Proposal for IEEE 802.16m Synchronization Channel

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Venue:
IEEE 802.16m-08/016r1, "Call for Contributions on Project 802.16m System Description Document (SDD)", On topic of "Preambles."

Base Contribution:
None

Purpose:
To be discussed and adopted by TGm for use in 802.16m SDD

Proposal for IEEE 802.16m Synchronization Channel

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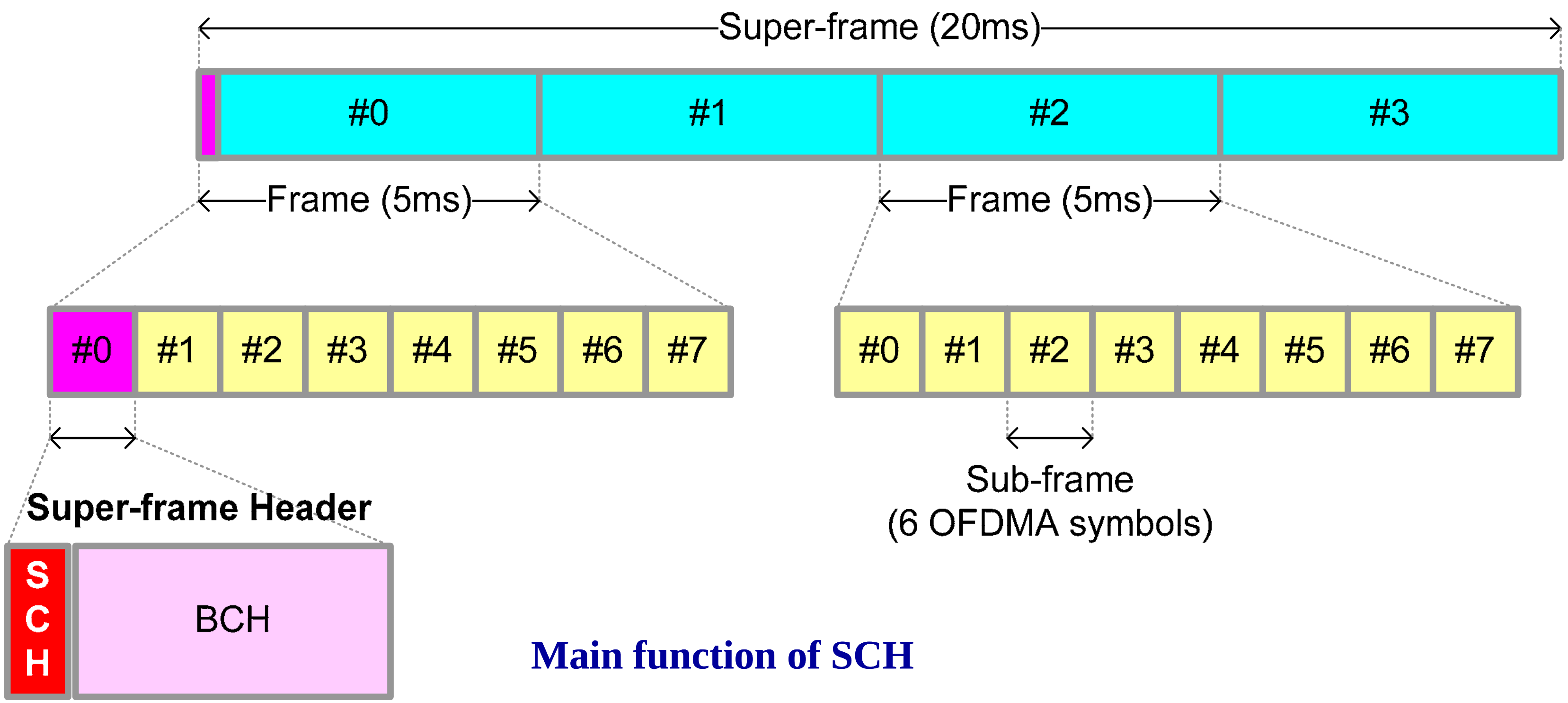
About This Contribution

- Goal and scope of this contribution
  - Propose a synchronization channel(SCH) design for 802.16m
- Issue to be addressed in this contribution
  - Transmit period of SCH
  - Number of SCH symbol per super-frame
  - Number of cell ID
  - Timing synchronization method
  - Bandwidth of SCH

Requirements

- Simple timing/frequency synchronization
  - Low computational complexity for power saving
  - Low implementation complexity
- More number of cell ID than 802.16e
  - Support femto cell
- Low overhead
  - No overdesign
- Support channel estimation
  - Flat frequency spectrum
- Low PAPR for power boosting

SCH Structure



Main function of SCH

- Provide reference of time/frequency synch, and BS identification

SCH structure

- 1 symbol in Super-frame header

SCH Features

Attribute			Value
Channel Structure	Tx Period		20ms
	Bandwidth		5MHz, 10MHz
	Position	Time	Within super-frame header
		Freq	Center of FFT BW
Symbol Structure	Num of cell IDs		1024
	Num of Symbols		1
	Time Sync method		2x time repetition (Minn's algorithm)
	Fast Cell Search		2 sets are interlaced in frequency domain
	Sequence		BPSK modulated Frequency Domain Sequence
Other functions than Sync	NBR Cell Search for Handover		Common Pilot (DL Ref. Signal, 5ms Tx period)
	Additional function/Information		TBD

SCH and Common Pilot Operation

- SCH [20ms Tx period]
  - Time/freq synchronization + cell ID detection
- Common Pilot (DL reference signal) [5ms Tx period]
  - Common (or predetermined cell-specific) time/freq position among cells
  - Covered by a cell-specific code
  - Provide reference signal for each antenna to support MIMO

Function	Update period	Channel
Time sync.	20ms	SCH
Freq sync.	20ms	SCH
Cell ID detection	20ms	SCH
CQI measure (per Ant)	5ms	Common Pilot (DL Ref. Signal)
RSSI measure	5ms	Common Pilot (DL Ref. Signal)
NBR cell measure	5ms	Common Pilot (DL Ref. Signal)

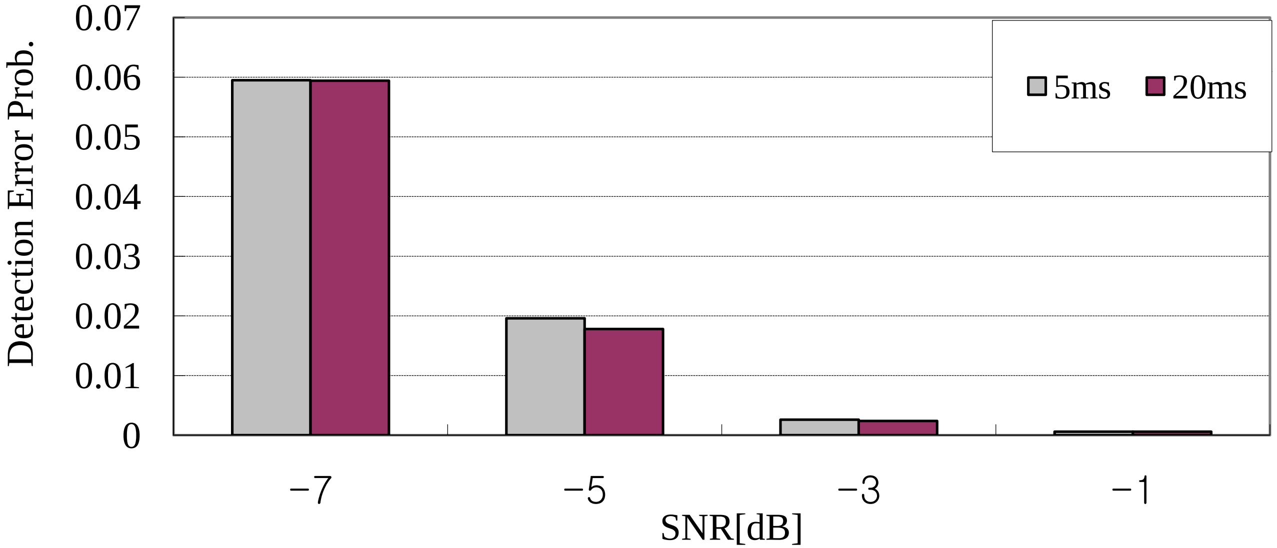
Convergence Time

- Convergence time
  - Time interval for the probability of error in SCH index acquisition to be less than 5%.
  - Handover is accomplished using Common Pilot which is transmitted at every 5msec.
  - Convergence time of SCH affects only initial network entry, so it is not so critical for subscriber.
  - RSSI measure is not essential requirement of SCH, it can be done using other resource such as common pilot.

Tx Period: 20 msec vs 5 msec

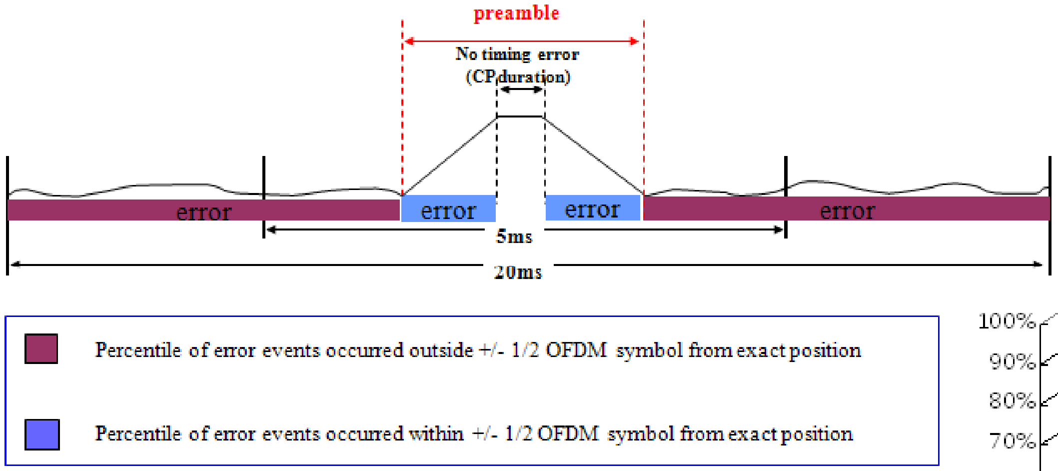
- Simulation Conditions
  - Y axis: timing detection error probability
  - Single transmission, no combining
  - 100% loading, 100% DL, random data, 2Rx
  - 10,000 trials , 7dB power boosting, no interference
  - **Timing synchronization performances are almost same.**

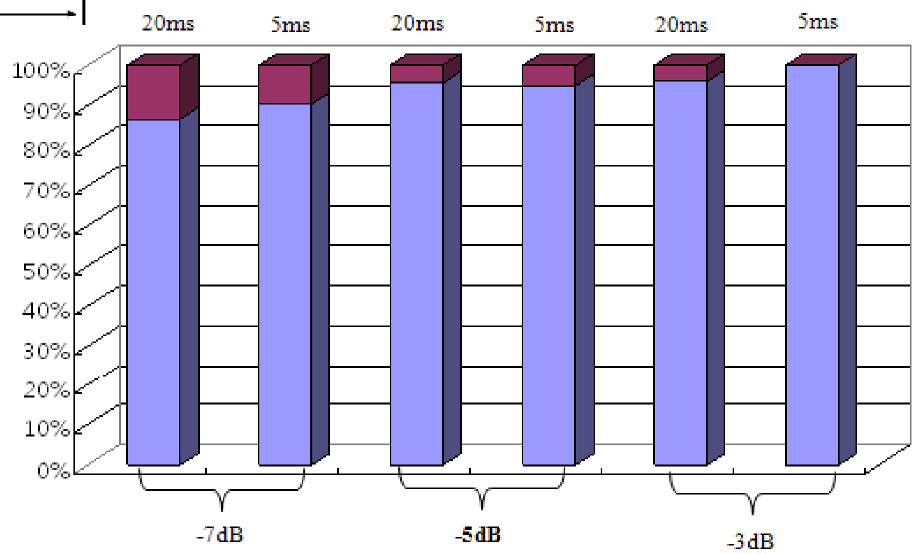
Ped B, 60km/h, 2Rx



Tx Period: 20 msec vs 5 msec

- Timing synchronization error analysis
  - Most of the timing errors are concentrated on the SCH symbol regardless of the Tx period.
  - That's the reason why 5msec and 20msec have almost same timing and cell ID detection performances.



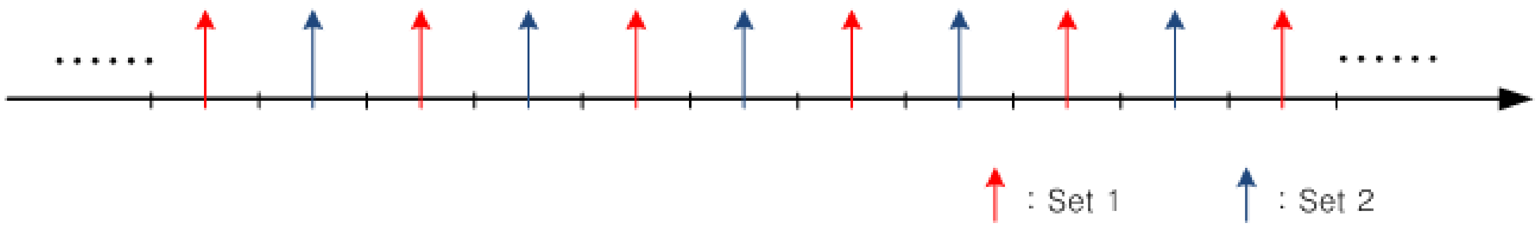


SCH Symbol Structure

- Number of cell ID = 1024
- 1 symbol used for time/freq synch & BS identification
- Time Synchronization by Minn's algorithm using 2x time repetition (Appendix 1)
- Low computational/implementation complexity
  - Two sets are interlaced in frequency domain
  - **Cell detection complexity is 1/32 compared to one set approach** (Appendix 2)
  - Each set has 32 sequences (32 x 32 = 1024)

	5 MHz	10 MHz
FFT size	512	1024
Sequence Length	108	216

- BPSK modulated frequency domain sequence with low PAPR and good correlation properties
  - Low complexity at terminal



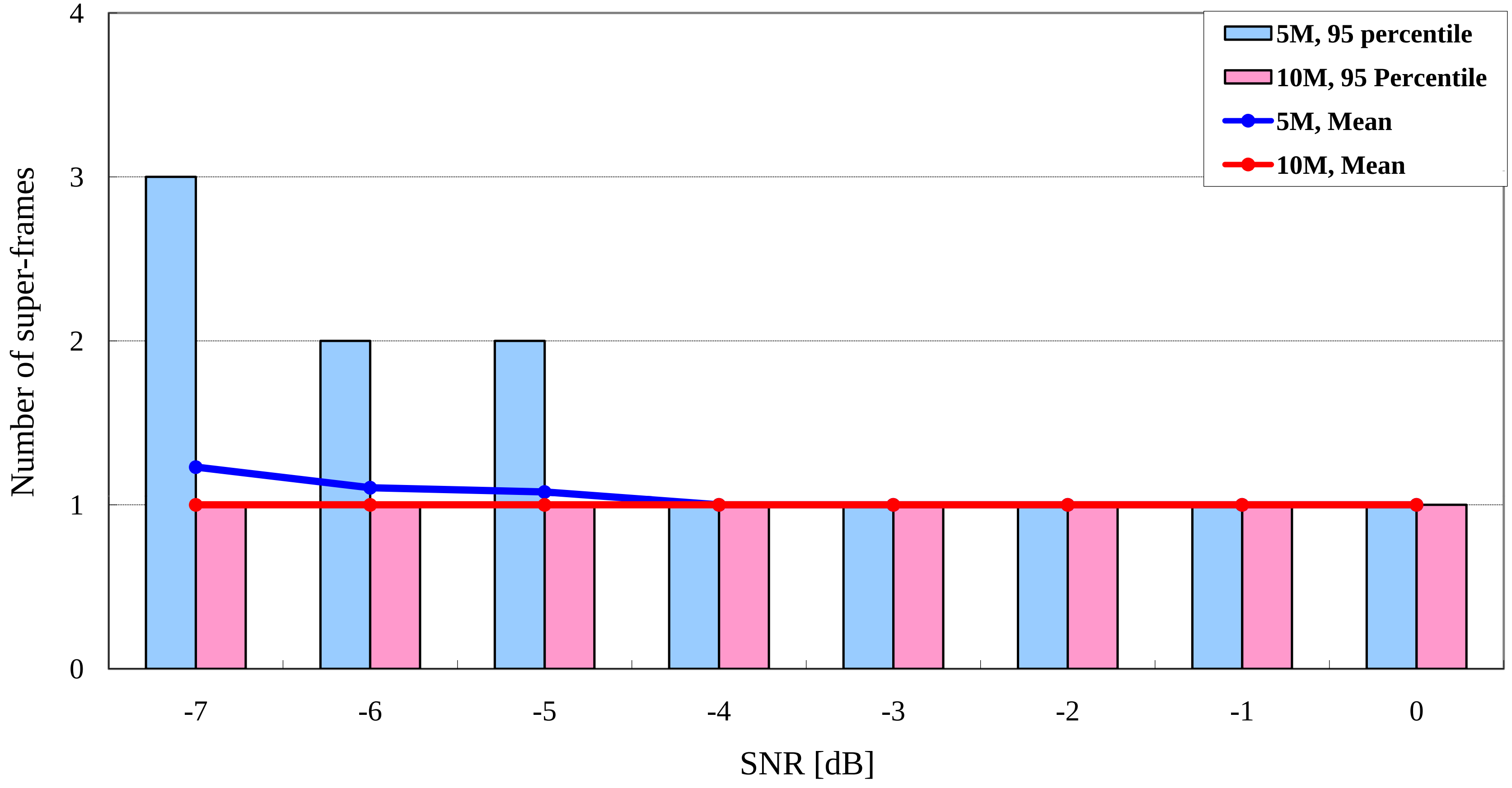
Simulation Assumption

Parameter	Assumption	
FFT size	512	1024
Total number of sub-carriers	432	864
Number of sub-carriers for SCH [1)]	216	432
Length of sequence in the set	108	216
Sequences	BPSK modulated sequence (FD)	
Channel Models	PED B, 60km/h	
Number of cell IDs	1024	
Number of antennas	1 Tx, 2 Rx	
Power Boosting	7 dB [2), 3)]	
Signal Generation	100% loading, 100% DL, Random data	
Cell ID Detection	Not ideal, but realistic timing compensation is assumed. (Appendix 3)	

1) SCH occupies every other subcarrier for 2x time repetition.
2) 7dB boosting comes from 3dB equal OFDM symbol power gain and 4dB PAPR gain against random data symbols. PAPRs of all SCH are 4dB lower than those of 99% random data symbols.
3) Power boosting is reflected on the timing synchronization only. It is assumed that there isn't any power boosting gain on cell ID detection. This is suitable for the interference limited environment.

Performance

- Timing & Cell Acquisition time (Number of super-frames)



Text Proposal to 802.16m SDD

Insert the following text into Physical Layer clause (Chapter 11 in [IEEE 802.16m-08/003r3])

11.x Downlink Control Structure

11.x.1 Downlink Control Information Classification

11.x.2 Transmission of DL control information

11.x.2.1 Synchronization Channel

The synchronization channel is a DL physical channel which provides a reference signal for time, frequency and frame synchronization, BS/femtocell identification and sector identification for system acquisition, and super-frame header synchronization.

11.x.2.1.1 SCH requirements

11.x.2.1.2 SCH architecture

11.x.2.1.2.1 Overview

11.x.2.1.2.1.1 Hierarchy

No hierarchy of synchronization channel (SCH) exists. The SCH shall be transmitted with a span of one OFDM symbol in order to facilitate time- and frequency-synchronization and cell-ID detection.

Text Proposal to 802.16m SDD

11.x.2.1.2.1.2 Multiplexing

Synchronization symbols are TDM

11.x.2.1.2.1.3 Number of symbols in SCH

A complete instance of the SCH exists within a superframe. In mixed deployments, the presence of the legacy preamble is implicit. There is one 16m synchronization symbol per superframe.

11.x.2.1.2.1.4 Location of synchronization symbols

In mixed deployments, the presence of the 16e preamble in the first symbol of the 16e frame is implicit. The location of the SCH symbol is fixed within the superframe. The SCH is within the SFH (location FFS) only (no reuse of legacy preamble)

11.x.2.1.2.2 Description of legacy support/reuse

16m system will exist in both greenfield and mixed (coexisting 16e and 16m equipment) deployments. In mixed deployments the 16e preamble will always be present. The 16m SCH is not to degrade the performance of legacy acquisition.

The IEEE 802.16m SCH shall support the IEEE 802.16m MSs to perform time, frequency and frame synchronization procedures without requiring the legacy preamble. In mixed deployments, the IEEE 802.16m SCH and the legacy preamble shall be transmitted in distinct OFDM symbols of the super-frame.

Text Proposal to 802.16m SDD

In mixed deployment, 16m system uses both a dedicated 16m synchronization symbol and the legacy 16e preamble symbols for DL synchronization, but in Greenfield 16m system only 16m specific synchronization symbols are used (no reuse of legacy preamble is required).

Synchronization channel differentiates 1024 unique cell identities. Synchronization channel is transmitted at every 20msec on the one OFDMA symbol in the super-frame header. For FFT sizes of 512 and 1024, Synchronization channel spans 432 and 864 subcarriers of the OFDMA symbol respectively, and occupies every other subcarrier over this span.

11.x.2.1.2.3 Cell ID support

The number of IDs is at least 1024. Sectors are distinguished by the synchronization channel; the number of sectors is 3. The ID is derived from a single symbol per superframe (without hierarchy).

11.x.2.1.2.4 Multicarrier and multi-bandwidth support

The support for multiple RF carriers can be accommodated with the same frame structure used for single carrier support. Each carrier may have its own synchronization channel and superframe header.

Text Proposal to 802.16m SDD

11.x.2.1.2.5 MIMO support and channel estimation

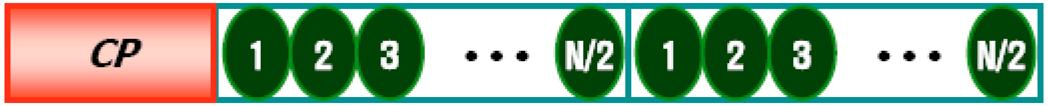
SCH can be transmitted using multiple transmit antennas. SCH shall not be required to support MIMO channel estimation.

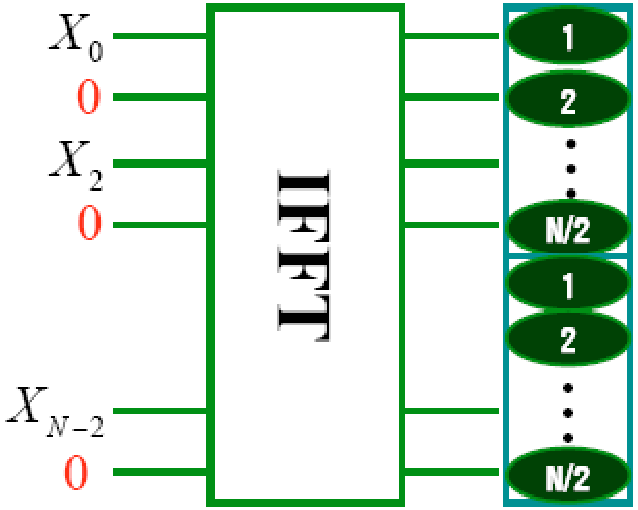
11.x.2.1.3 Preamble Sequence Design Properties

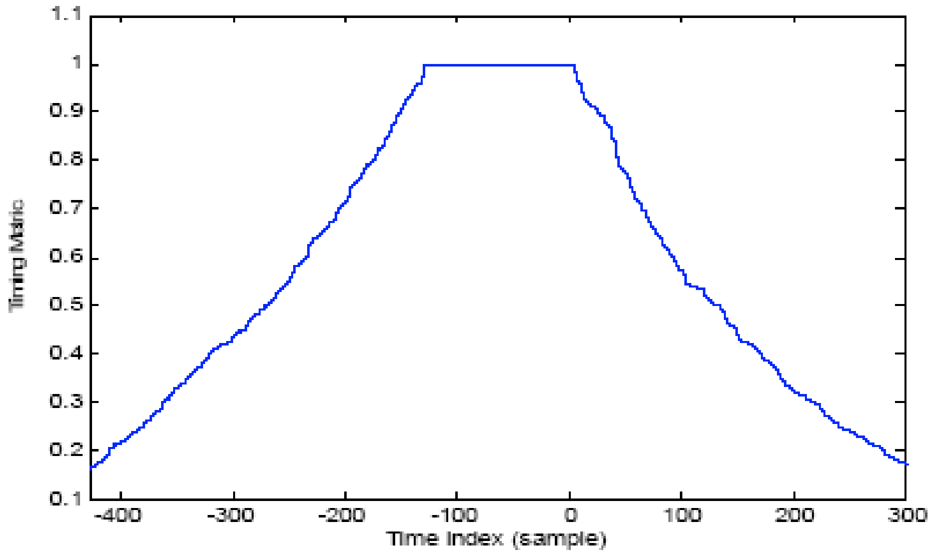
The SCH shall enable timing synchronization by autocorrelation. The SCH is mapping with every 2 subcarriers on the frequency domain.

Appendix 1. Timing Synchronization Algorithm

- Schmidl & Cox Algorithm [1]







Appendix 1. Timing Synchronization Algorithm

- Schmidl & Cox Algorithm [1]
  - Timing Metric:

$$M(d) = \frac{|P(d)|^2}{(R(d))^2}$$

Correlation Part

$$P(d) = \sum_{m=0}^{N/2-1} r^*(d+m)\, r(d+m+N/2)$$

Energy Part

$$R(d) = \sum_{m=0}^{N/2-1} |r(d+m+N/2)|^2$$

  - Method 1
    - Simply find the maximum of timing metric
  - Method 2
    - Find the maximum, find the points to the left and right in the time domain, which are 90% of the maximum, and average these two 90% times to find the symbol timing estimate.
    - Try to determine the center of this plateau.
    - Method 2 performs significantly better than Method 1, and it involves only slightly more computation.

Appendix 1. Timing Synchronization Algorithm

- Minn's Algorithm (Sliding Window Method) [2]
  - Reduce the uncertainty due to the timing metric plateau and thus improve the timing offset estimation scheme proposed by Schmidl and Cox.
  - Timing Metric:

$$M(d) = \frac{1}{N_g + 1} \sum_{k=-N_g}^{0} \frac{\left|P(d+k)\right|^2}{R^2(d+k)}$$

where $P(d) = \sum_{m=0}^{N/2-1} (r_{d+m}^{*} r_{d+m+N/2})$: Auto-Correlation

$R(d) = \frac{1}{2} \sum_{m=0}^{N-1} \left|r(d+m)\right|^2$: Power Normalization

※ N and N_g denote the FFT size and CP length, respectively

※ Note that the timing estimate is desired to lie within guard interval, the mean was shifted to the left (i.e., advanced) by CP/2.

Appendix 2. Two vs One Sequence Set

- Assumption
  - *L* : total number of used sub-carriers for SCH
  - *N*: number of cell ID
- One sequence set
  - *L*: length of sequence in the set
  - *N*: number of sequences in the set
- Two sequence sets
  - *L*/2: length of sequence in the set
  - 2**sqrt* (*N*): total number of sequences in the two sets
- Cell ID detection complexity comparison

Two Sets	One Set
*O(L*sqrt(N))*	*O(L*N)*

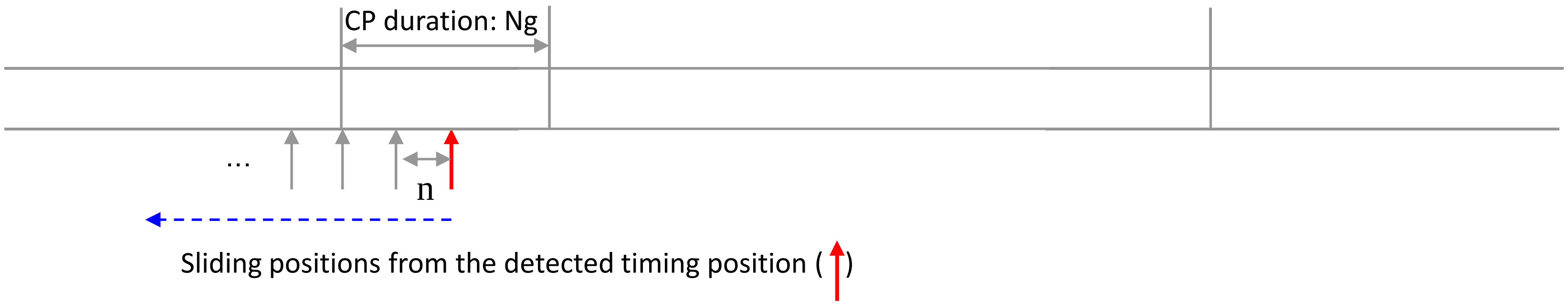
  - **If *N*=1024, one set is 32 times more complex than two set.**

Appendix 3. Residual Timing Error Recovery

- Residual Timing Error
  - It may have a bad influence on cell-search performance even though the detected timing position is within CP length.
  - If it is less than some value, e.g., 8~10 sub-carriers, it doesn't influence cell-search performance at all.
- Solution: Sliding Position Method

Step 1) FFT at (detected position – $i*n$) position, i=0,1,2,...,$ceiling(N_g/n)$-1, and find the peak cross-correlation value and the corresponding sequence index for each position

Step 2) Find the largest value among $ceiling(N_g/n)$ cross-correlation values, and the corresponding sequence index and timing position



Appendix 3. Residual Timing Error Recovery

- Proposed Solution: Sliding Position Method
  - Cell ID and more accurate timing can detected.
  - Simulation result shows that timing & cell detection performance of proposed solution is same that of ideal timing error compensation.
  - **Thus, ideal timing error compensation is valid for simulation assumption.**
  - It is obvious that the performance is enhanced and the complexity increases as n decreases. Therefore, the n should be chosen as the largest value not affecting the cell-search performance degradation.
    (For Samsung's design, *n*=8 is preferred)
  - The complexity can be reduced further by adjusting some design amounts of Minn's algorithm.

References

[1] T. M. Schmidl and D. C. Cox, "Robust frequency and timing synchronizationfor OFDM," IEEE Trans. Commun., vol. 45, pp. 1613–1621, Dec. 1997.

[2] H. Minn, M. Zeng, and V. K. Bhargave, "On Timing Offset Estimation for OFDM Systems," *IEEE Com. Letters*, vol. 4, pp. 242-244, Jul. 2000