Analysis of Ranging Accuracy for UWB Localization

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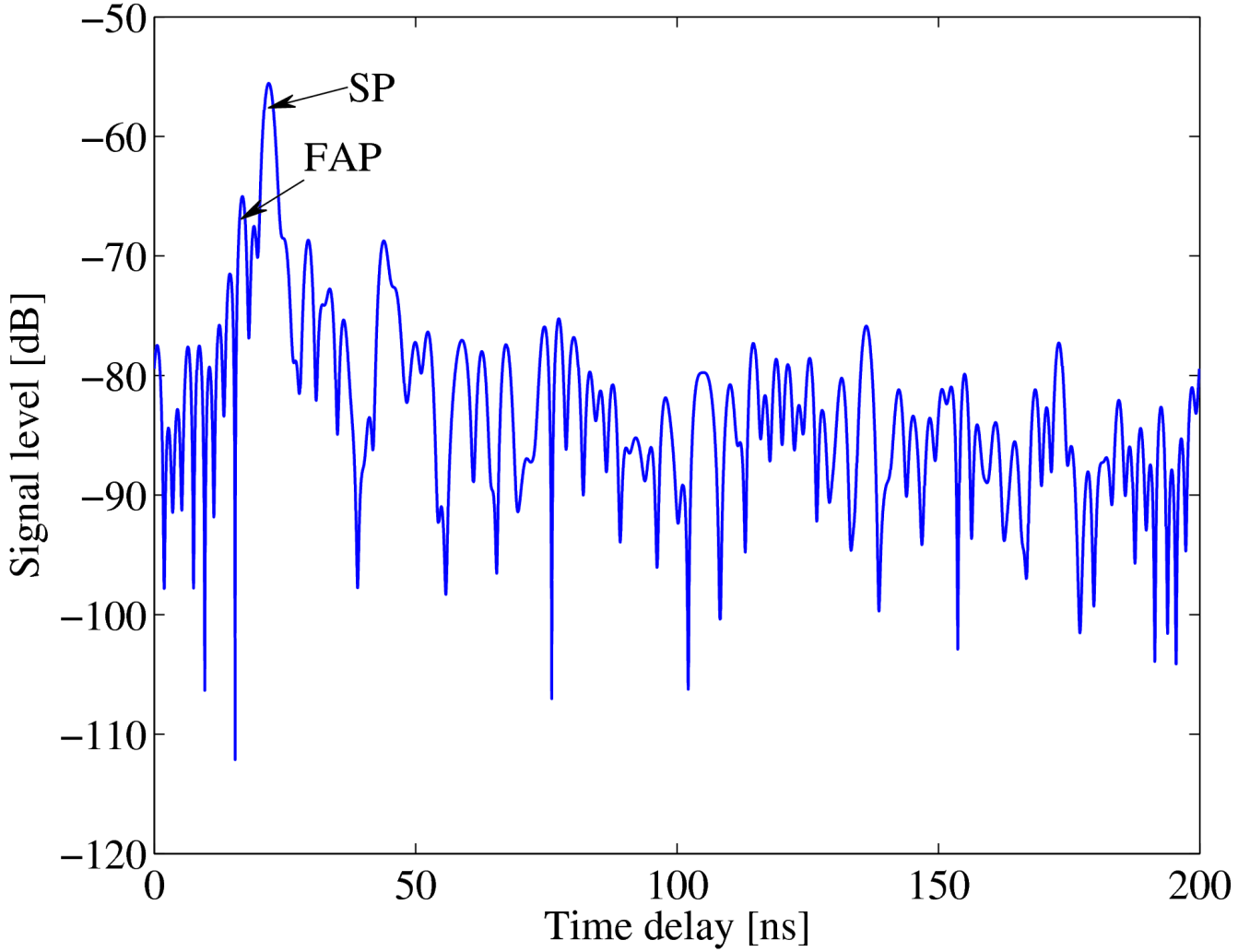
Introduction

- Time-of-arrival (ToA) is widely used for location estimation.
- UWB provide the widest bandwidth and consequently the most accurate ToA-based ranging result.
- Propagation time (ToA) of direct line-of-sight (LoS) path is supposed to used in ranging estimation.
- It is observed that in a real LoS propagation scenario, direct LoS path is not identical to strongest path (SP).
- Multipath interference to the direct path misplaced the direct path.

Problem Identification

- Because of multipath interference, direct LoS path is not identical to SP



A typical measured channel impulse response

Research Purpose

- For precise ranging, ToA of first arrival path (FAP) shall be used rather than ToA of SP
- Several scheme can be used for detection of FAP, concerning noise floor (NF) or strongest path signal level threshold
- We propose an iterative algorithm for detection of FAP.
- The accuracy of FAP detection depends upon the noise floor estimation
- Multi path interference and false estimation of NF cause wrong detection of FAP delay time
- Understanding the cause of errors in estimating the ToA of FAP between the transmitter (Tx) and the receiver (Rx) for precise indoor localization
- Behavior of the ranging error, its relation to the bandwidth of the system is needed for development of localization algorithms

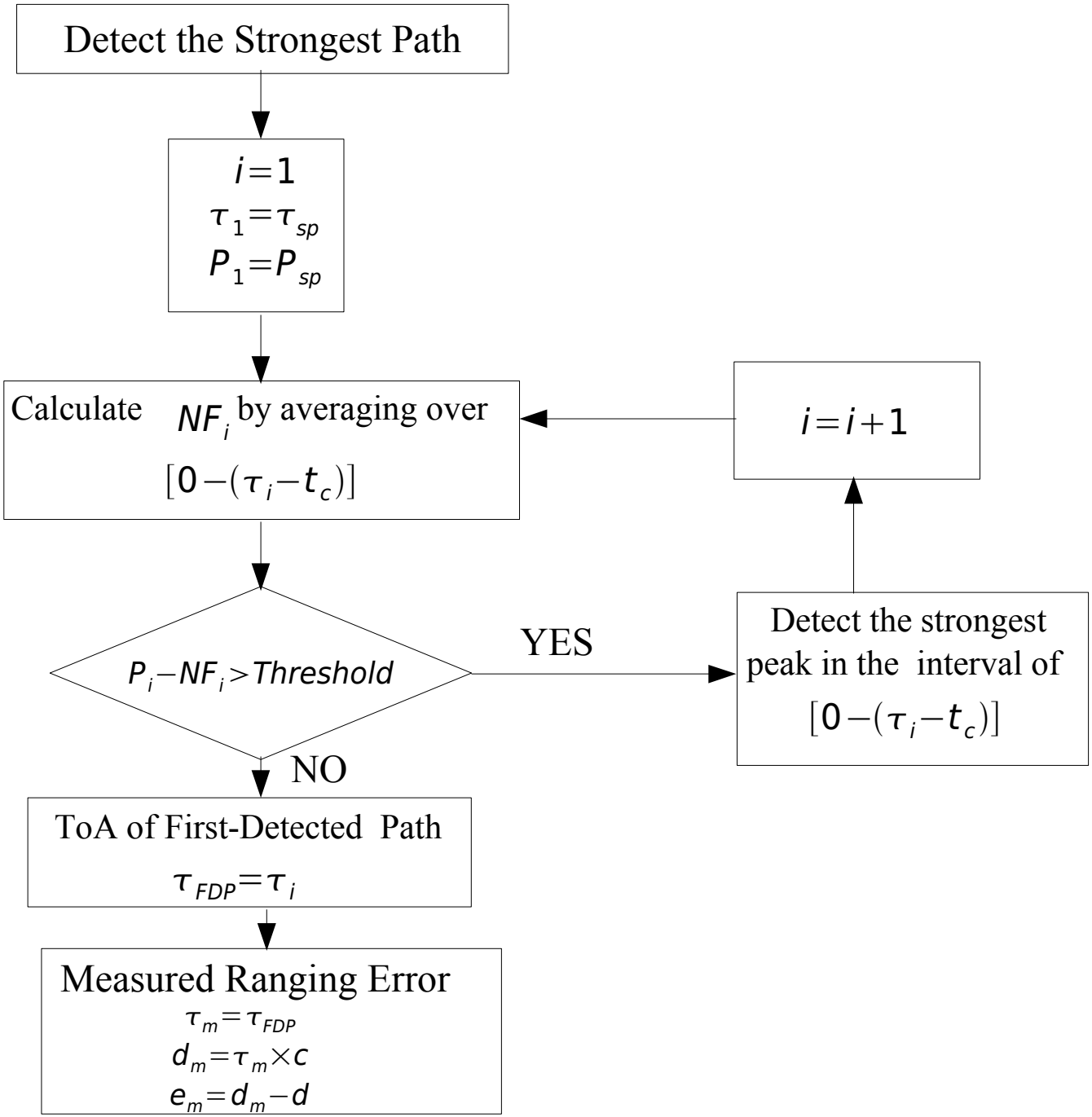
Outline

- Description of the proposed scheme for detection of first arrival path (FAP)
- Brief description of the measurement data used in this research
- Ranging errors analysis
- Investigation of the effect of frequency band and frequency bandwidth on ranging accuracy

First Arrival Path Detection Algorithm

- We proposed an iterative algorithm for detection of FAP
- In first iteration, algorithm detects the SP
- Calculates the NF by averaging over the interval $[0, (\tau_{sp} - t_c)]$
- Interval is t_c(delay resolution) less than the SP delay to exclude the effect of SP signal
- In next iterations process is repeated for new interval $[0, (\tau_i - t_c)]$, it will continue to find the new peak value and new NF
- τ_i is ToA of the peak detected in the ith iteration
- Algorithm will be continue until finding the first peak higher than the NF by predefined threshold value (L_{th})

Flowchart of First Arrival Path Detection Algorithm



Advantage of Proposed Algorithm

- In the proposed FAP detection, the detecting of first peak started from SP , going to the origin, and it continue till finding the first peak higher than calculated NF by predefined threshold value

- This algorithm has the advantage of detecting the peak after a few iteration number

Measurement

- For a precise investigation of the ranging error, a joint measurement (TAKADA Lab. and NICT) was done in testbed room developed by the NICT for measurement proposes.
- The measurements were conducted in an office room and covers wide areas inside it.
- We measured the channel transfer function of various locations (4175 combination of Tx and Rx) in the rooms at 3.1-10.6 GHz.
- There were several desks, chairs, and television displays in the room.

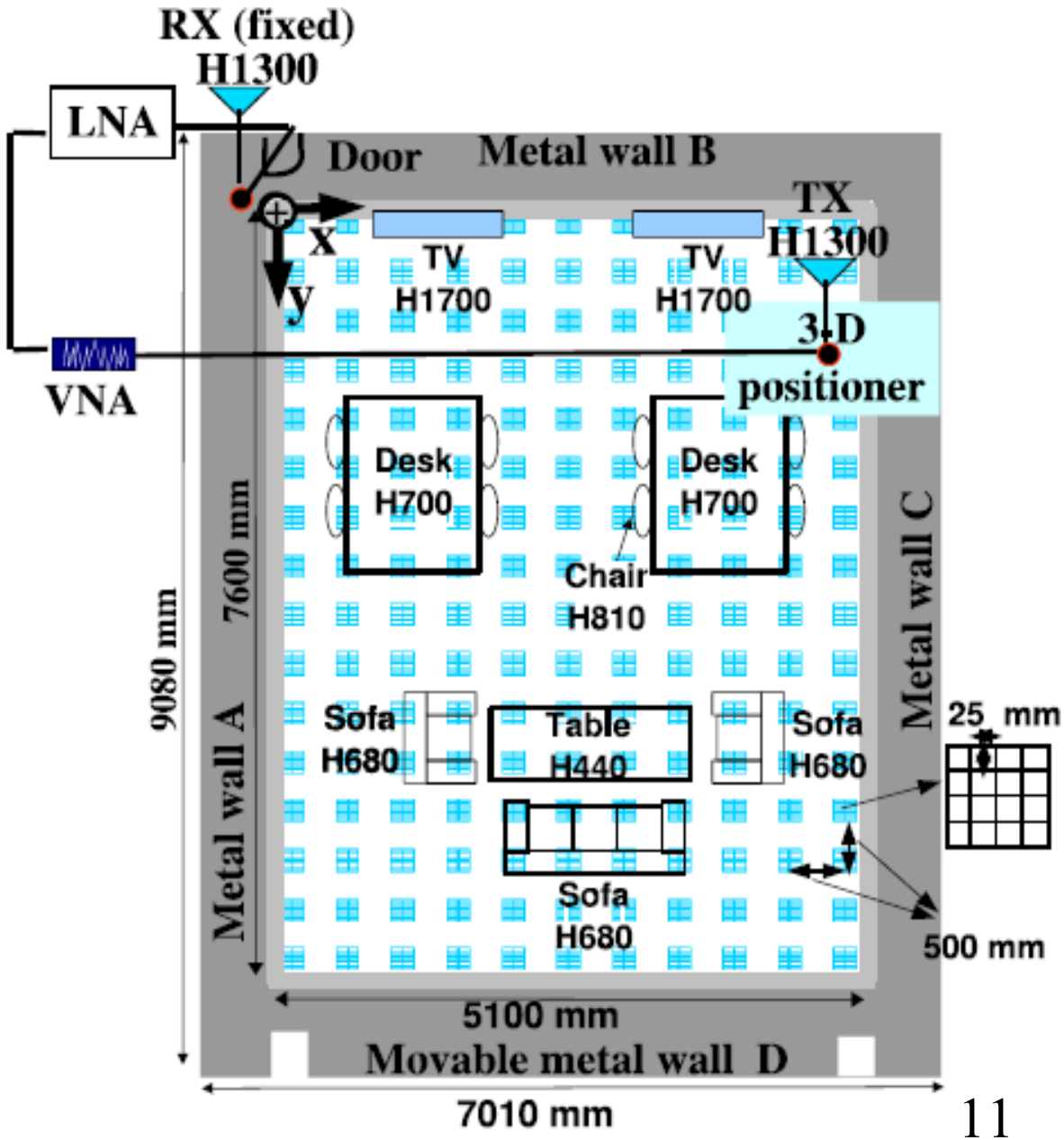
Measurement Environment

Bandwidth	3.1-10.6 GHz
Measurement equipment	Vector network analyzer Room-wide spatial scanner Low-noise amplifier (30dB)
Frequency sweeping points	1501
Antenna	UWB monopole
Transmitted power	-17 dBm (CW)'
Measured area	$5.1 \times 7.6\, m^2$
Tx-Rx antenna separation	0.6 to 9.3 m
Tx and Rx antenna height	1.3 m above the floor

Floor Plan of Measurement Room

Rx antenna was fixed at the corner of the room

Tx antenna could be positioned at almost any place in the room by the aid of a large spatial scanner covering the whole areas of the room



Band Allocation Defined in IEEE802.15.4a Standard

Channel number	Center frequency(MHz)	Bandwidth (MHz)	Mandatory /Optional
0	499.2	499.2	Mandatory below 1GHz
1	3494.4	499.2	Optional
2	3993.6	499.2	Optional
3	4492.8	499.2	Mandatory in low band
4	3993.6	1331.2	Optional
5	6489.6	499.2	Optional
6	6988.8	499.2	Optional
7	6489.6	1081.6	Optional
8	7488	499.2	Optional
9	7987.2	499.2	Mandatory in high band
10	8486.4	499.2	Optional
11	7987.2	1331.2	Optional
12	8985.6	499.2	Optional
13	9484.8	499.2	Optional
14	9984	499.2	Optional
15	9484.8	1354.97	Optional

Ranging Error

Measured distance between the Tx and Rx antennas:

$$d_m = \tau_m \times c$$

τ_m Propagation delay of FAP

c Speed of light

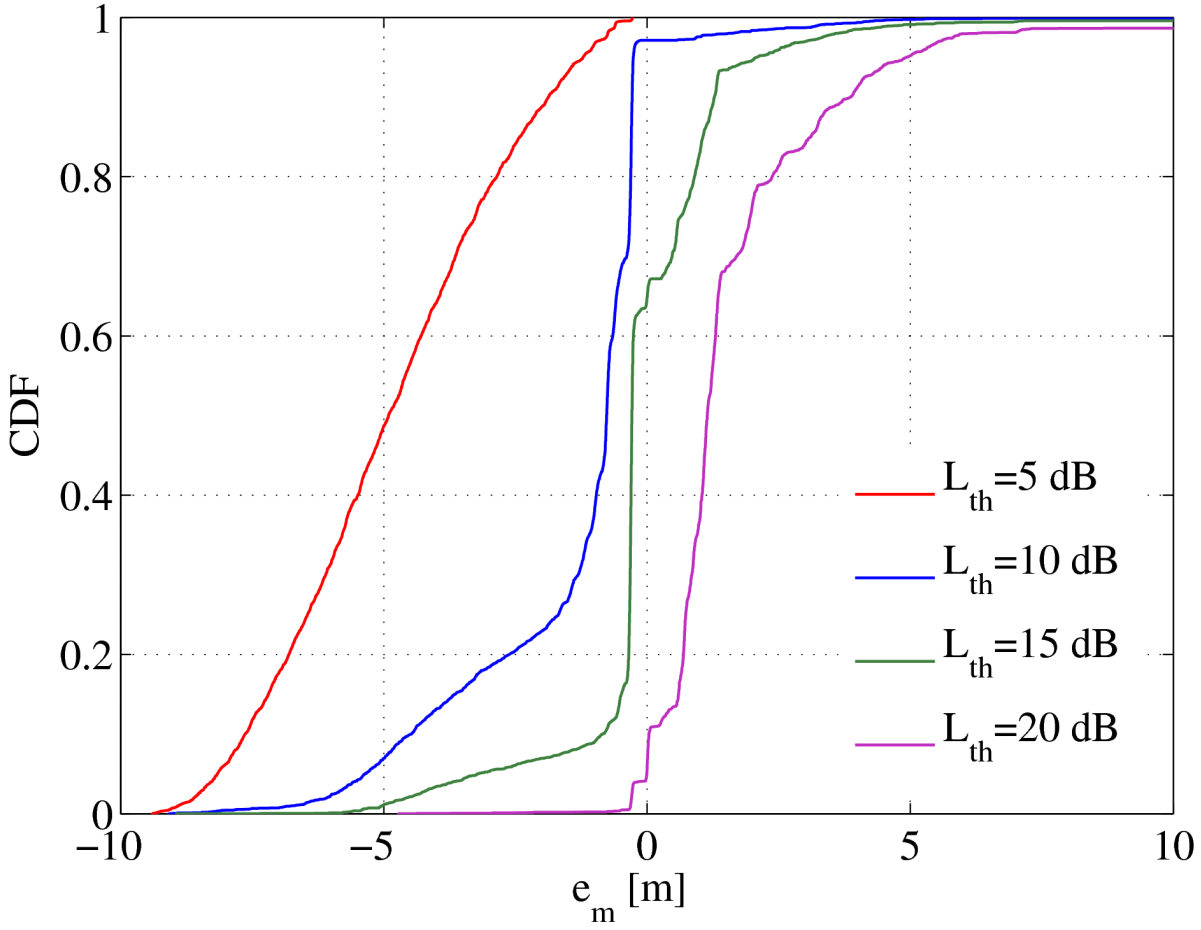
Ranging error:

$$e_m = d_m - d$$

d Real distance between Tx and Rx antennas

Choosing Threshold Value (1)

- L_{th} level is chosen different for each channel
- CDF of ranging error using different L_{th} for Channel 4
- L_{th} was chosen 15 dB for Channel4



Choosing Threshold Value (2)

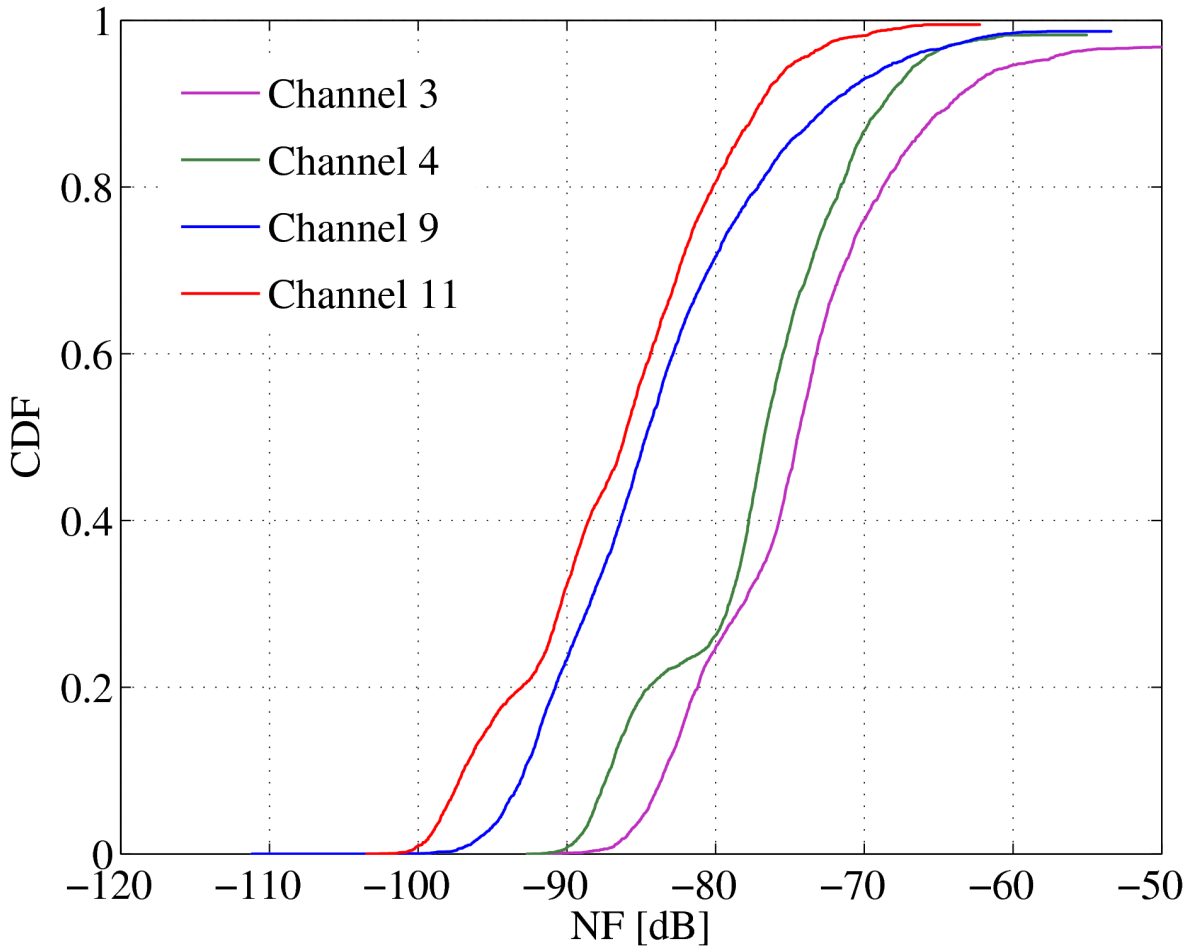
- To obtain the optimum L_{th}, which gives lowest error, we calculated the ranging error using several L_{th}, such as 5, 10,15 and 20 dB

μ_e Average of ranging error
σ_e Variance of ranging error

Channel	5 dB		10 dB		15 dB		20 dB	
	μ_e	σ_e	μ_e	σ_e	μ_e	σ_e	μ_e	σ_e
3	-4.27	4.9	-0.26	7.93	0.83	6.91	1.93	9.09
4	-4.83	4.41	-1.42	3.51	-0.01	2.9	1.7	4.61
9	-4.16	5.08	-0.22	3.12	1.07	1.66	1.94	1.6
11	-5.05	4.24	-1.05	2.35	0.33	2.08	0.14	2.46

Estimated Noise Floor in Different Sub-bands

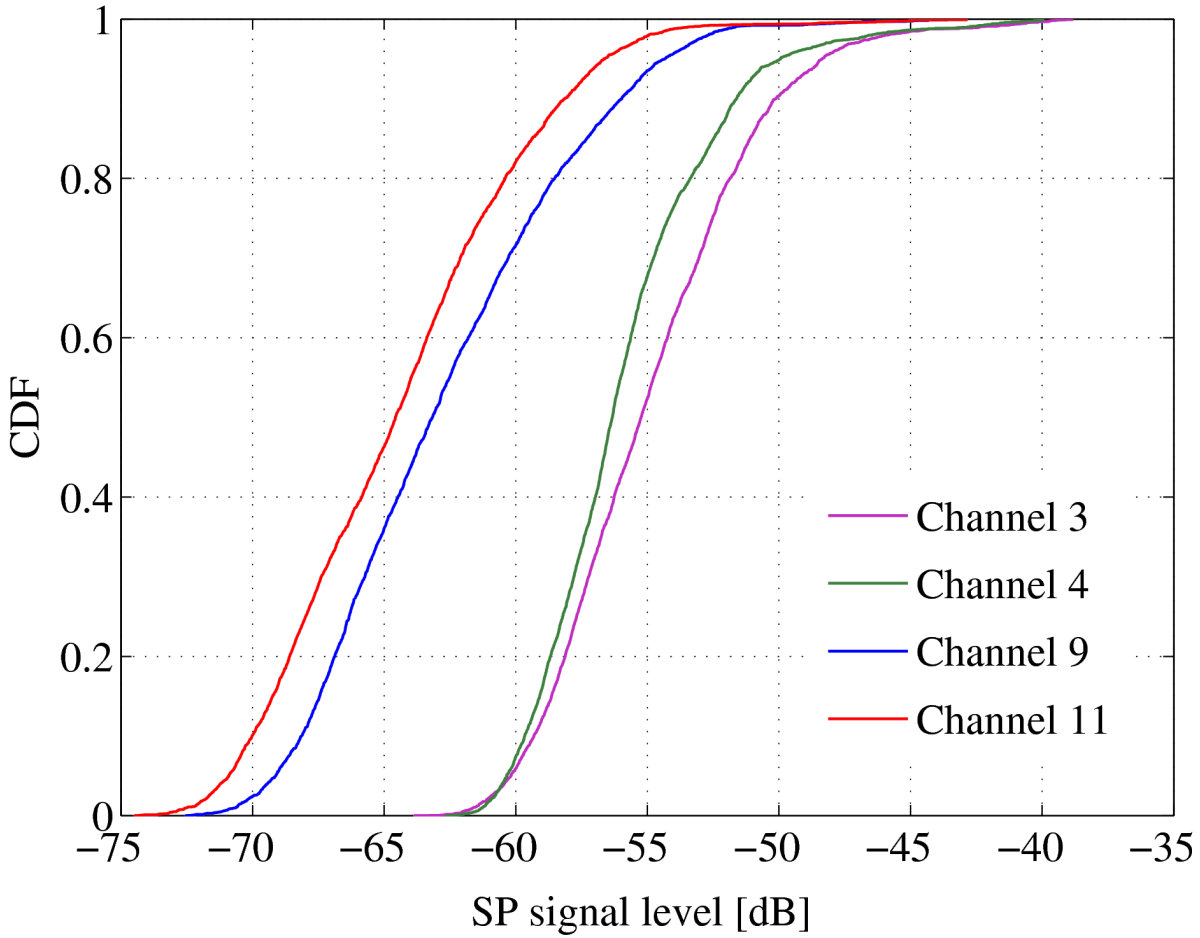
- It is observed that NF decrease by increasing BW
- NF decreases for higher bands



CDF of calculated NF for Channels 3,4,9 and 11

Strongest Path Signal Level in Different Sub-bands

- The peak value decrease by increasing BW
- The peak value decrease in higher bands because path loss increase as the frequency increase.



CDF of SP signal level in different sub-bands

First-Detected Path (FDP) Instead of SP

- The proposed algorithm search for detection of first arrival path
- Using the first detected path (FD P) by algorithm, ranging error decrease
- The average and variance of e_m decrease by using FDP instead of SP
- However still some errors remain caused by wrong detection of FAP

Channel	SP		FDP	
	μ_e	σ_e	μ_e	σ_e
3	1.93	9.08	-0.26	7.93
4	1.73	4.50	-0.01	2.90
9	1.94	1.60	-0.22	3.12
11	1.70	1.20	0.33	2.08

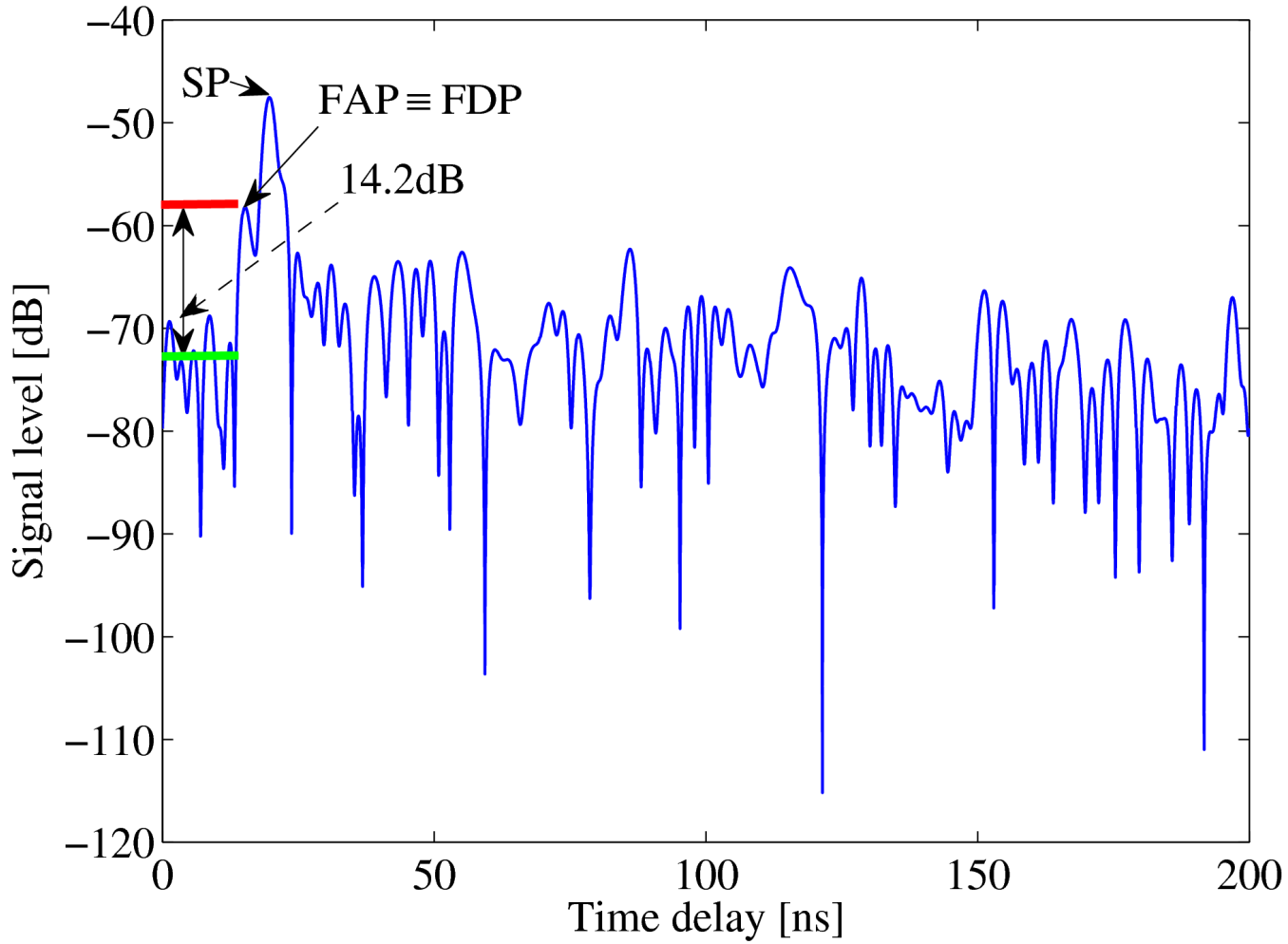
μ_e Average of ranging error

σ_e Variance of ranging error

Ranging Errors Categories

- The proposed algorithm decrease ranging error
- However still some errors remain caused by wrong detection of FAP
- We categorize the ranging errors to three main categories:
  - Small errors
  - Large positive errors
  - Large negative errors

Impulse Response of a Position with Small Error



Channel 3

$L_{th} = 10\,dB$

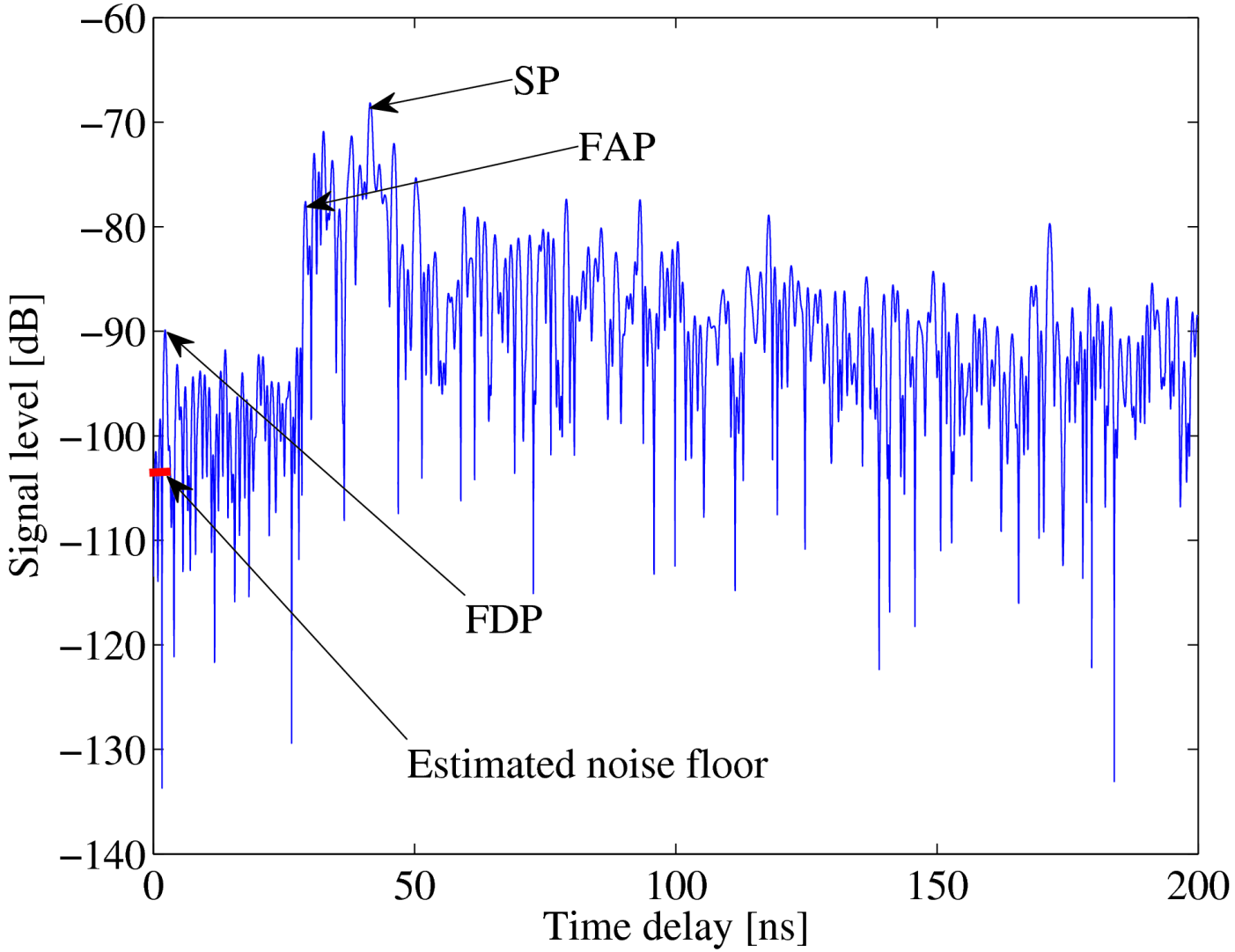
- Correct FAP was detected after only 2 iteration

Small Errors

Because of multipath interference (path which are very close to direct path, nearer than the resolution of the system), peak of channel response gets a little shifted from the expected ToA to shorter/longer ToA

→ Resulting small errors in ToA estimation

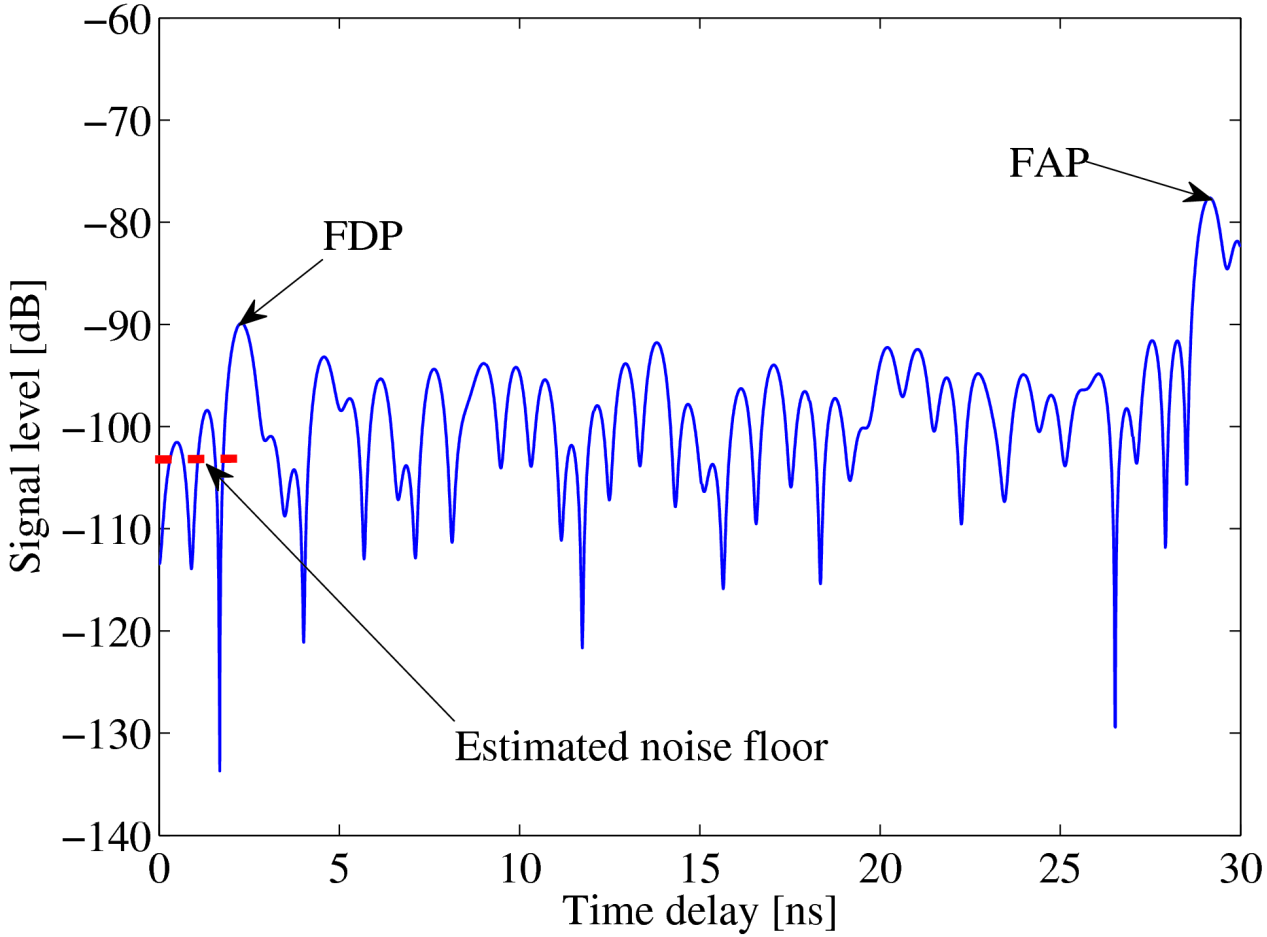
Impulse Response of a Position with Large Minus Error(1)



Channel 9

$L_{th} = 10\,dB$

Impulse Response of a Position with Large Minus Error(2)



Channel 9

$L_{th} = 10\,dB$

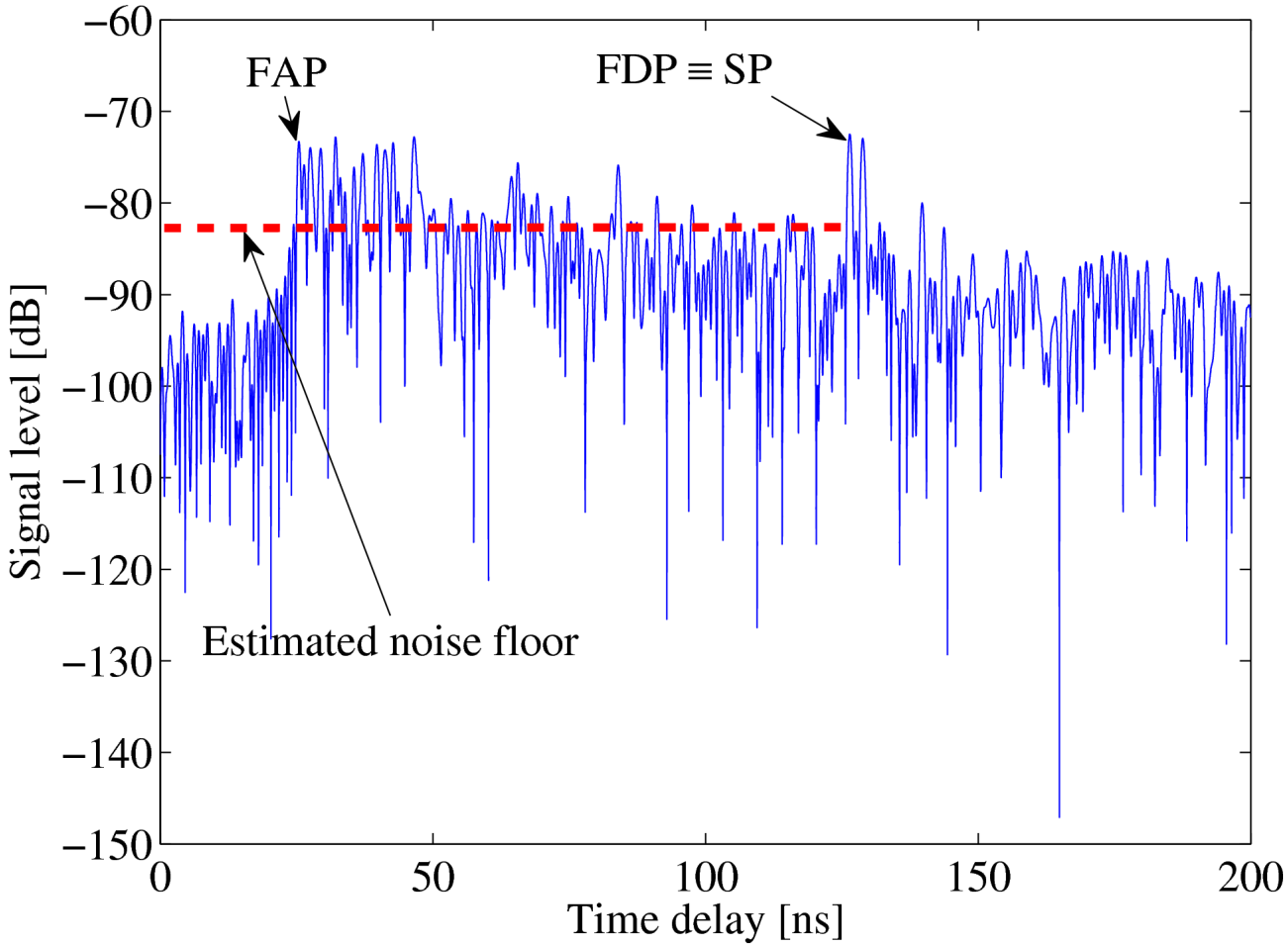
- A zoom selection area of impulse response shown in previous figure
- The calculated NF for this point is -104dB, and the FDP level is 14dB higher than this NF
- This peak is not the real FAP, so cause relatively large minus error

Large Minus Ranging Error

Occurrence of high peak in noise area, cause the wrong first path detection by algorithm → Resulting large minus ranging error

Detection of first arrival path is a challenge in such these cases

Impulse Response of a Position with Large Positive Error



Channel 9

$L_{th} = 10\,dB$

- Algorithm could not find the expected FA P

Large Positive Ranging Error

- Two or more multipath signals do in constructive way in a specified time delay and cause a strong peak with large time delay

- Detection algorithm started from origin and going to SP may eliminate the error of such these cases

Influence of Frequency Band and Bandwidth

Influence of Frequency Band

- By increasing system band width, the variance of the error decrease
- By increasing system bandwidth ranging accuracy improves

Influence of Frequency Band

- Ranging error average and variance decrease in channel 9 compared with channel 3

Summary and conclusion (1)

- An iterative algorithm was proposed for detection of first arrival path in channel impulse response
- Analysis of ranging accuracy based on SP and FDP was done for two allocated mandatory sub bands for ranging according to IEEE802.15.4a2007 and two optional sub bands
- Ranging error was used as an criteria to evaluate the performance of this algorithm
- The proposed algorithm decrease ranging errors, but still some errors remain

Summary and conclusion (2)

- We differentiate the small errors caused by multipath from the large errors produced by the occurrence of strong path in noise area or caused by false detection of noise floor
- Since occurred ranging errors have different physical reasons reasons, decreasing all type of errors is a challenge
- The improvement of the algorithm is undergoing by investigating the individual impulse responses of the point with a false ranging estimate to propose an algorithm which decrease all type of errors

Thank you for your attention!