# Evaluation of D-TDOA Positioning

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# Introduction

- During LBS DG meeting in Jeju, Korea (IEEE Session # 63), it was recommended to evaluate performance of D-TDOA based positioning method using SA-Preamble signals
- Several companies have volunteered to participate in LBS evaluation group activity and prepare the document with assumptions/criteria to be used for LBS simulations [1]
- The developed document is compliant with the latest version of IEEE 802.16m EMD [2] and IEEE 802.16m/D1 [3] and defines some specific assumptions required for D-TDOA based LBS evaluation
- This presentation highlights link level and system level simulation results for D-TDOA performance that were obtained in accordance with agreed assumptions

# Motivation

- Location Based Services are expected to explosively grow in the upcoming years.
- Different categories of the location services are defined including emergency services, navigation, asset tracking, workforce management, location based events, location based advertisement, location based search, and many others.
- Existing location services like wireless E911 and new upcoming services dictate strict requirements on user positioning accuracy.
- To achieve higher location accuracy the precise measurements of signal location parameters are required.
- In order to enhance performance of current LBS solutions, the additional PHY, MAC and Network Level support is needed.

# IEEE 802.16m SRD - LBS Requirements

- IEEE 802.16m System Requirements for LBS support [4, 6]
  - IEEE 802.16m shall provide support for high resolution location determination
  - IEEE 802.16m systems should satisfy the requirements in Table 15

**Table 15–Location-based service requirements**

<table>
<tr><th>Feature</th><th>Requirement</th><th>Comments</th></tr>
<tr><td>Location determination latency</td><td>< 30 s</td><td></td></tr>
<tr><td>Handset-based position accuracy (in meters)</td><td>50 meter (67%-tile of the CDF of the position accuracy)<br>150 meter (95%-tile of the CDF of the position accuracy)</td><td rowspan="2">Need to meet E911 Phase II Requirements</td></tr>
<tr><td>Network-based position accuracy (in meters)</td><td>100 meter (67%-tile of the CDF of the position accuracy)<br>300 meter (95%-tile of the CDF of the position accuracy)</td></tr>
</table>

# Overview of Location Technologies

- The main cellular systems (GSM, 3GPP W-CDMA and 3GPP2 CDMA2000) support the same positioning methods listed below:
  - Cell ID based positioning;
  - D-TDOA (Downlink – Time Difference of Arrival);
  - U-TDOA (Uplink – Time Difference of Arrival);
  - GNSS (Global Navigation Satellite System – e.g. GPS) based positioning.
- The performance of currently used cellular location solutions such as (D-TDOA and U-TDOA methods) can be improved if additional support is introduced at the PHY and MAC layers.
- Evaluation of D-TDOA positioning method in application to IEEE 802.16m systems is a focus of this presentation.

# D-TDOA Network Radiolocation Challenges

- Network based radio-location may suffer from:
  - *Multipath & Non Line of Sight (NLOS) channel*
    - In multi-path channel the first arrival path may have less power than its post-cursors
      - Strong inter-symbol interference complicates timing estimation of the first arrival path even when there is no external interference from other sources.
    - In NLOS channel, the positive offset in TOA estimate appears, even if the first arrival path timing is perfectly estimated
      - The first arrival path does not carry information about real range between MS and BS and thus it signal propagation delay is higher.
  - *Near Far Problem (Hearability issue)*
    - MS receives signals from neighboring BSs with different RX power levels. If received signals are not orthogonal then MS shall have enough processing gain to overcome negative SINR to get accurate timing estimate
  - *Convergence/ambiguity of positioning algorithms*
    - It is known that if BSs are placed on the straight line then position of MSs is ambiguous and can not be resolved w/o additional information [8]
- To overcome D-TDOA challenges it is important to ensure that PHY & MAC do not impose limitations that may impact accuracy of signal location parameter measurements

# TOA Estimation
# Link Level Analysis

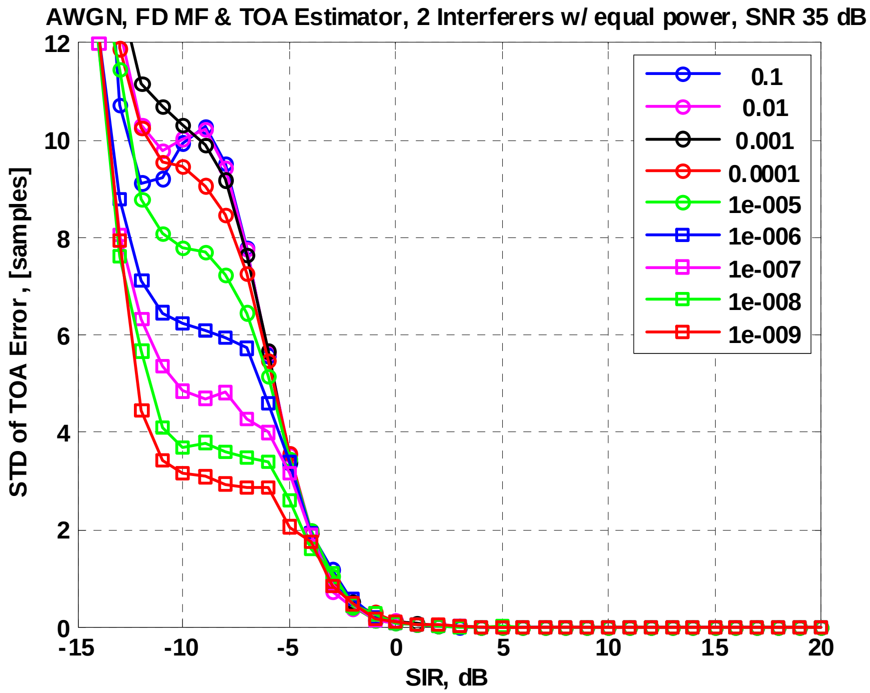
# Description of Threshold Based TOA Estimation Algorithm

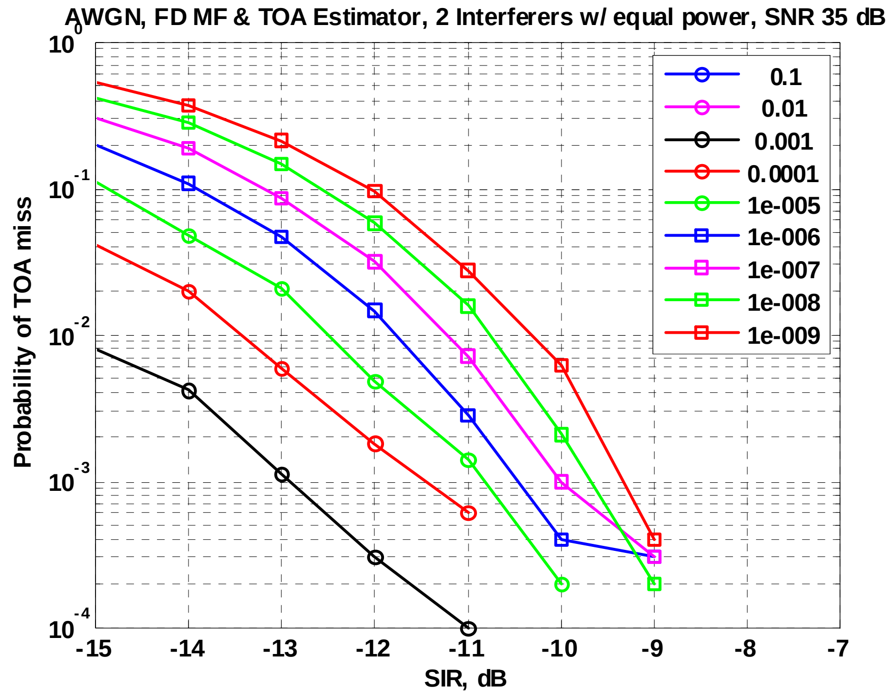
- Channel Estimation
  - Assuming that SA-Preamble Signal is known the channel transfer function is estimated in frequency domain (FD) on the corresponding carrier set.
- FD Channel Interpolation
  - Since only third preamble subcarrier within SA-Preamble subblock is non-zero, interpolation of the estimated frequency domain channel transfer function is performed to get estimate for every subcarrier that is active in the data transmission mode.
- Conversion to Time Domain
  - IFFT is taken to obtain an estimate of the channel impulse response (CIR) in time domain (TD).
- TOA Estimation
  - The CIR response tap with maximum power is found.
  - As a next step, the CIR estimate is refined by excluding false channel taps that may appear due to noise and interference realizations (the threshold is selected to guarantee predefined maximum false alarm level) and due to ‘spectrum leakage’ effect. The thresholds are calculated and the maximum one is selected and then applied to the CIR estimate.
  - The first channel tap remaining after application of the threshold in precursors window is declared as a TOA estimate. If none of the channel taps exceeds threshold the TOA miss is declared.

# Link Level Analysis of TOA Estimation
## Simulation Assumptions

- Simulation setup
  - Bandwidth 10 MHz;
  - FFT size 1024;
  - CP ratio = 1/8 (128 samples);
  - P802.16m/D1 preamble sequence (QPSK);
  - One TX antenna and one RX antenna;
  - Channel Models: eITU Ped B and AWGN
  - Interference and noise limited scenario were considered
- Assumptions
  - Initial coarse TOA error was assumed to be uniformly distributed within interval [-32, 32] samples;
  - Fine TOA estimation is evaluated

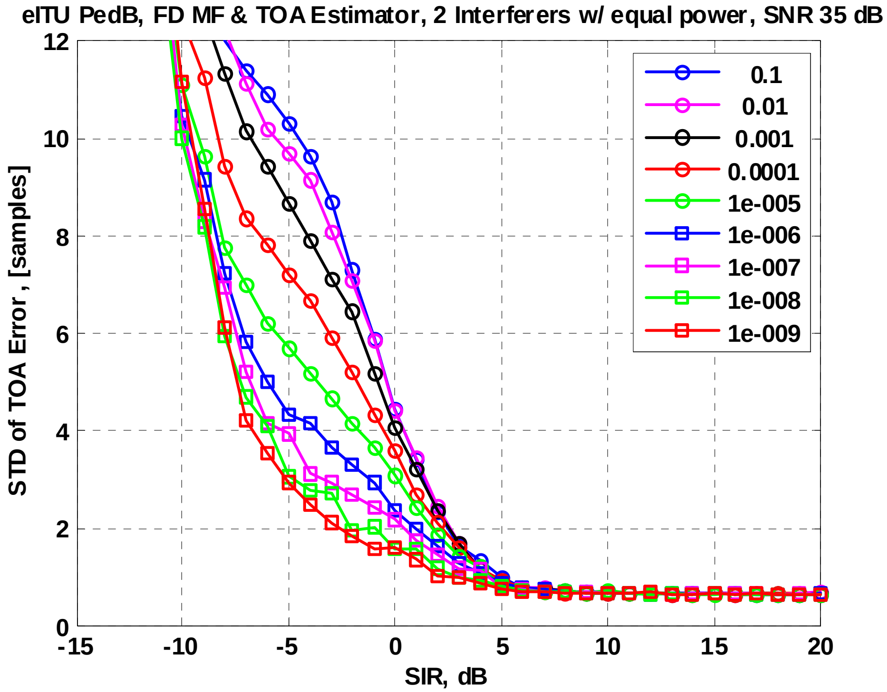
# Link Level Analysis of TOA Estimation
## Interference Limited Scenario – AWGN

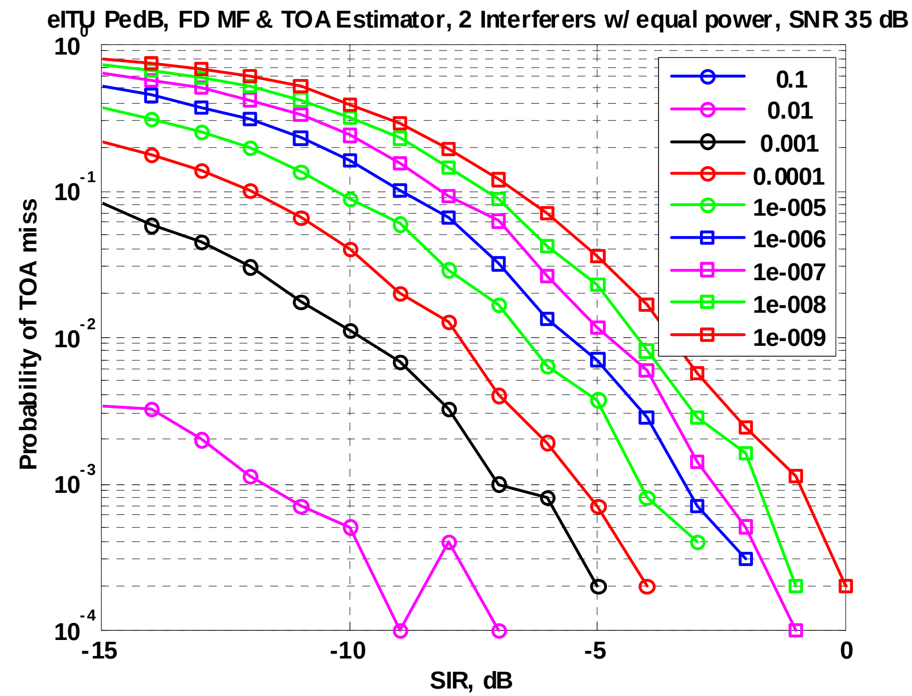



- Developed TOA estimation algorithm was evaluated for interference and noise limited scenarios
- Similar performance characteristics were achieved for both scenarios

# Link Level Analysis of TOA Estimation
## Interference Limited Scenario – eITU PedB




- Almost the same TOA estimation performance characteristics were observed in noise-limited scenario for eITU Ped B channel model
- The decreasing of false alarm probability results in more accurate TOA measurements however the probability of TOA miss is increased ⬄ Tradeoff between accuracy and TOA miss

# Link Level Analysis of TOA Estimation
## Conclusions

- A simple practical TOA estimation algorithm was considered and its performance characteristics were evaluated in the noise limited and interference limited scenarios for the AWGN and eITU Ped B channels
- A summary of the most important LLS results is:
  - For the multi-path eITU Ped B channel model
    - Standard deviation of TOA estimation error is about 2 samples at -3dB SIR/SNR (for 10MHz channel bandwidth)
    - Probability of missing TOA estimate at -3dB is about $10^{-3}$ for the probability of false alarm of $10^{-7}$
  - For the AWGN (flat) channel model
    - Standard deviation of TOA estimation error is about 2-3 samples at -10dB SIR/SNR
    - Probability of missing TOA estimate at -10dB is about $10^{-3}$ for probability of false alarm of $10^{-7}$

# D-TDOA
# System Level Analysis

# D-TDOA System Level Analysis

## System Level Simulation Assumptions

- The following assumptions compliant with [1] were used for simulations:
  - AMS knows its neighborhood ABSs (IDcells and coordinates);
  - AMS is coarsely synchronized with its serving ABS/sector;
  - Signal propagation delay associated with the first ray of channel impulse response carries information about LOS distance between AMS and ABS;
  - Ideal hexagonal deployment (each of three ABS sectors/segments use orthogonal carrier sets for preamble transmission);
  - Threshold based TOA estimation algorithm (described above) is applied for time of arrival measurements;
  - 2-Dimensional location using 3 ABSs selected by AMS (2 TDOAs);
  - Positioning method – trilateration (TDOA) based on Taylor algorithm [7];
    - initial guess - is average coordinate of ABSs selected for trilateration;
    - number of iterations is 20;
    - location error covariance matrix is equal to identity matrix;
  - One snapshot processing (SA-Preamble from IEEE802.16m/D1);
  - Random SA-Preamble assignment with no overlapped IDcells inside 19-cell hexagon.

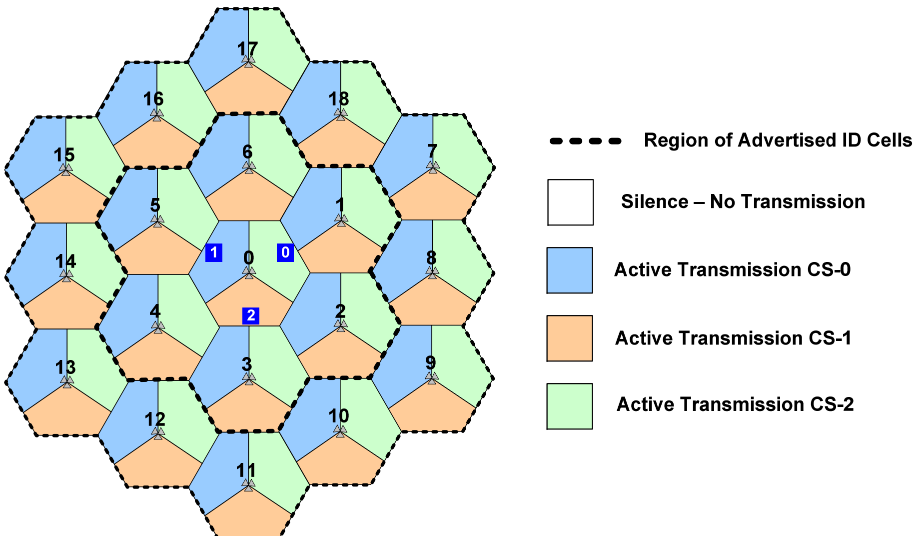
# D-TDOA System Level Analysis

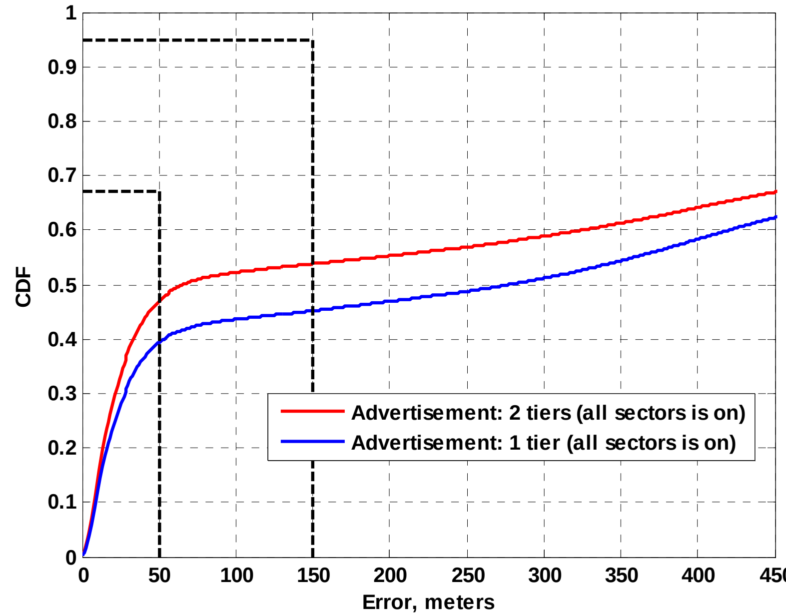
## System Level Simulation Parameters

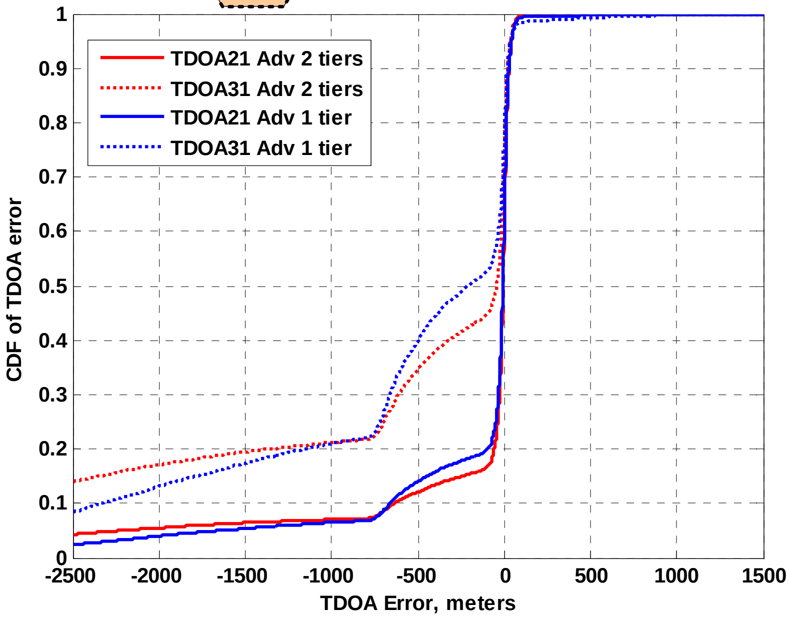
| Parameter | | Value | | |
|---|---|---|---|---|
| **System Parameters** | | | | |
| | FFT Size / CP ratio | 1024 points / 1/8 | | |
| | Bandwidth | 10 MHz | | |
| | Preamble Sequence | IEEE 802.16m, Draft1 | | |
| **Equipment Model** | | **BS** | **MS** | |
| | Number of TX antennas | 1 | Number of RX antennas | 1 |
| | BS antenna Front-to Back ratio | 20 dB | Height | 1.5 m |
| | TX Power | 46 dBm | Noise Figure | 7 dB |
| | Cable Loss | 2 dB | Cable Loss | 0 dB |
| | Antenna gain | 17dBi, 70 deg. HPBW | Antenna gain | Omni, 0dBi |
| **Deployment parameters** | | | | |
| | Wrap around | On | | |
| | SF | On | | |
| | SF type | Correlated SF grid is applied ( coefficient 0.5, correlation distance 50 m. ) | | |
| | SF standard deviation | 8 dB | | |
| | Network topology | Hexagonal deployment, 19 cells, 3 sectors | | |
| | Site to site distance, km | 1.5 km | | |
| | Number of users simulated | 10000 | | |
| | Channel | eITU PedB channel model | | |
| | Path loss type | 16m EVM Baseline Path Loss Model | | |

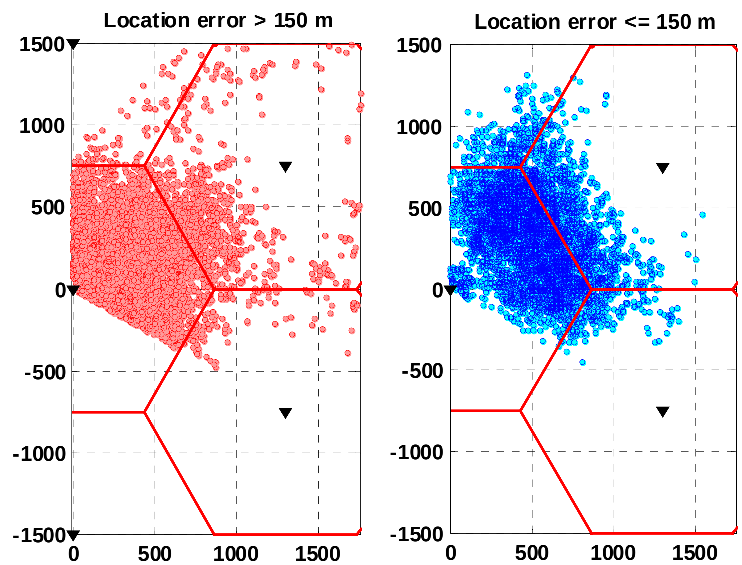
# D-TDOA System Level Analysis

## SLS Results Using SA-Preamble Sequence



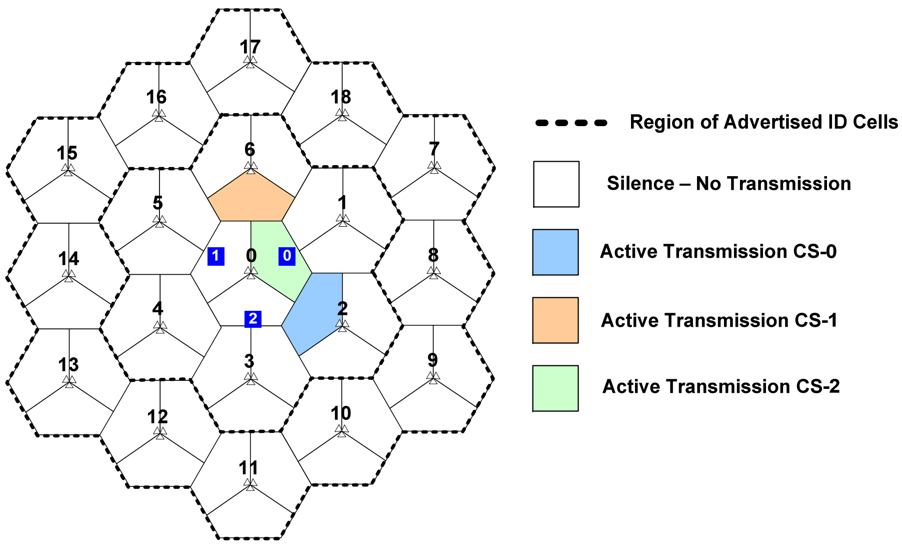



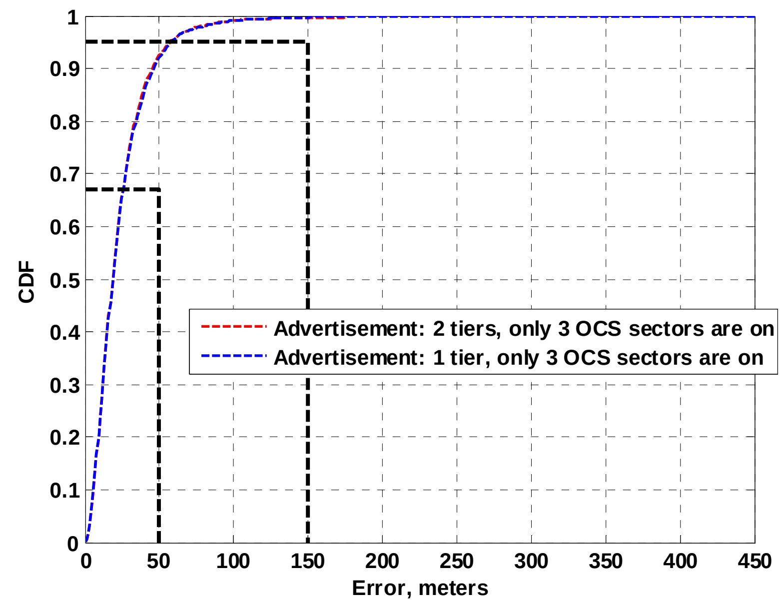



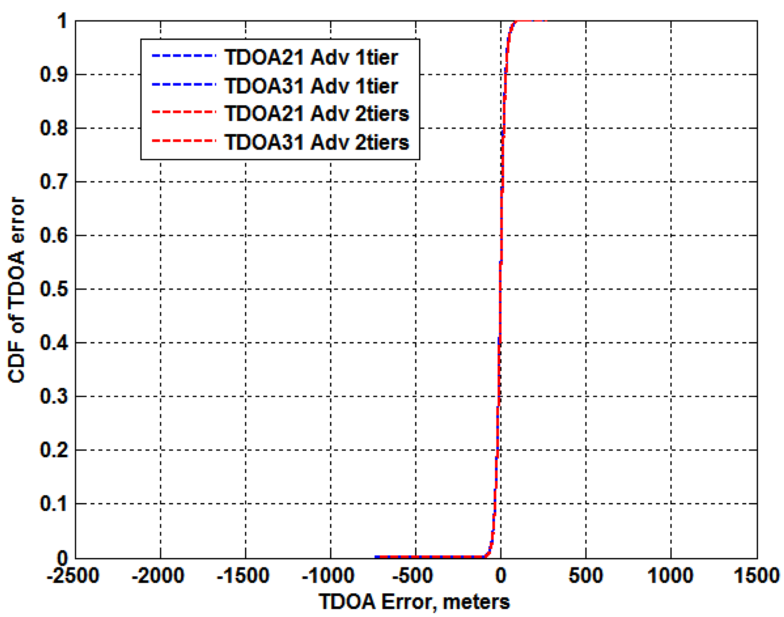



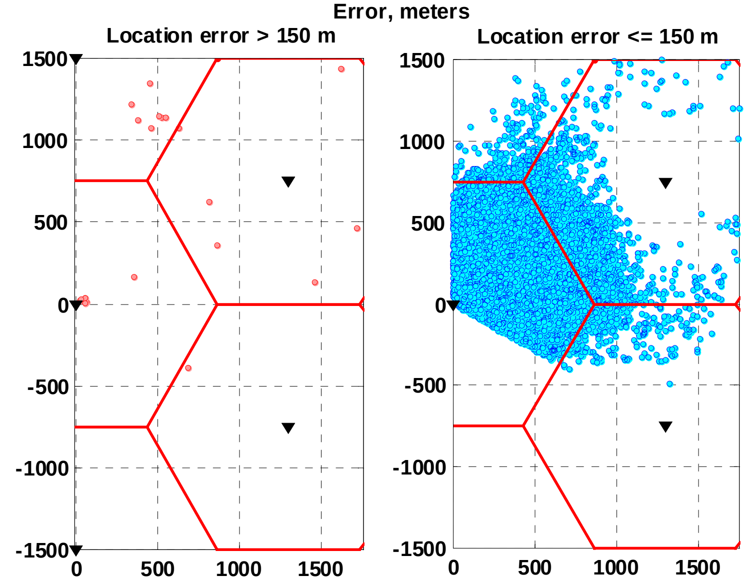
# D-TDOA System Level Analysis

## SLS Results Using SA-Preamble Sequence



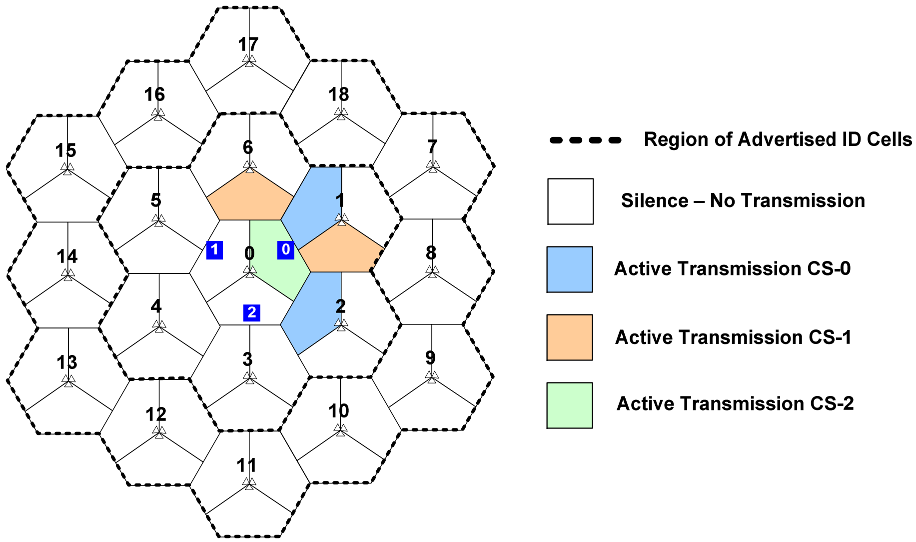



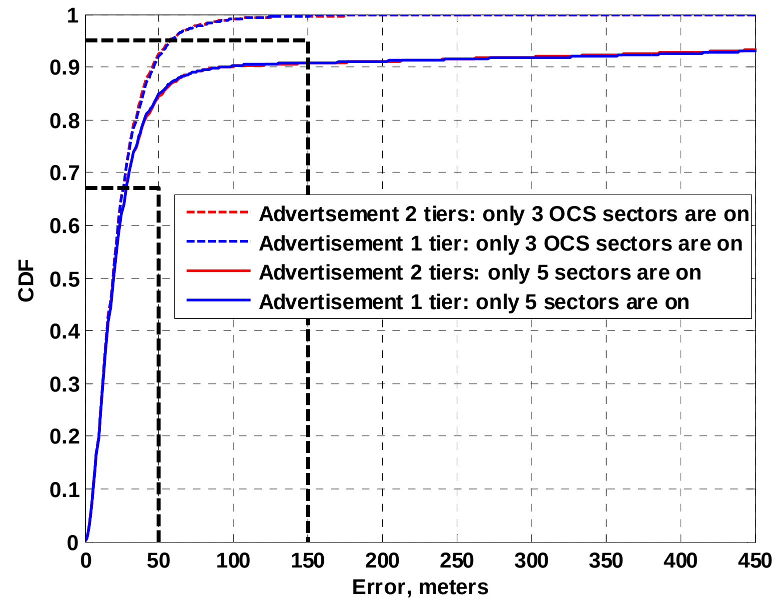



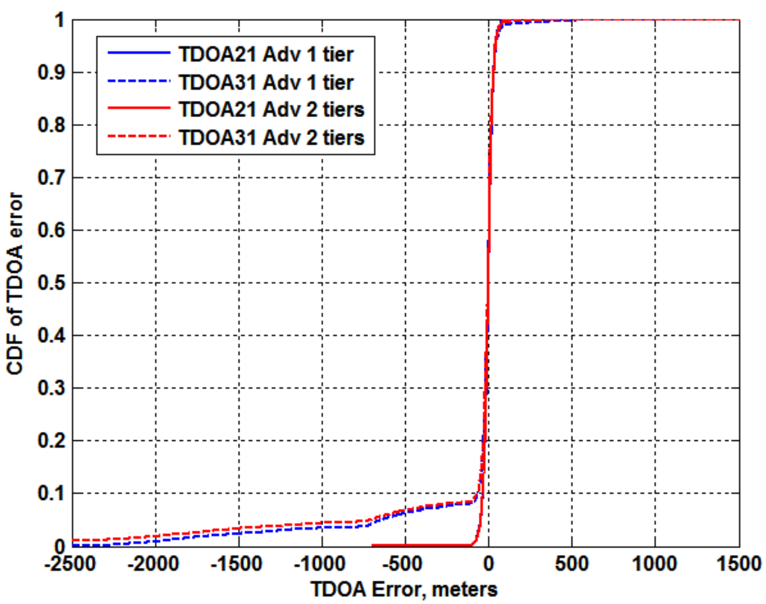



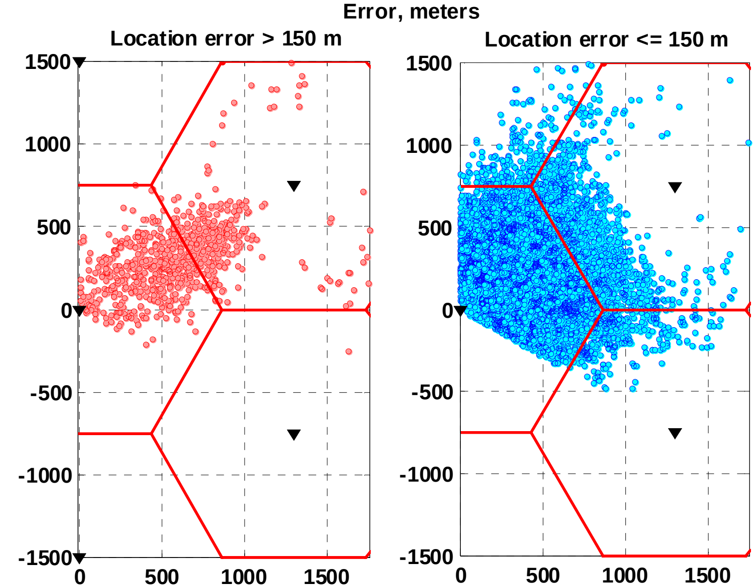
# D-TDOA System Level Analysis

## SLS Results for SA-Preamble Sequence

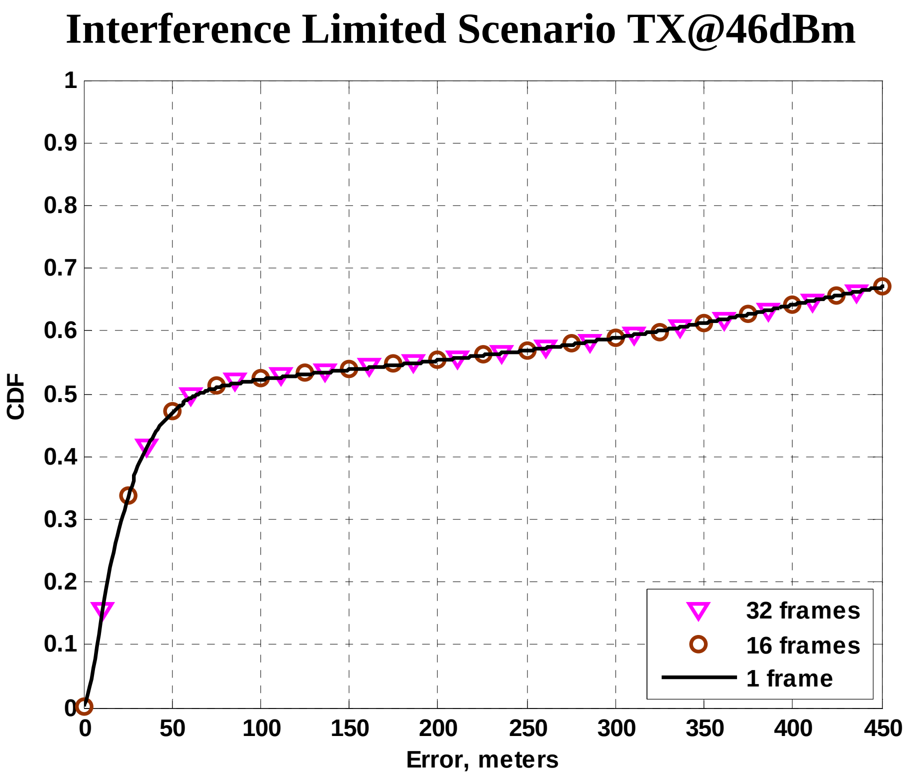


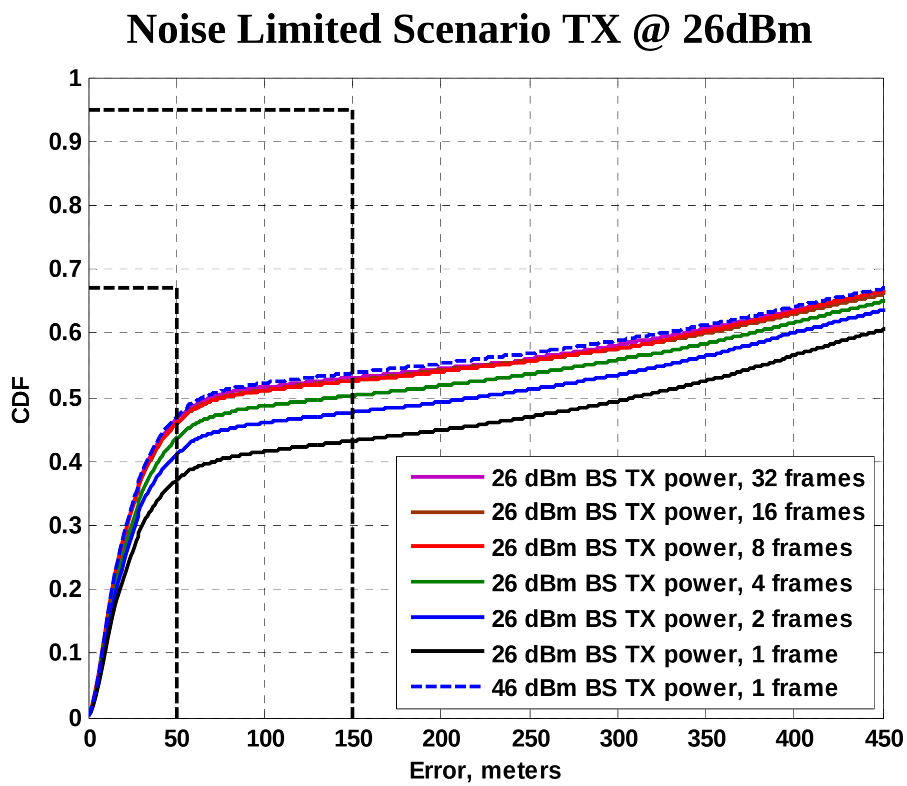



# Effect of Multiple Frame Averaging




- Reduction of TX power leads to additional degradation of MS positioning error due to approaching noise level
- Averaging over multiple frames helps to improve location accuracy, however performance is saturated at the level that is restricted by mutual interference from different BSs

# Conclusions on D-TDOA SLS Results

- D-TDOA positioning requires that relative TOAs from several neighboring BSs was accurately measured (at least 3 BSs are required)
- Performance of the preamble only based D-TDOA location is saturated at some level due to mutual interference from different BSs.
- The preambles from all the BSs are transmitted at the same time and the same preambles are repeated in different frames. This does not allow improving the interference environment by coherent combining/averaging when interference is almost stationary.
- System level simulations have demonstrated that for the case of stationary interference-limited scenario the preamble based D-TDOA positioning does not allow to meet strict accuracy requirements of the wireless E911 service in severe multipath environment.
- The additional DL signaling mechanism is recommended to improve accuracy of D-TDOA measurements.

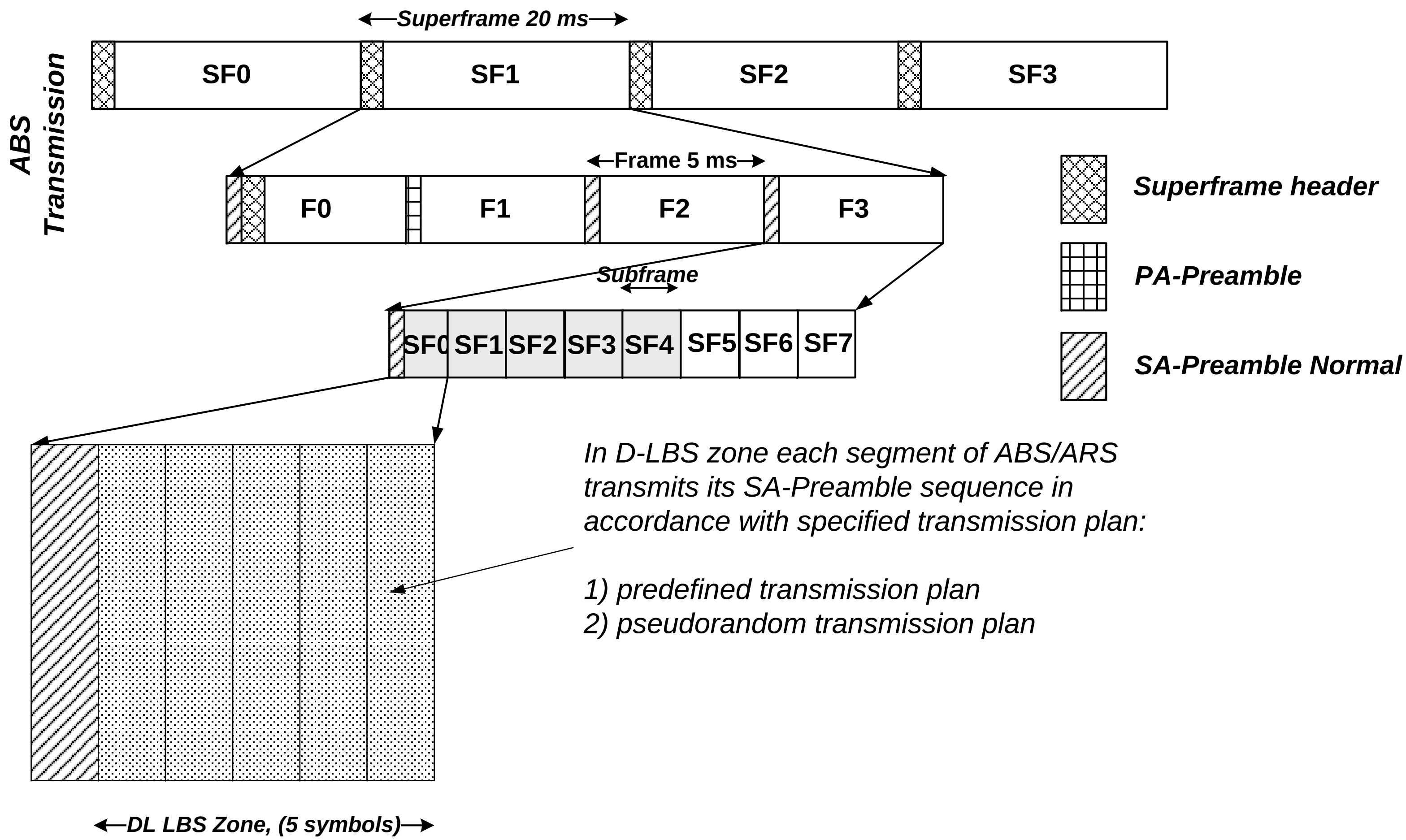
# Enhanced LBS Support

# D-LBS Zone
## Design Considerations

- D-LBS zone is synchronous over network [10]
- Position in frame
  - when D-LBS zone is allocated it is placed in the first DL subframe of the last frame of the superframe, following the normal SA-Preamble transmission
- Duration
  - whole DL subframe;
- D-LBS zone Location Beacons are SA-Preamble sequences
  - SA-Preambles are specifically designed for synchronization purposes and contain information about *IDcells*
- D-LBS zone Location Beacons are transmitted from one TX antenna
  - required for accurate wideband channel estimation
- Transmission plans (inside one D-LBS zone):
  - pseudorandom transmission plan;
  - predefined transmission plan;
- Transmission modes (for allocation of multiple D-LBS zones) [10]:
  - *periodic mode* (D-LBS zone is allocated all the time on a regular basis)
  - *event triggered mode* (several D-LBS zones are allocated on demand during fixed time interval)
- D-LBS zone period/frequency is parameterized in units of superframe
  - Period 4, 8, 16, 32 superframes <=> Frequency 12.5, 6.25, 3.125, 1.5625 Hz

# D-LBS Zone

## Position in Superframe




*In D-LBS zone each segment of ABS/ARS transmits its SA-Preamble sequence in accordance with specified transmission plan:*

*1) predefined transmission plan*
*2) pseudorandom transmission plan*

# SLS Results for D-LBS Zone

## Predefined Transmission Plan

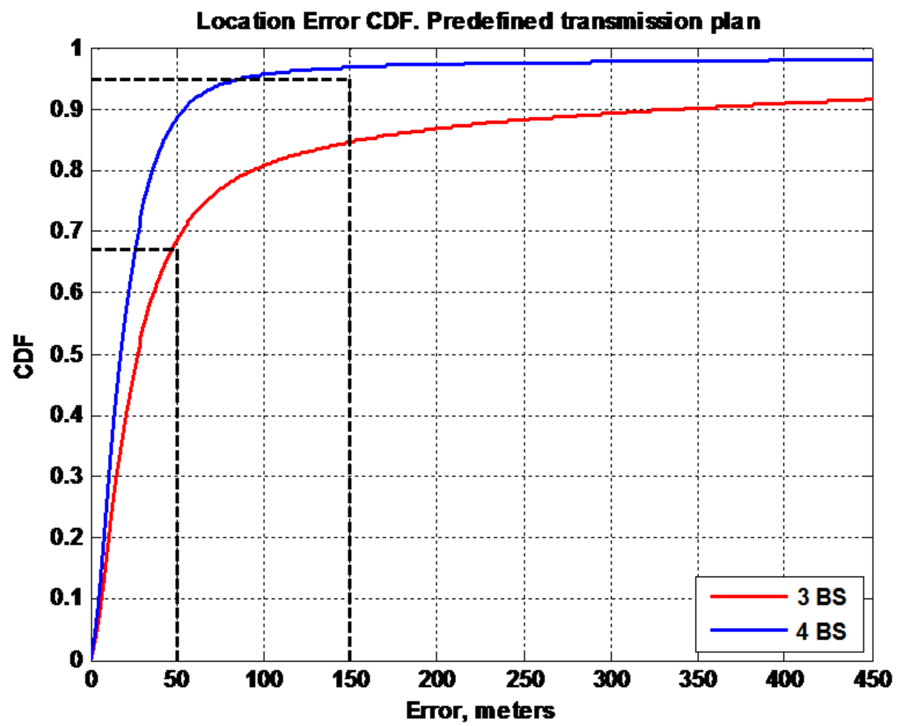
- All available *IDcells* are split to *Q* preamble location/LBS groups (PLG) ($PLG_0$, $PLG_1$, …, $PLG_{Q-1}$), where *Q* can be set to the number of D-LBS zone symbols
- *IDcells* that belong to *i*-th PLG are determined by equation ($i = 0, 1, \ldots, Q-1$):

$$\boldsymbol{IDcell_{PLGi} = 256\, n + Idx_{PLGi}; \quad n = 0, 1, 2;}$$

  here, $Idx_{PLGi}$ – is index from the set [$i$ : $Q$ : 255]; (increment by *Q* from *i* to 255)
- Transmission on particular symbol of D-LBS zone is allowed to one carrier set of particular PLG as it is defined in Table below

*Predefined Transmission Plan (Q=5)*

| D-LBS Zone Symbol Number | Carrier Sets | | |
|---|---|---|---|
| | Carrier Set 0 | Carrier Set 1 | Carrier Set 2 |
| 0 | PLG0 | PLG1 | PLG2 |
| 1 | PLG3 | PLG4 | PLG0 |
| 2 | PLG1 | PLG2 | PLG3 |
| 3 | PLG4 | PLG0 | PLG1 |
| 4 | PLG2 | PLG3 | PLG4 |



# SLS Results for D-LBS Zone

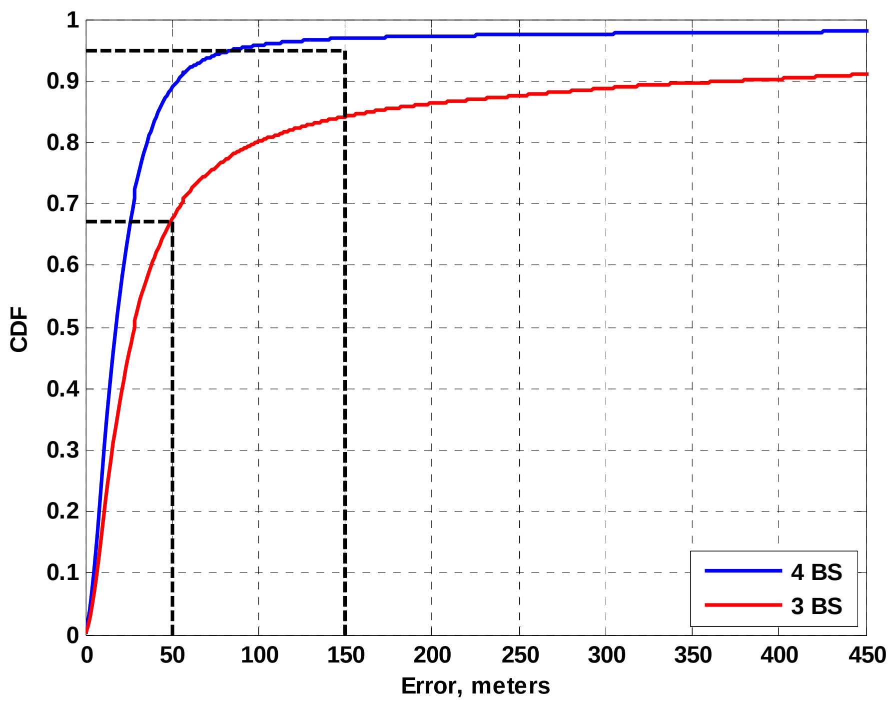
## Pseudorandom Transmission Plan

- Each ABS/ARS uses Linear Congruential Generator (LCG) to randomize its transmission (OFDM symbol position) inside D-LBS zone
- All the time when the superframe count is equal to zero ($p = 0$), each station/segment shall reset its LCG initial value to the assigned *IDcell* plus 1
- For D-LBS zone allocated to the $p^{th}$ superframe the station with *IDcell* transmits its SA-Preamble signal on the symbol that is defined by symbol offset

**LCG Constants**

$$X_p = (aX_{p-1} + c) \bmod m;$$

$$a = 219 \qquad c = 0 \qquad m = 2^{12} - 3 = 4093$$



# D-LBS Zone Summary

- To improve performance of the D-TDOA based positioning in IEEE 802.16m systems, the design of D-LBS zone is proposed.
- The D-LBS zone transmission plan can be either predefined or pseudorandom where each BS is allowed to transmit during one out of five OFDMA symbols in the D-LBS zone.
- System level simulations results have demonstrated that both approaches improve the interference environment to the level sufficient for the D-TDOA positioning algorithm to meet the wireless E911 accuracy requirements.
- Support of the D-LBS zone with the predefined and pseudorandom transmission plans is recommended for the IEEE 802.16m specification.

# References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