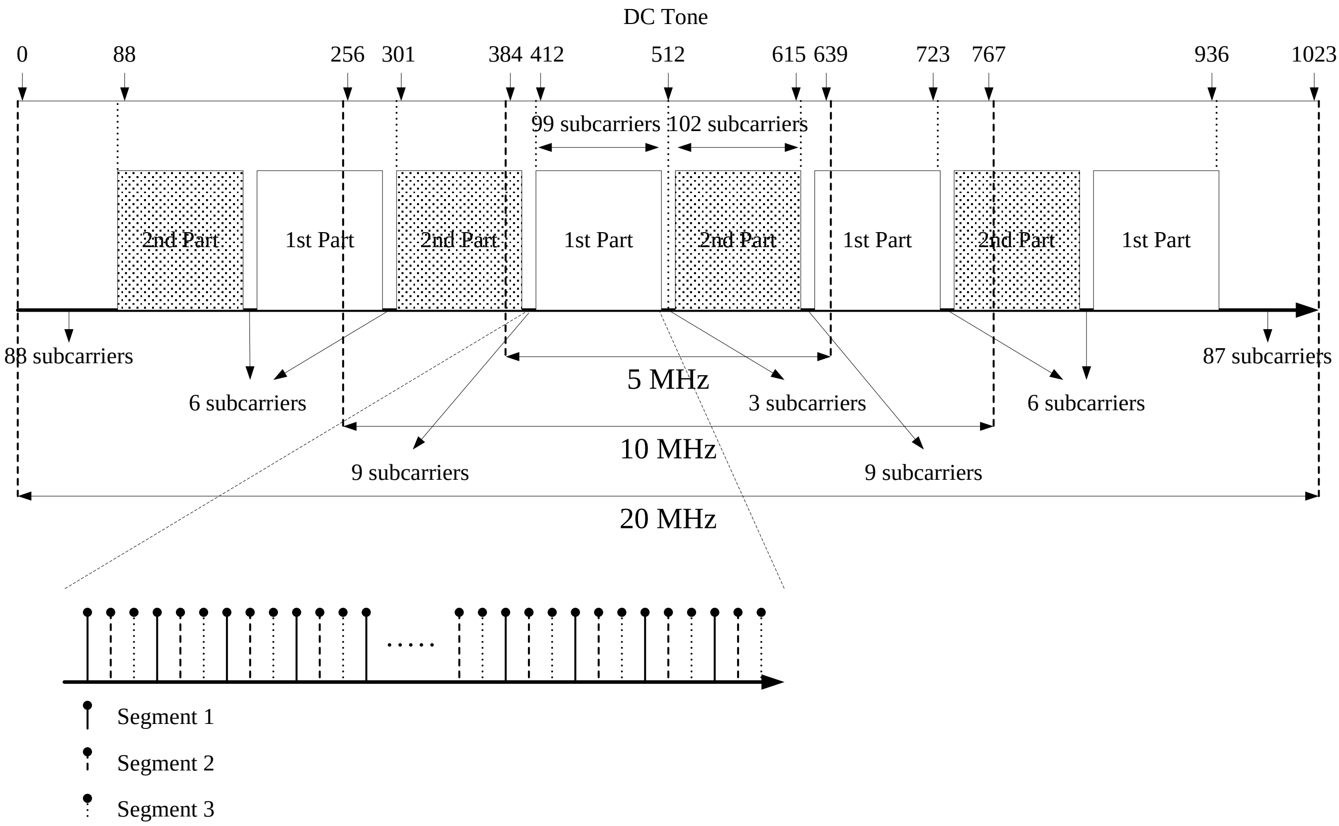


Figure X-4 Example of S-SCH Frequency Domain Structure

For the deployment of femtocells, interferences between femtocells and other cells in S-SCH shall be mitigated. The interference mitigation scheme is FFS.

15.3.7.2.1.3 Support of WirelessMAN-OFDMA

Advanced Air Interface shall exist in both green field and mixed deployments. In mixed deployments, the WirelessMAN-OFDMA preamble shall be always present. The Advanced Air Interface SCH shall enable AMSs to synchronize in frequency and time without requiring WirelessMAN-OFDMA preamble.

Figure X-5 shows an example of Advanced Air Interface SCH architecture in mixed deployments.

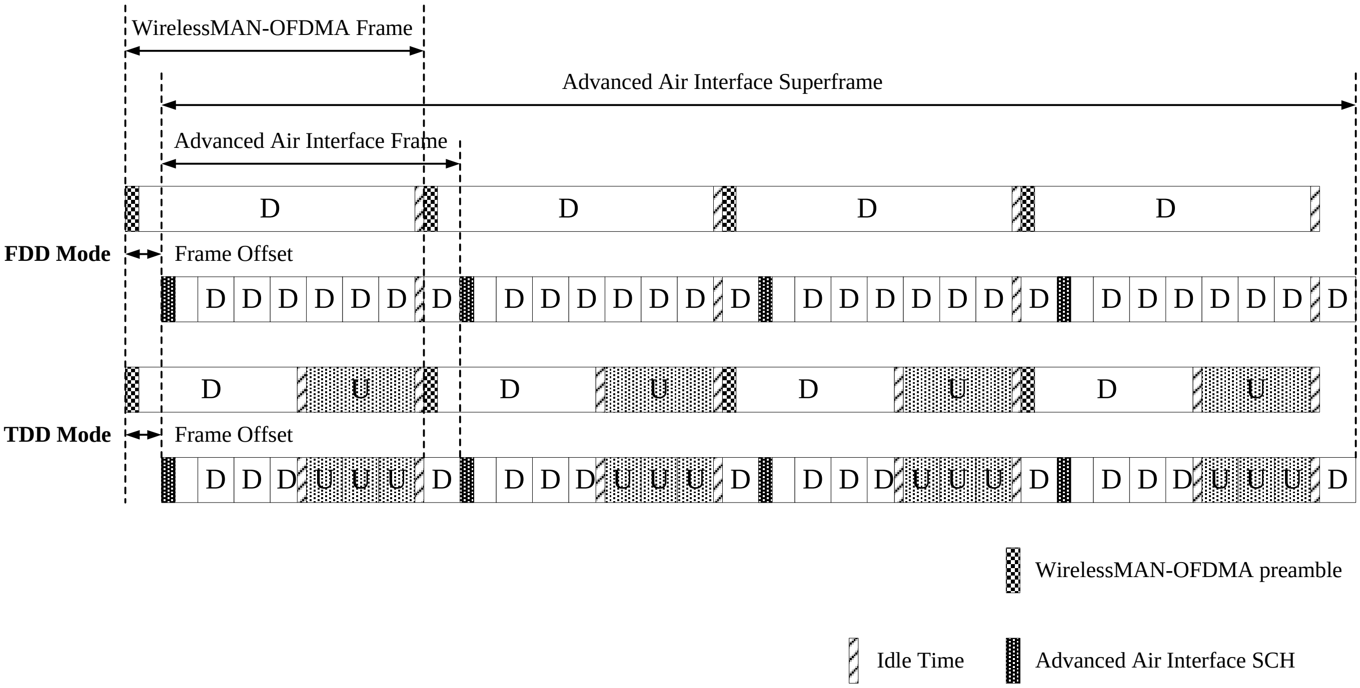


Figure X-5 Advanced Air Interface SCH Architecture Supporting WirelessMAN-OFDMA

--End of the Text--

Appendix

Related Issues (1/3)

- Is there any ISI?
  - No, since the repeated waveform in P-SCH is generated by duplicate one time domain sequence into two copies, the first copy plays a role of CP and there is no ISI anymore
- Do we have to apply different sampling frequency?
  - No, sampling frequency remains the same as regular data OFDM symbols. The only difference is shorter symbol time.
- Do we need another FFT size for P-SCH and S-SCH?
  - No, we can reuse original FFT size by rearranging the sequence and multiplying a normalized factor to it
  - However, MS still needs to keep 3 FFT sizes to adapt to different channel bandwidths
    - 512-FFT, 1024-FFT and 2048-FFT

Related Issues (2/3)

- 128-point Fourier transform using 512-FFT
  - Step 1: Upsample time domain series from the length of 128 to 512 by inserting three zeros between any two consecutive non-zero values
  - Step 2: Use 512-FFT for the upsampled series
  - Step 3: Take the first 128 values
  - Step 4: Multiply these 128 values by $\sqrt{4}$

- 128-point Inverse Fourier transform using 512-IFFT
  - Step 1: Upsample frequency domain series from the length of 128 to 512 by inserting three zeros between any two consecutive non-zero values
  - Step 2: Use 512-IFFT for the upsampled series
  - Step 3: Take the first 128 values
  - Step 4: Multiply these 128 values by $\sqrt{4}$

Related Issues (3/3)

- Shorter P-SCH will induce less collected energy for SCH detection?
  - Autocorrelation algorithm is to utilize the time domain structure of SCH for detection
  - Proposed SCH architecture has very unique time domain structure than regular data OFDM symbols and it can be utilized for SCH detection
  - Autocorrelation algorithm can be modified to improve the detection performance
    - Two suggestions are illustrated in the following slides

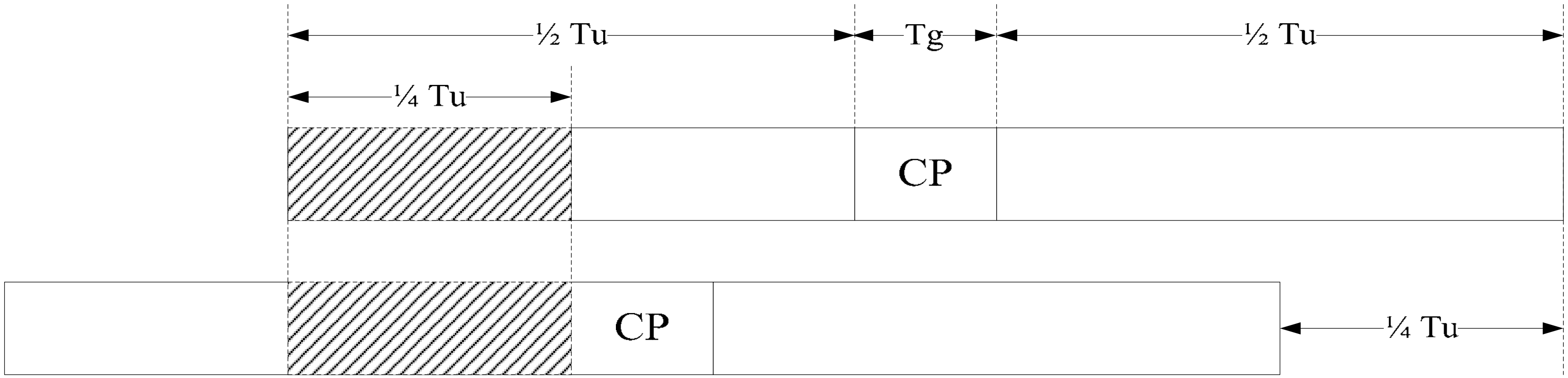
SCH Autocorrelation Detection (1/3)

- Auto-correlation approach can be applied
  - Prior art: S&C algorithm, ***1/4Tu×P*** energy can be collected

$$\Gamma(\tilde{t}) = \frac{\sum_{k=\tilde{t}}^{\tilde{t}+N/4-1} r(k+N/4)r^*(k)}{\sum_{k=\tilde{t}}^{\tilde{t}+N/4-1} \left|r(k+N/4)\right|^2},$$

$$\hat{t} = \arg\max_{\tilde{t}} \left\{ \left|\Gamma(\tilde{t})\right|^2 \right\},$$

where N is the FFT size of a regular OFDM symbol, $r(\bullet)$ is the received signal.

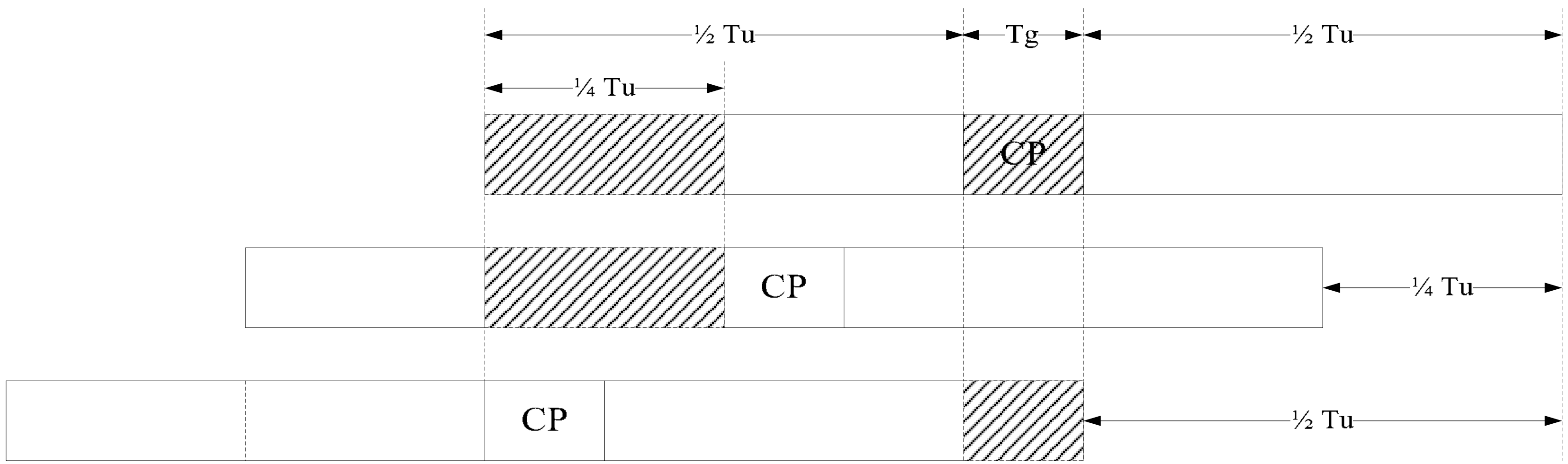


SCH Autocorrelation Detection (2/3)

- To collect more energy for SCH timing detection, auto-correlation approach is modified
  - Algorithm 01: ***3/8Tu×P*** energy can be collected

$$\Gamma(\tilde{t}) = \frac{\sum_{k=\tilde{t}}^{\tilde{t}+N/4-1} r(k+N/4)r^*(k) + \sum_{k=\tilde{t}+N/2}^{\tilde{t}+N/2+N/8-1} r(k+N/2)r^*(k)}{\sum_{k=\tilde{t}}^{\tilde{t}+N/4-1} \left|r(k+N/4)\right|^2 + \sum_{k=\tilde{t}+N/2}^{\tilde{t}+N/2+N/8-1} \left|r(k+N/2)\right|^2},$$

$$\hat{t} = \arg\max_{\tilde{t}} \left\{ \left|\Gamma(\tilde{t})\right|^2 \right\}$$

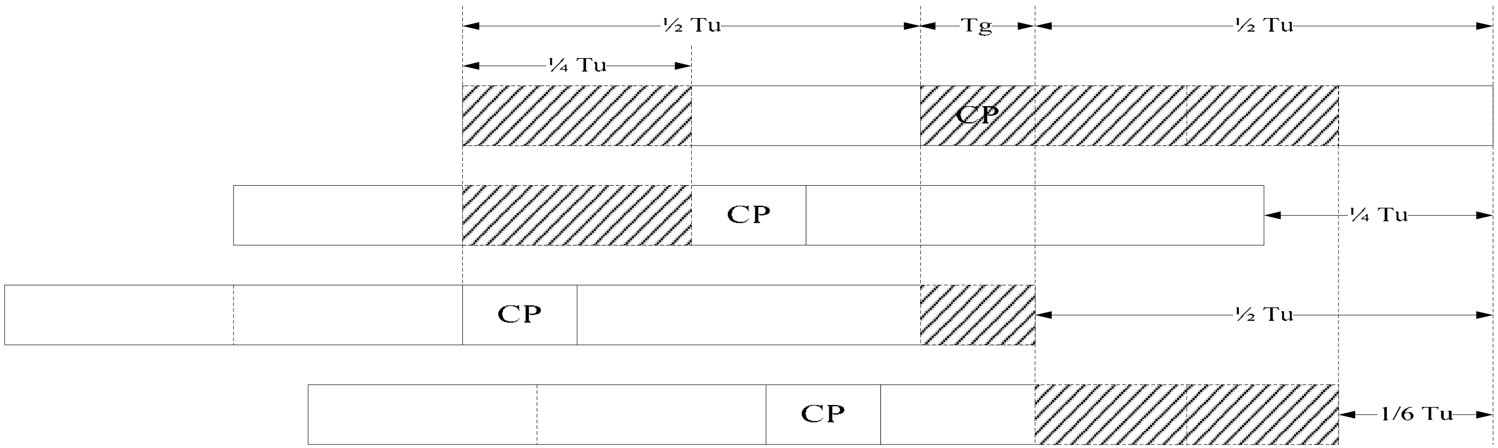


SCH Autocorrelation Detection (3/3)

- To collect more energy for SCH timing detection, auto-correlation approach is modified
  - Algorithm 02: ***17/24Tu×P*** energy can be collected if there is 3-period time domain structure in S-SCH

$$\Gamma(\tilde{t}) = \frac{\sum_{k=\tilde{t}}^{\tilde{t}+N/4-1} r(k+N/4)r^*(k) + \sum_{k=\tilde{t}+N/2}^{\tilde{t}+N/2+N/8-1} r(k+N/2)r^*(k) + \sum_{k=\tilde{t}+N/2+N/8}^{\tilde{t}+N/2+N/8+\lfloor N/3 \rfloor} r(k+\lfloor N/6 \rfloor)r^*(k)}{\sum_{k=\tilde{t}}^{\tilde{t}+N/4-1} |r(k+N/4)|^2 + \sum_{k=\tilde{t}+N/2}^{\tilde{t}+N/2+N/8-1} |r(k+N/2)|^2 + \sum_{k=\tilde{t}+N/2+N/8}^{\tilde{t}+N/2+N/8+\lfloor N/3 \rfloor} |r(k+\lfloor N/6 \rfloor)|^2},$$

$$\hat{t} = \arg\max_{\tilde{t}} \left\{ |\Gamma(\tilde{t})|^2 \right\}$$



Remarks

- Collected energy is small if directly applying S&C algorithm to P-SCH in proposed SCH architecture
  - Only ***1/4Tu×P*** energy can be collected

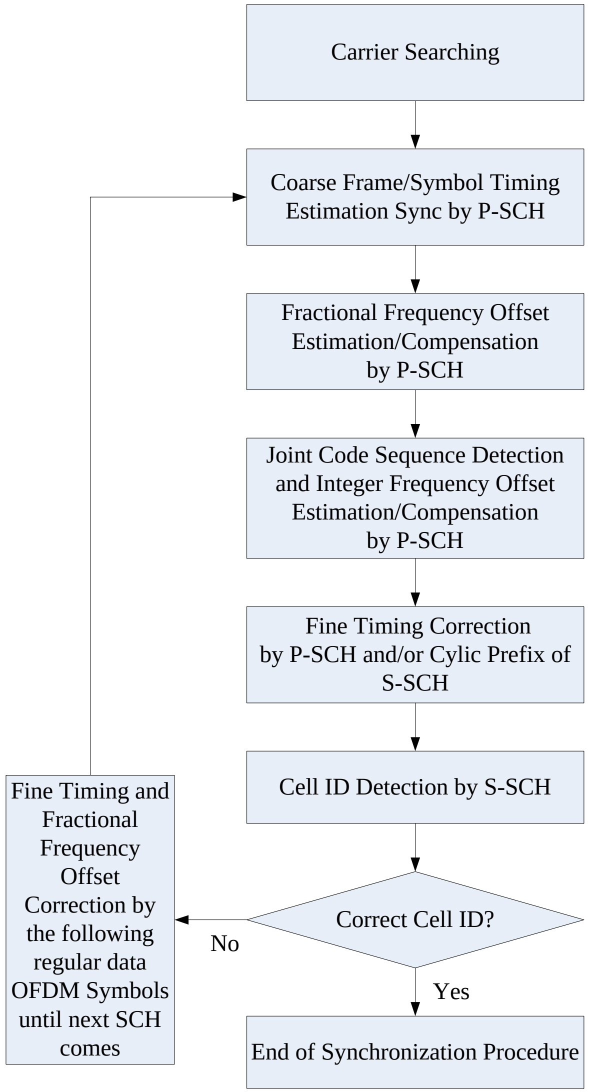
- Due to unique structure of proposed SCH architecture, the modified auto-correlation algorithm can collect more energy to achieve better preciseness of SCH timing detection
  - Algorithm 01: ***3/8Tu×P*** energy can be collected
  - Algorithm 02: ***17/24Tu×P*** energy can be collected if there is 3-period time domain structure in S-SCH

Synchronization Procedure (1/4)

Single-carrier Scenario:

- Step 1: Carrier searching
- Step 2: Coarse timing estimation using SCH time-domain structure
- Step 3: Fractional frequency offset estimation/compensation using P-SCH
- Step 4: Joint code sequence detection and integer frequency offset estimation/compensation using P-SCH
- Step 5: Fine timing correction using P-SCH and/or the cyclic prefix of S-SCH
- Step 6: Cell ID detection using S-SCH
- Step 7: Check if detected cell ID is correct
  - Yes, synchronization procedure completed
  - No, adjust OFDM symbol timing and fractional frequency offset compensation by the following regular data OFDM symbols until next SCH comes and then go to step 2
    - Step 2 and step 3, which can skipped, are for confirmation of symbol timing and fractional frequency offset estimation

Synchronization Procedure (2/4)



Synchronization Procedure (3/4)

Multi-carrier Scenario:

- Step 1: Carrier searching
- Step 2: Coarse timing estimation using SCH time-domain structure
- Step 3: Fractional frequency offset estimation/compensation using P-SCH
- Step 4: Joint code sequence detection and integer frequency offset estimation/compensation using P-SCH
- Step 5: Check if the carrier is a partially configured carrier
  - Yes, go to step 1
  - No, next step
- Step 6: Fine timing correction using P-SCH and/or the cyclic prefix of S-SCH
- Step 7: Cell ID detection using S-SCH
- Step 8: Check if detected cell ID is correct
  - Yes, synchronization procedure completed
  - No, adjust OFDM symbol timing and fractional frequency offset compensation by the following regular data OFDM symbols until next SCH comes and then go to step 2
    - Step 2 and step 3, which can skipped, are for confirmation of symbol timing and fractional frequency offset estimation

Synchronization Procedure (4/4)