Toward Standard Non-Line-of-Sight Benchmarking of Ultra-wideband Radio-based Localization

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Why Do We Care About Indoor Localization?

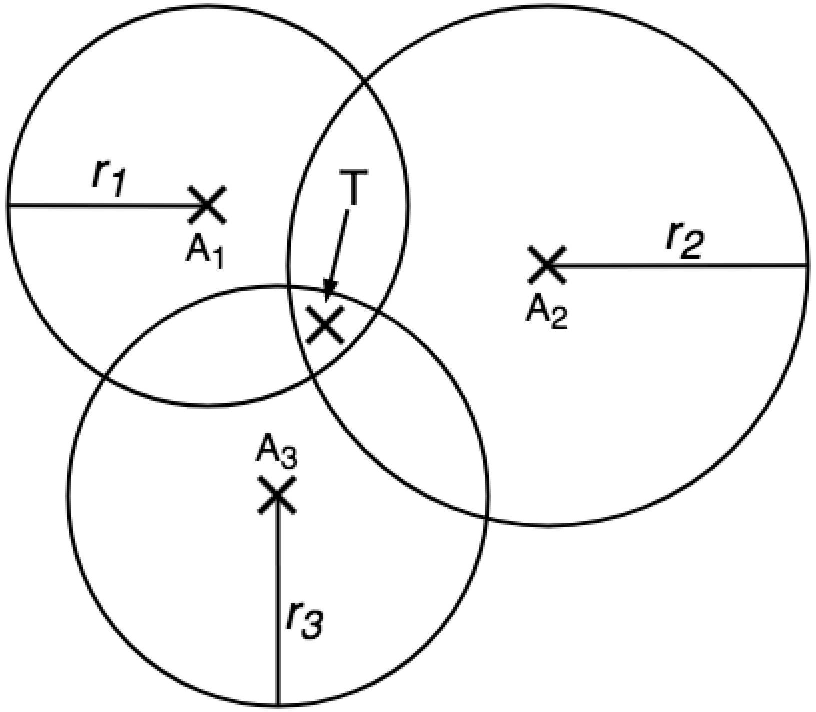
- Locating, tracking, monitoring, and navigation
- 130,000+ articles and studies
- Revenue of 8.5 billion USD by 2020*

https://futurelab.assaabloy.com/en/the-future-of-indoor-positioning/

* https://www.technavio.com/report/global-machine-machine-m2m-and-connected-devices-global-indoor-lbs-market-2016-2020

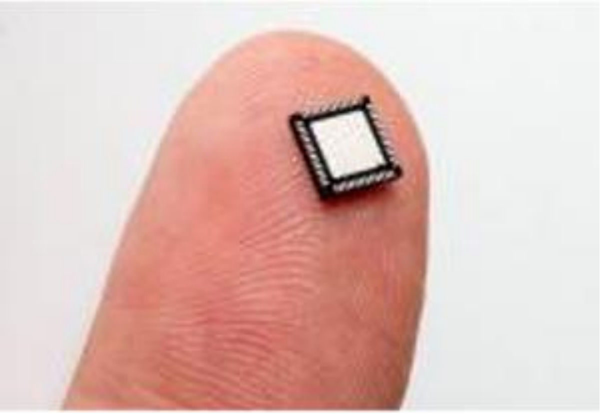
Indoor Localization and Ranging

- Goal: Finding estimated location of T
- Given: Locations of A_1, A_2, and A_3
- Method:
  - Estimating distance of T from A_1, A_2, and A_3
  - Trilateration



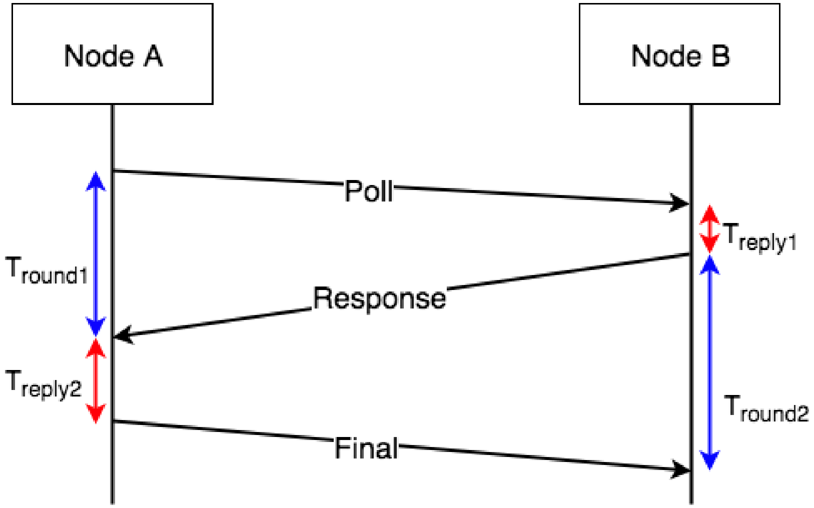
Ultra-wideband Radios and Two-way Ranging

- Decawave DW1000 chip:
  - Impulse-based Radio
  - Ultra-low Power
  - Ultra-wide Frequency Bandwidth (≥ 500 MHz)
  - High-resolution time-of-arrival estimation (~15.6 ps)
- Asymmetrical Double-sided Two-way Ranging



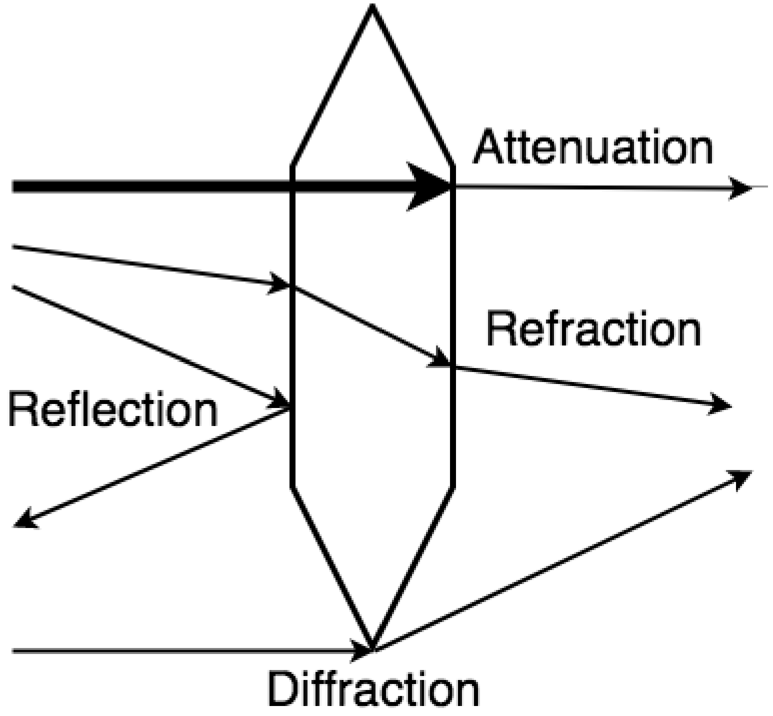
https://www.decawave.com/products/overview

$$ToF = \frac{T_{round1} \times T_{round2} - T_{reply1} \times T_{reply2}}{T_{round1} + T_{round2} + T_{reply1} + T_{reply2}}$$

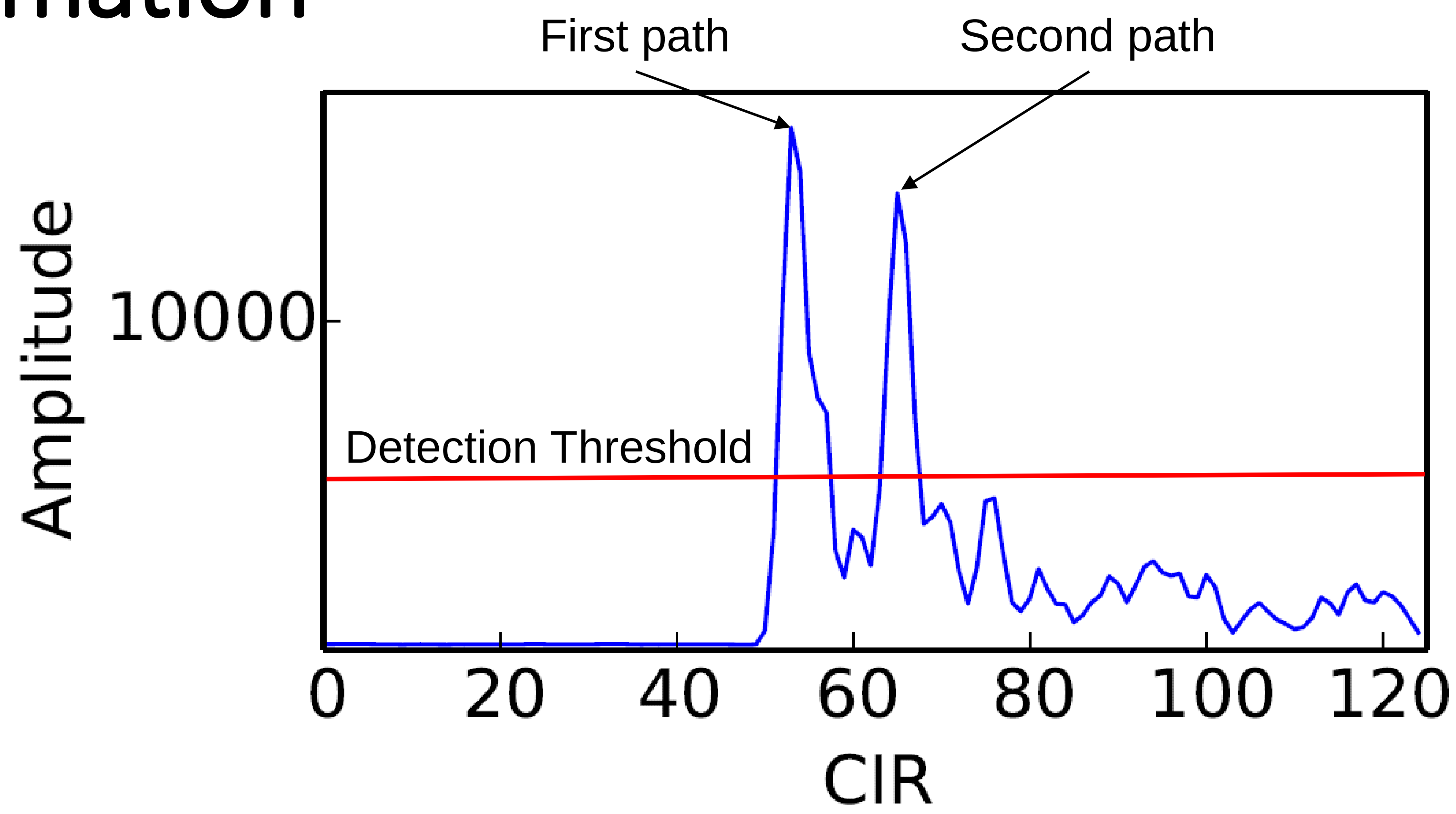


Propagation of Radio Signals

- Line-of-Sight (LoS): direct path is not obstructed
- Visual Non-Line-of-Sight (Visual NLoS)
- Radio-Frequency Non-Line-of-Sight (RF NLoS)
    - Attenuation
    - Refraction
    - Reflection
    - Diffraction



Channel Impulse Response – Time of Arrival Estimation



Amplitude of received signal over time, showing reflections as multipath components

State-of-the-Art Evaluation of UWB Localization

Ref	Test Environment	Type of Materials	Most Probable Materials
IPSN 2017	Room in a commercial building	Not Reported	Wooden Walls
SenSys 2016	20m x 20m in academic building	Not Reported	Concrete and Wooden Walls
IEEE 2015	Office space	Not Reported	Wooden Walls
WSA 2015	The hole of a building	Not Reported	Concrete Walls
ICIT 2017	A residential apartment	Not Reported	Wooden and Brick Walls
IECON 2016	Heavy machines lab	Metallic surface and motors	Metal
IPIN 2010	A lecture room	Not Reported	Wooden and Concrete Walls
IEEE 2017	Several offices, hallways, one laboratory, and a large lobby	Not Reported	Wooden and Concrete Walls

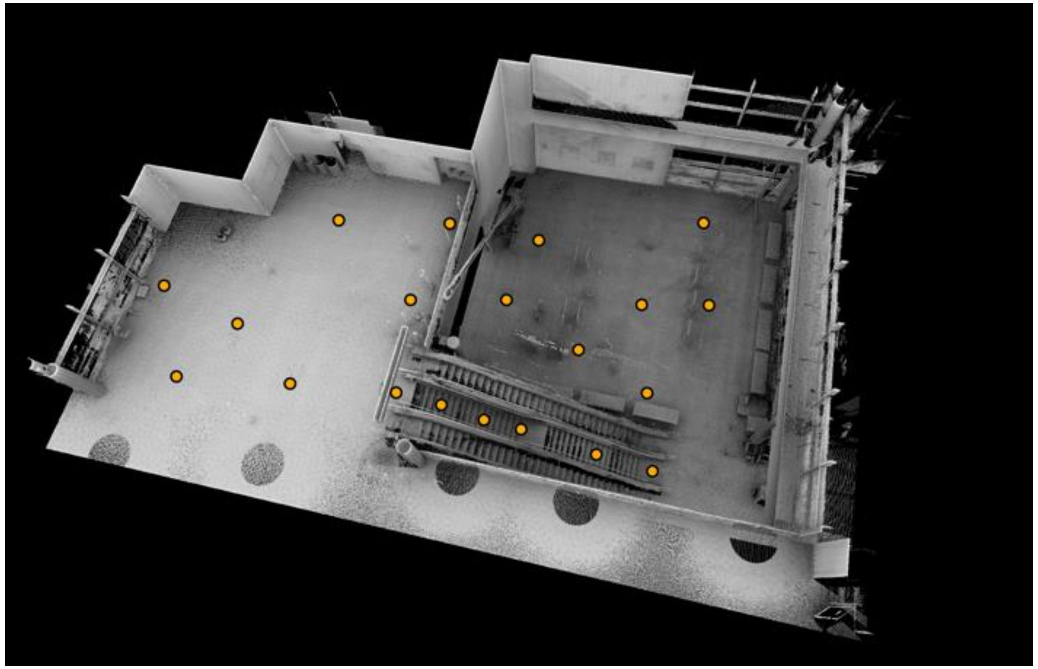
UWB localization studies did not report type of materials used in their evaluation environment

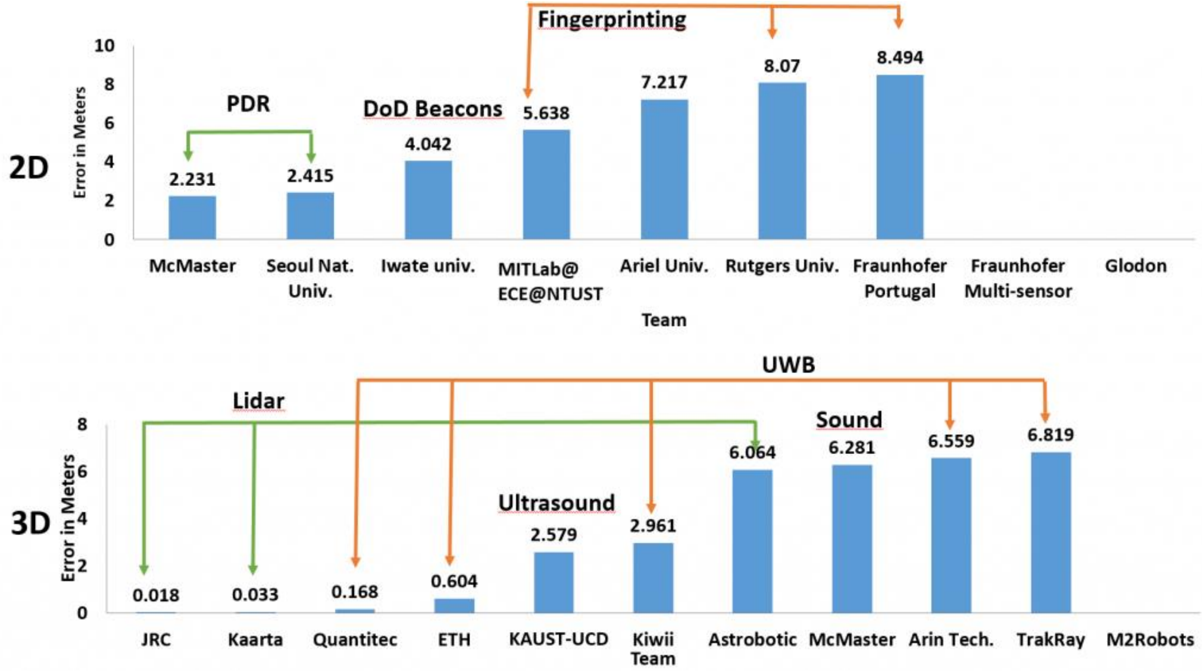
Problem

- Lack of standard for benchmarking UWB-based localization solutions especially in NLoS scenarios
- Results from different studies are not comparable
- Comparison is only possible if evaluated at the same location
  - Microsoft Indoor Localization Competition [1]
  - 2018 NIST Localization and Tracking System Test & Evaluation Event [2]

[1] https://www.microsoft.com/en-us/research/event/microsoft-indoor-localization-competition-ipsn-2018/
[2] https://perfloc.nist.gov/2018-nist-lts-tne-event.php

Microsoft Indoor Localization Competition 2017



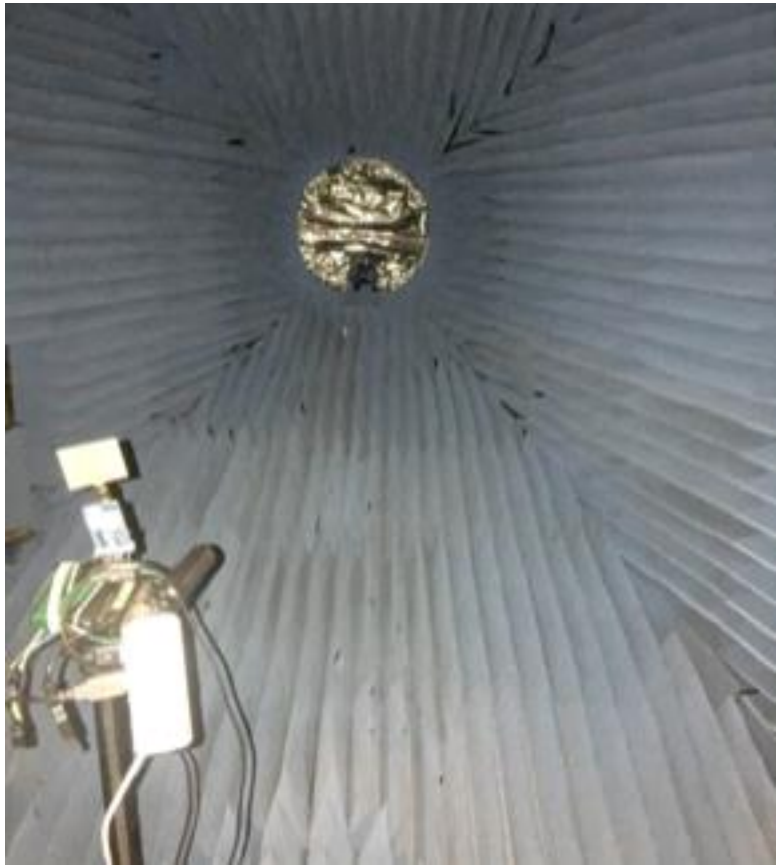


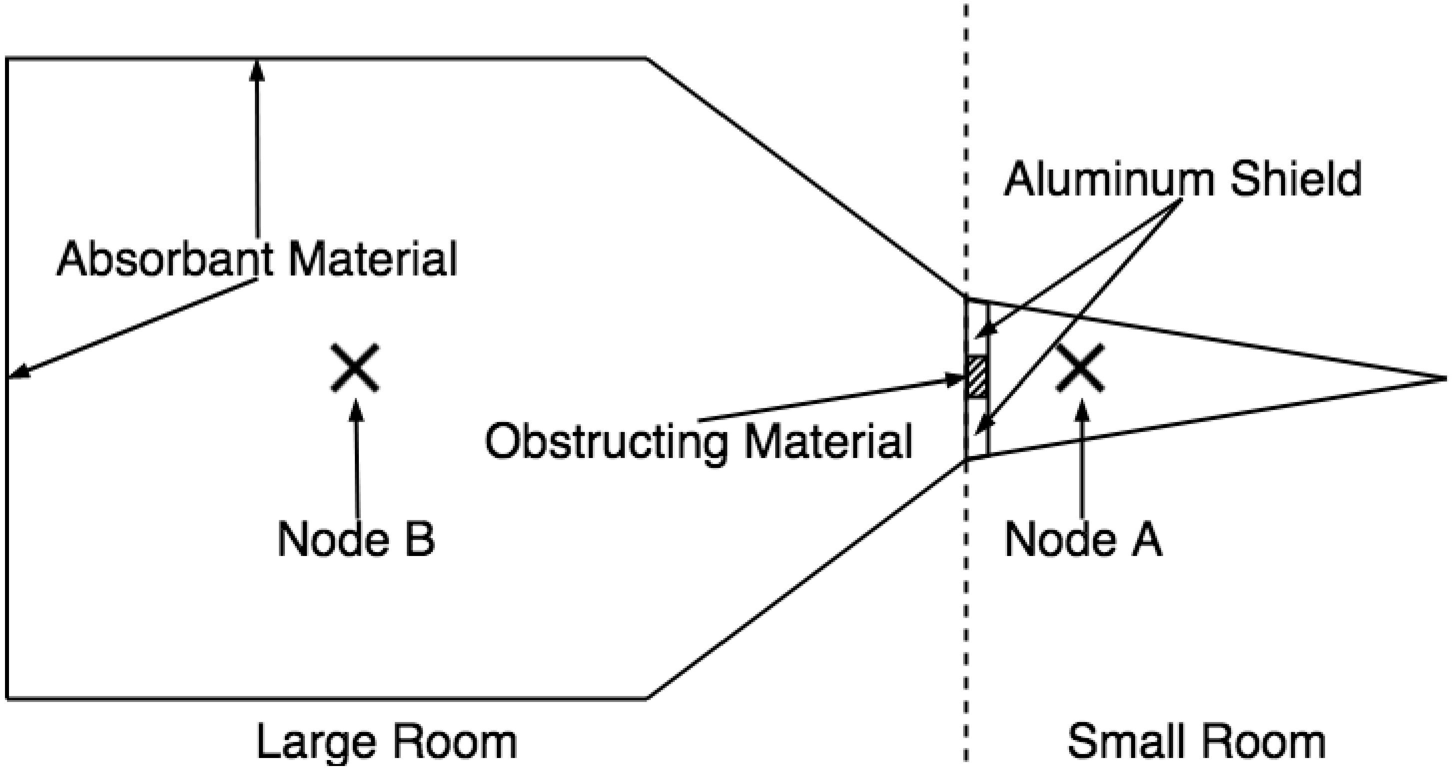
19 teams with various solutions competed in a 600 m^2, two floor evaluation area.
Ranked based on average localization error across the 20 test points.

Figures borrowed from https://www.microsoft.com/en-us/research/event/microsoft-indoor-localization-competition-ipsn-2017/

Studying UWB NLoS Scenarios

Experiment Setup





Experiment setup in an anechoic chamber

Materials Used to Obstruct LoS

Material	Aluminum Foil	Paver Brick	Ceramic Tile	Porcelain Tile	Drywall
Photo					
Thickness (mm)	0.024	59	5	5	10

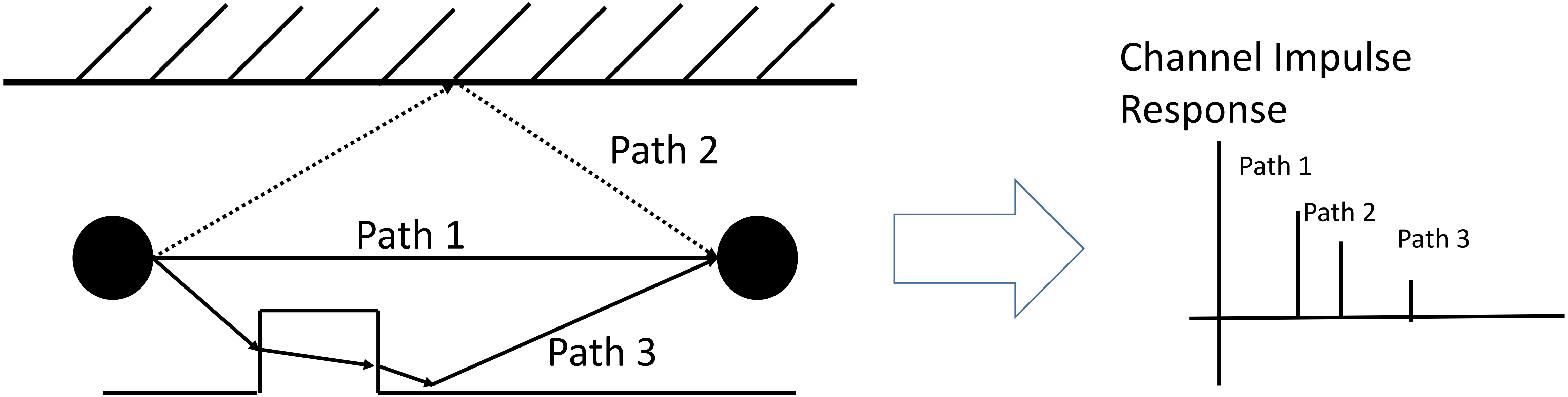
Material	Rumble Stone Brick	Glass	Wood	Granite Tile	Concrete Block
Photo					
Thickness (mm)	43	59	5	5	10

Channel Impulse Response

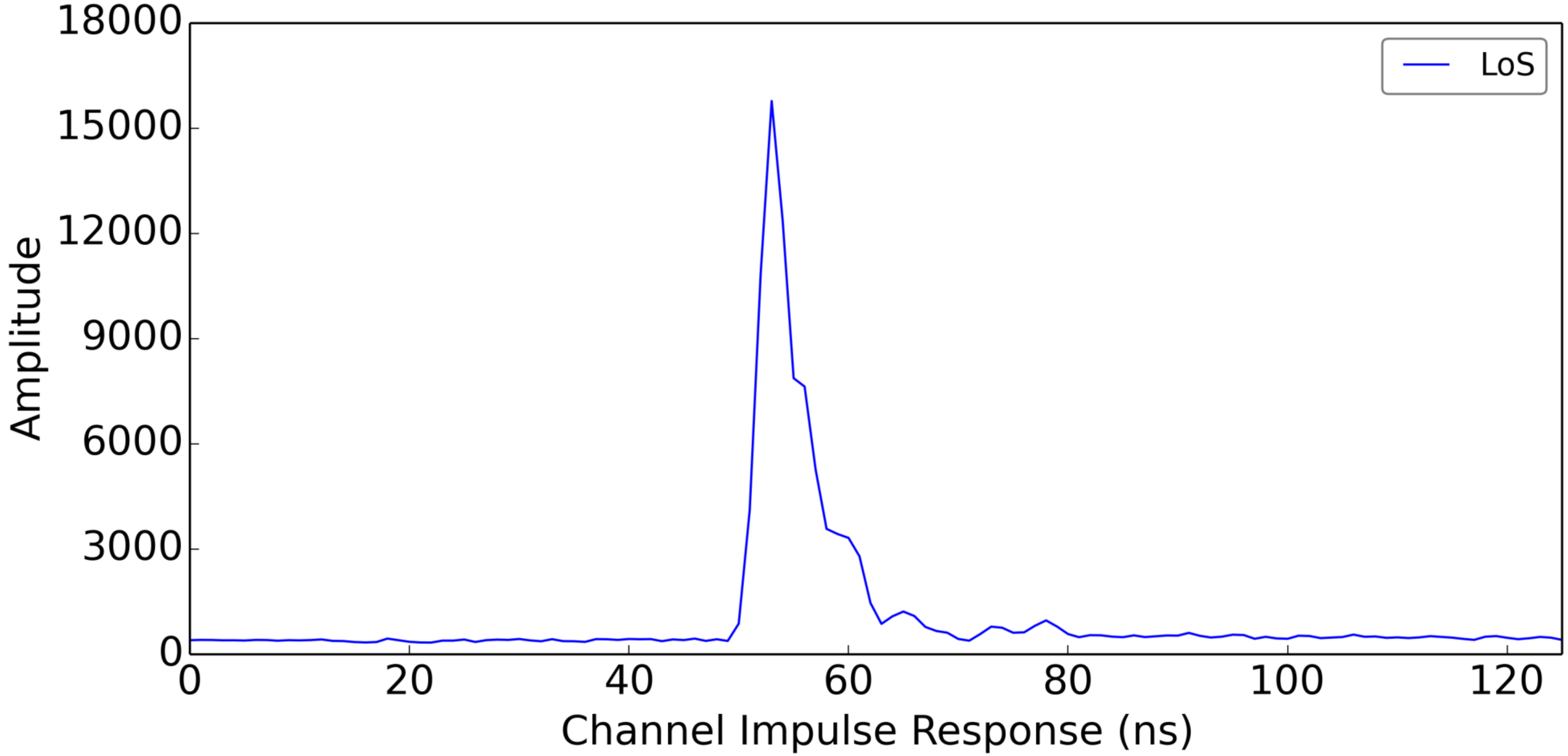
- Impulse response of UWB channels

$$h(t) = \sum_{i=1}^{N} a_i \, e^{-j\theta_i} \delta(t - t_i)$$

- CIR is a very good representative of reflected multipath signals



Results – Channel Impulse Response



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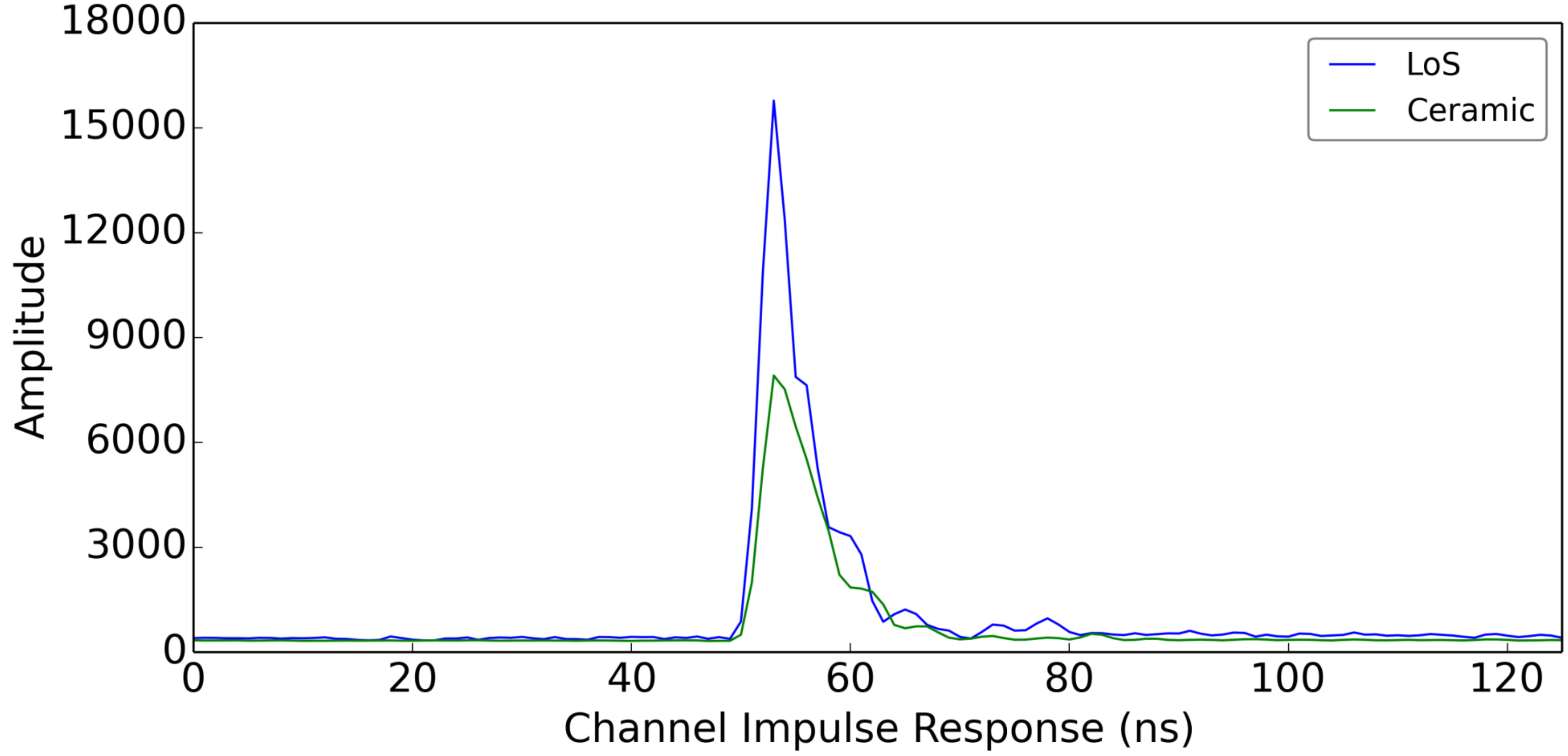

Amplitude drops but shape remains the same

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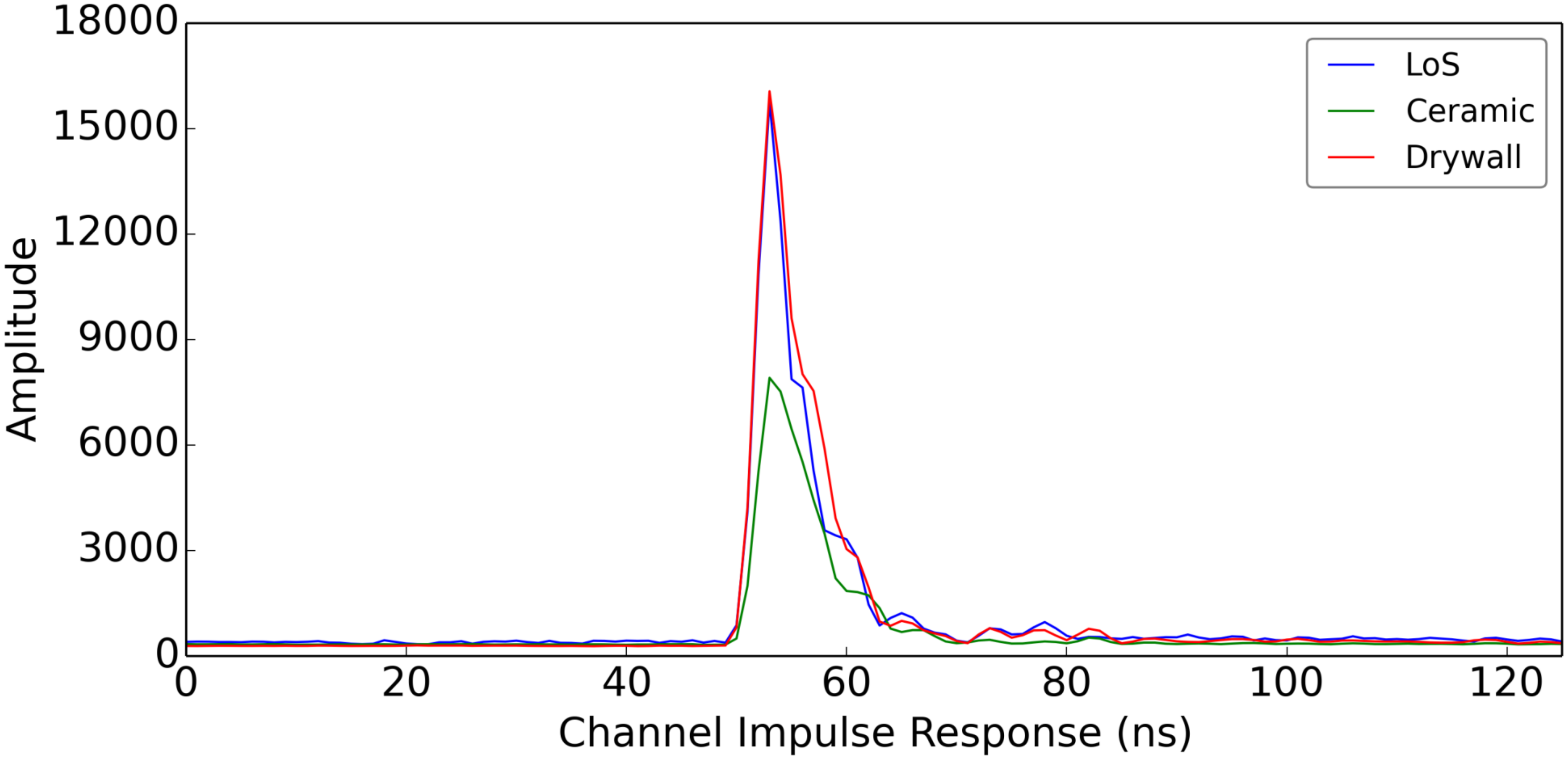

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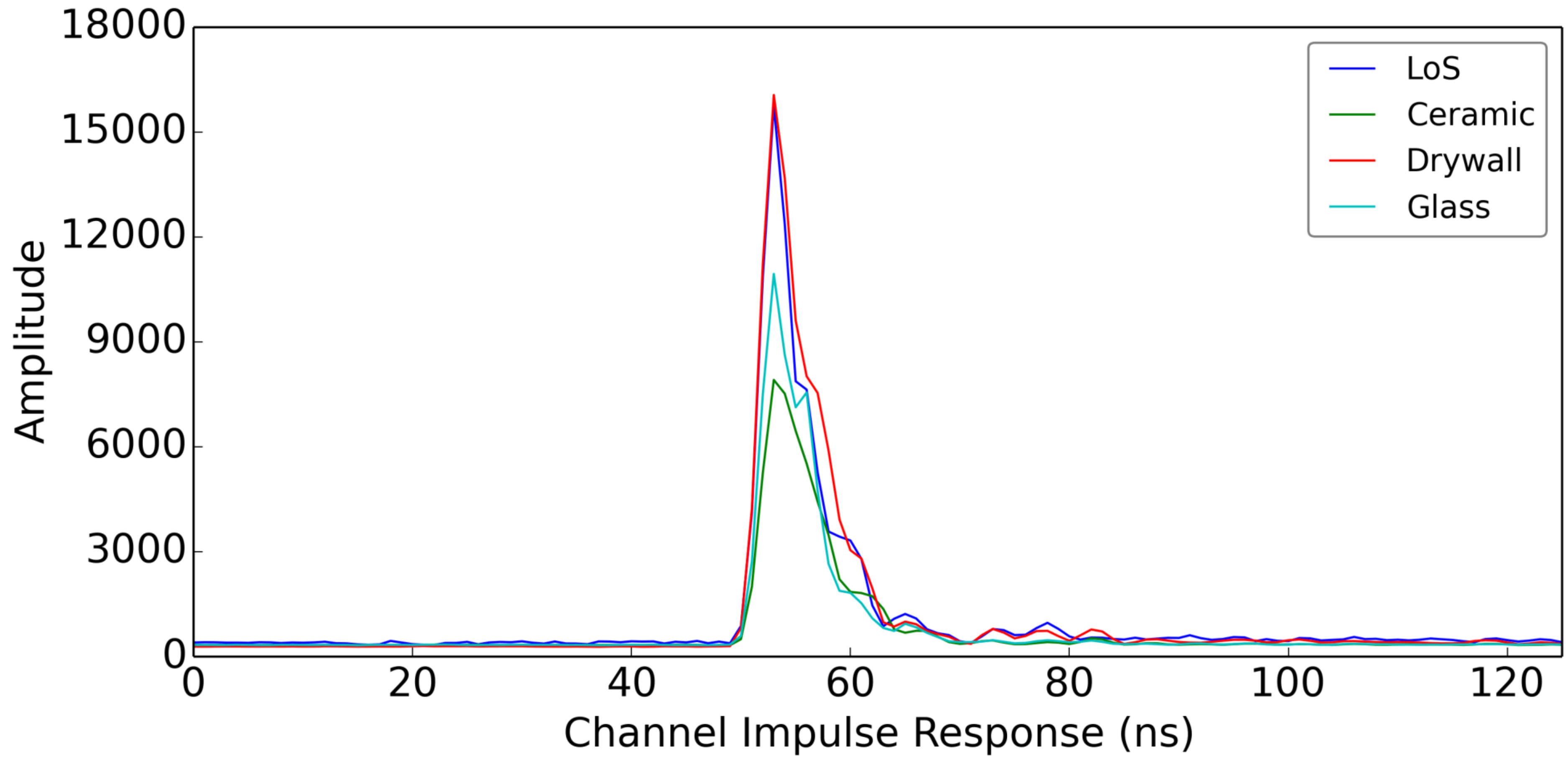

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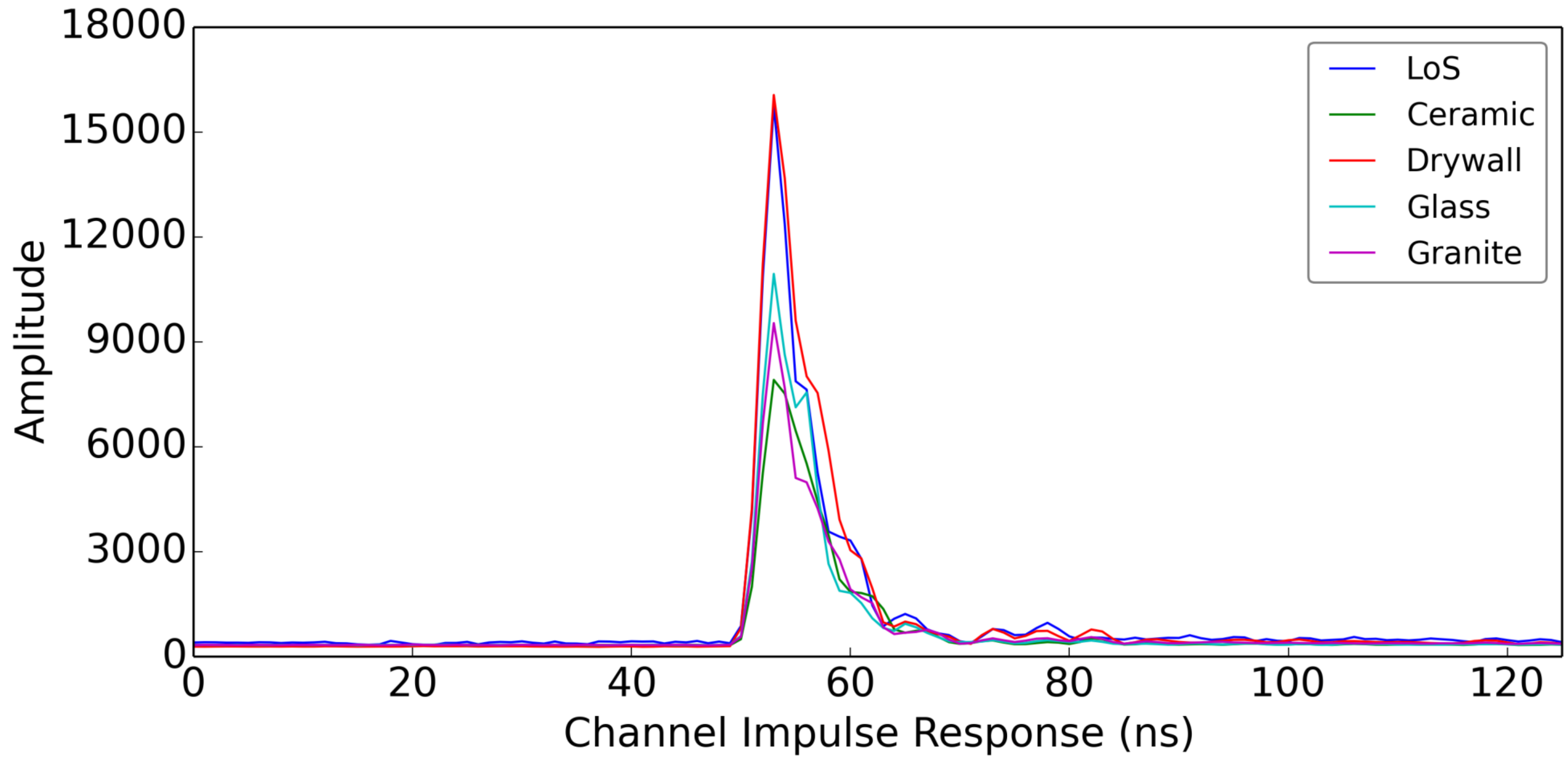

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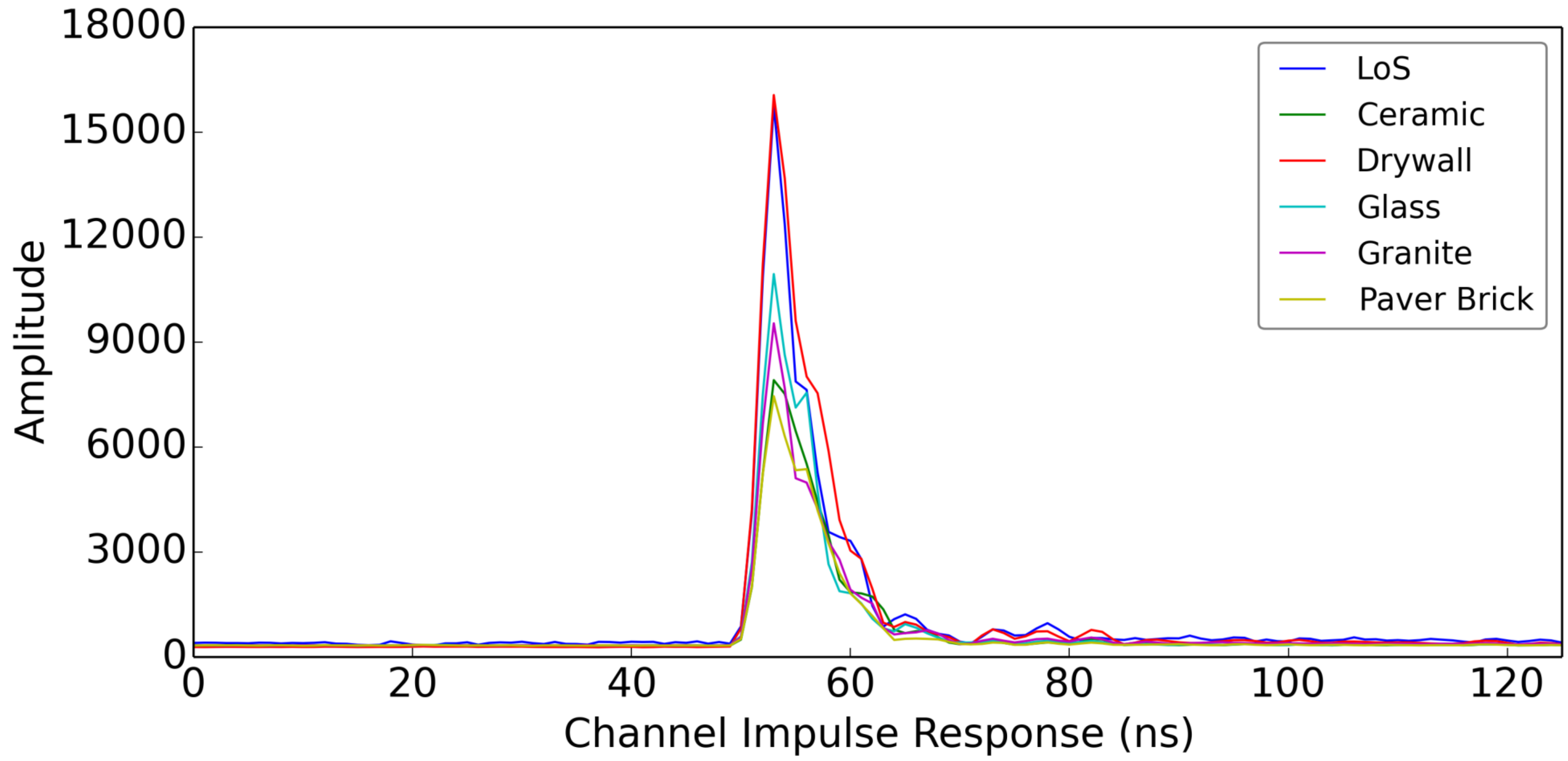

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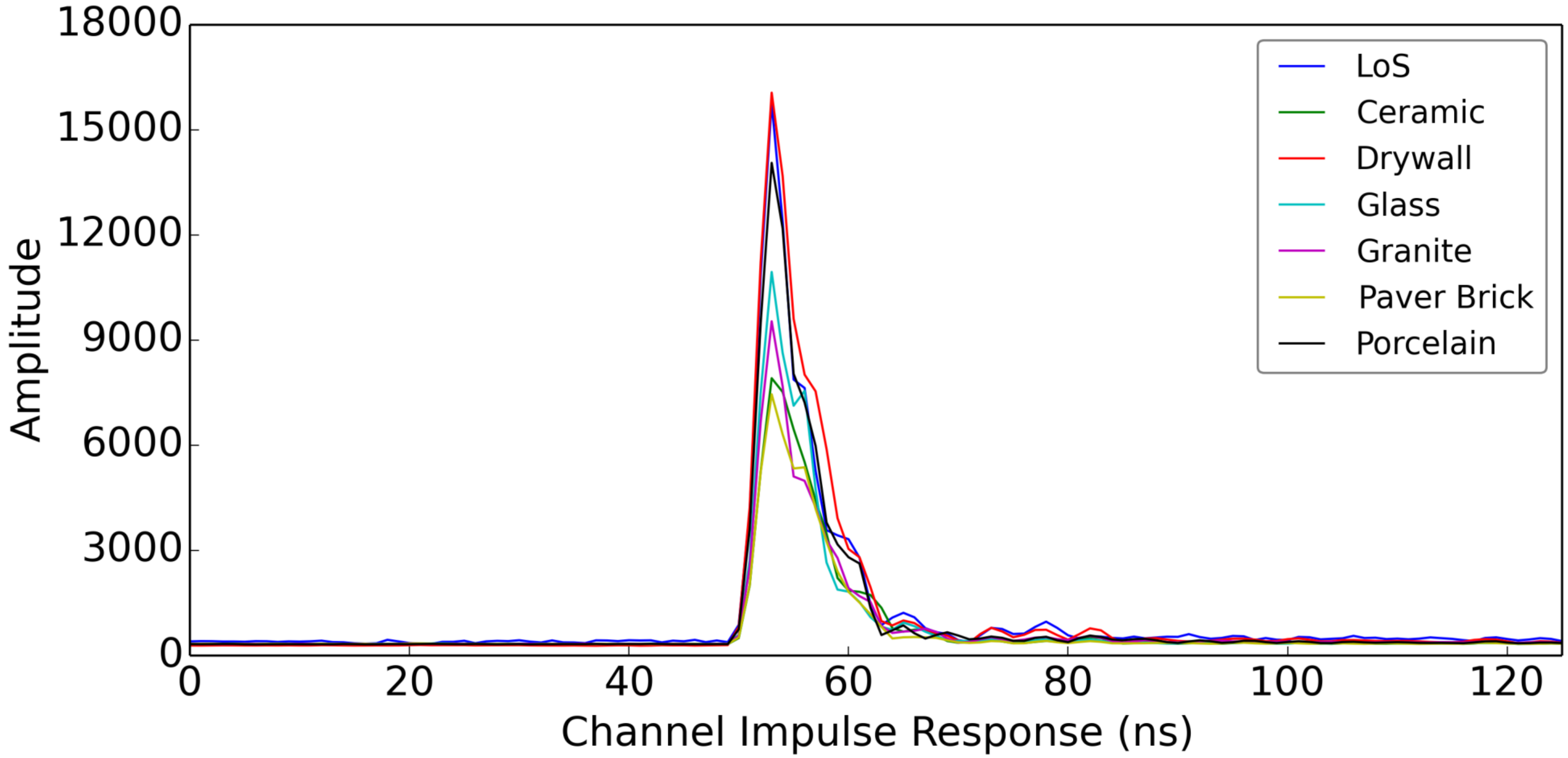

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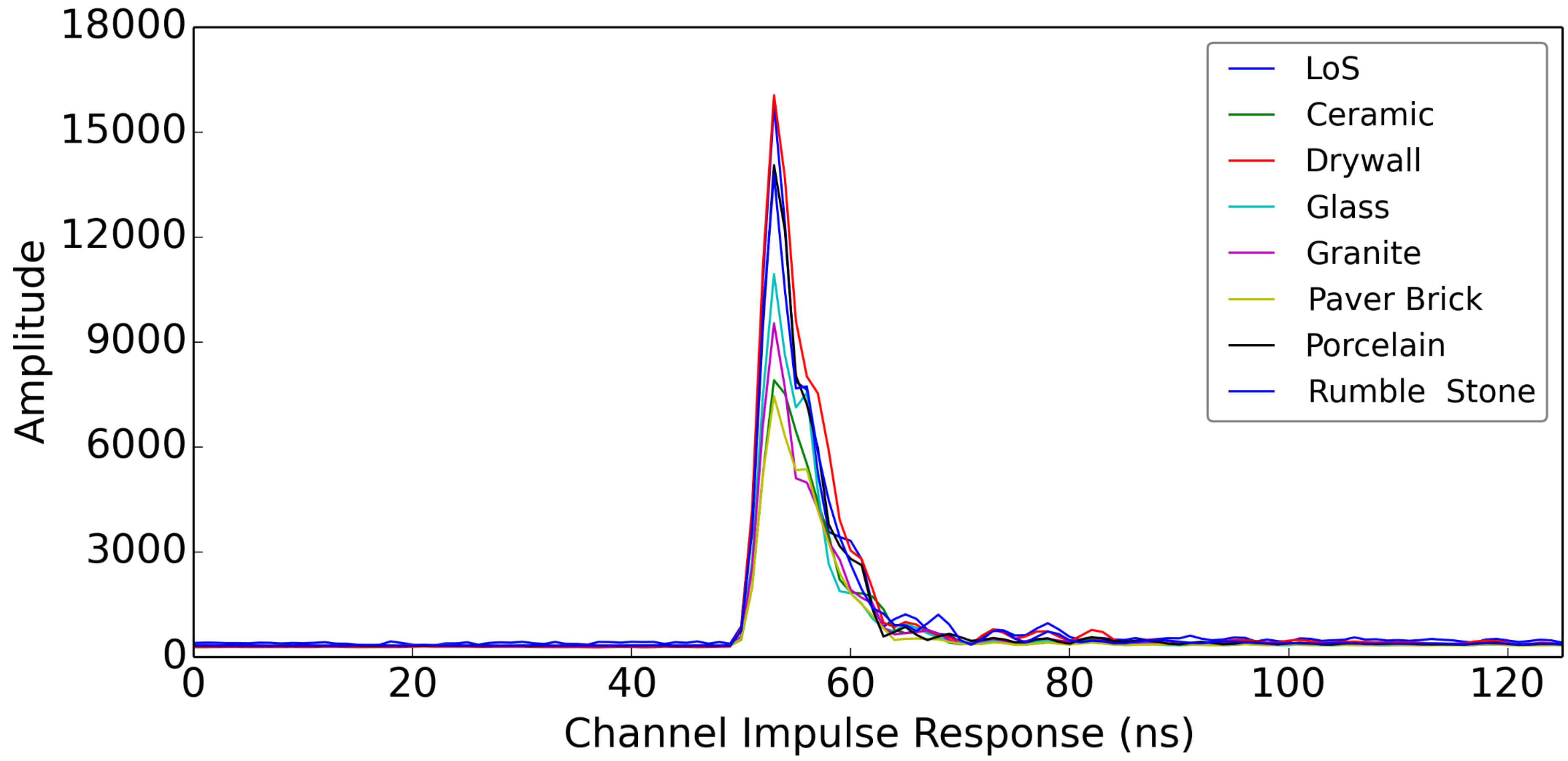

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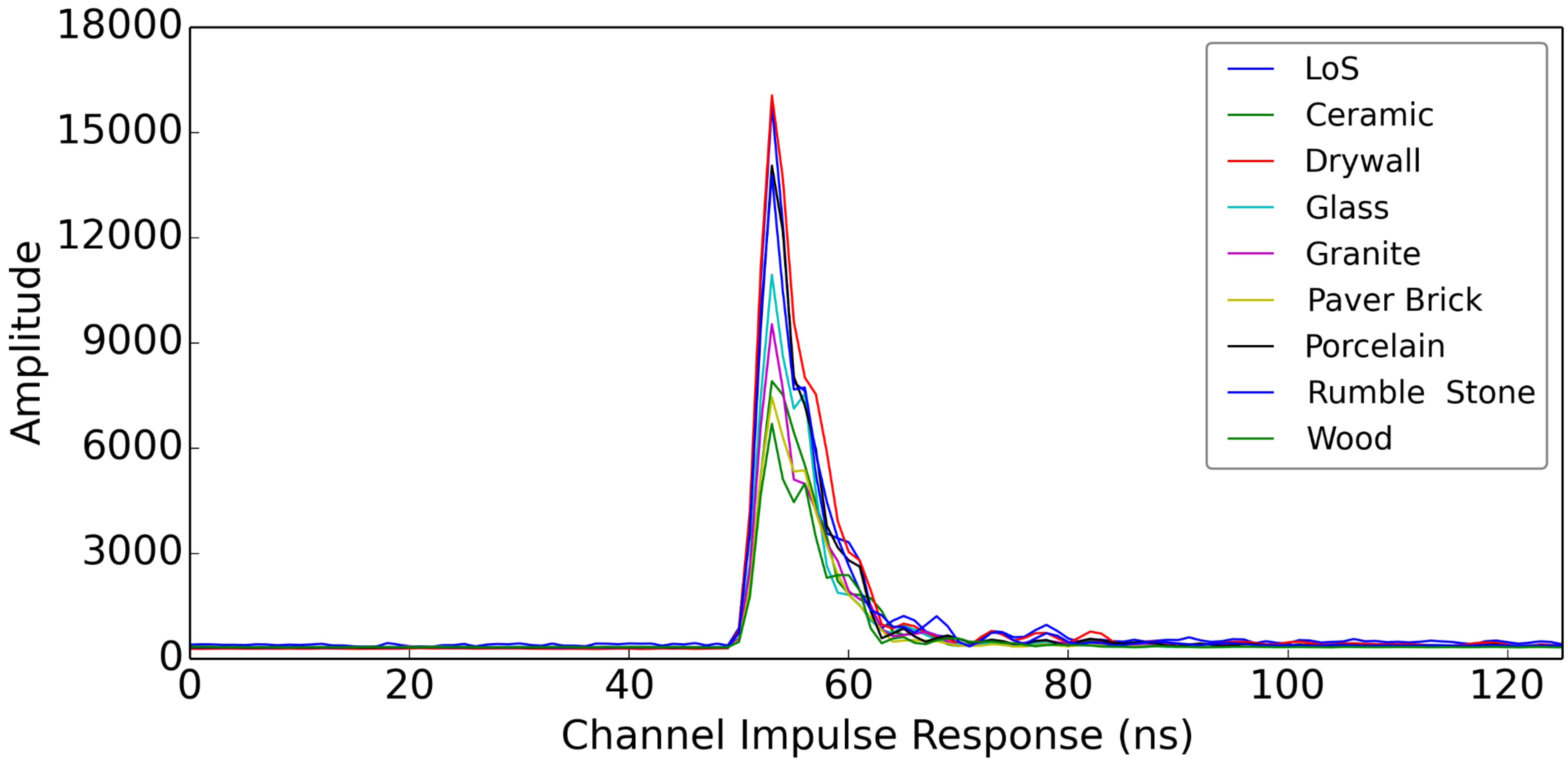

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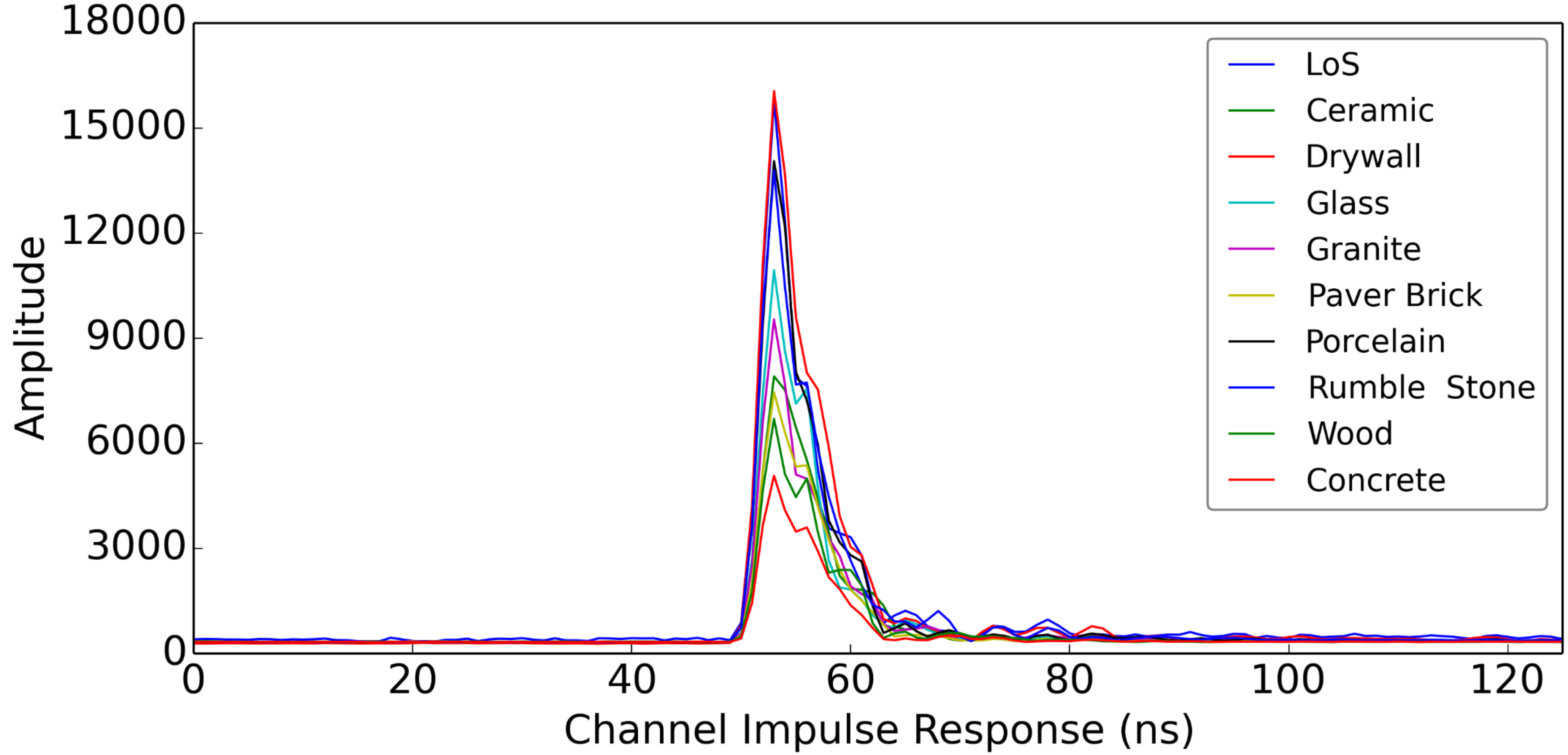
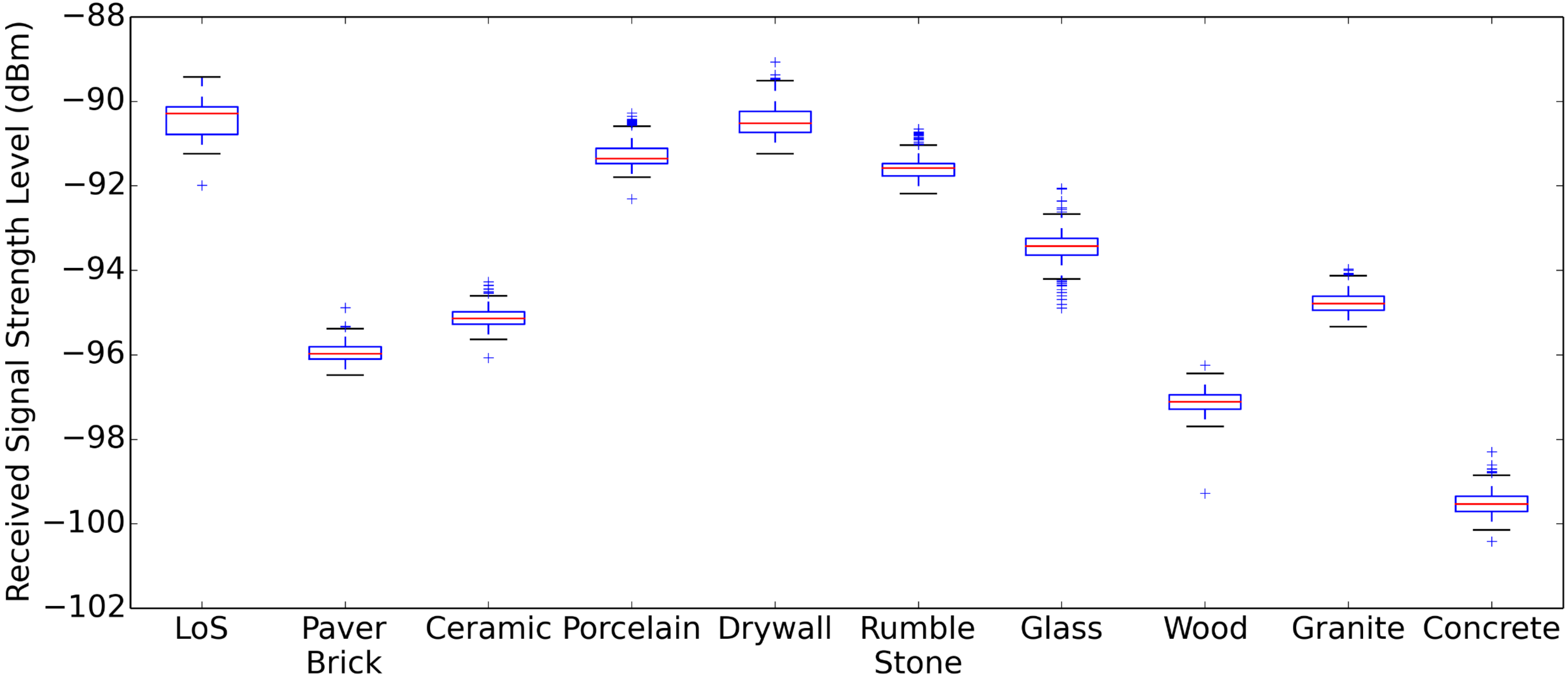


Amplitude drops but shape remains the same

Results – Received Signal Strength



Drywall has the least impact and Concrete has the most impact on RSS

Impact of Received Signal Strength on Ranging

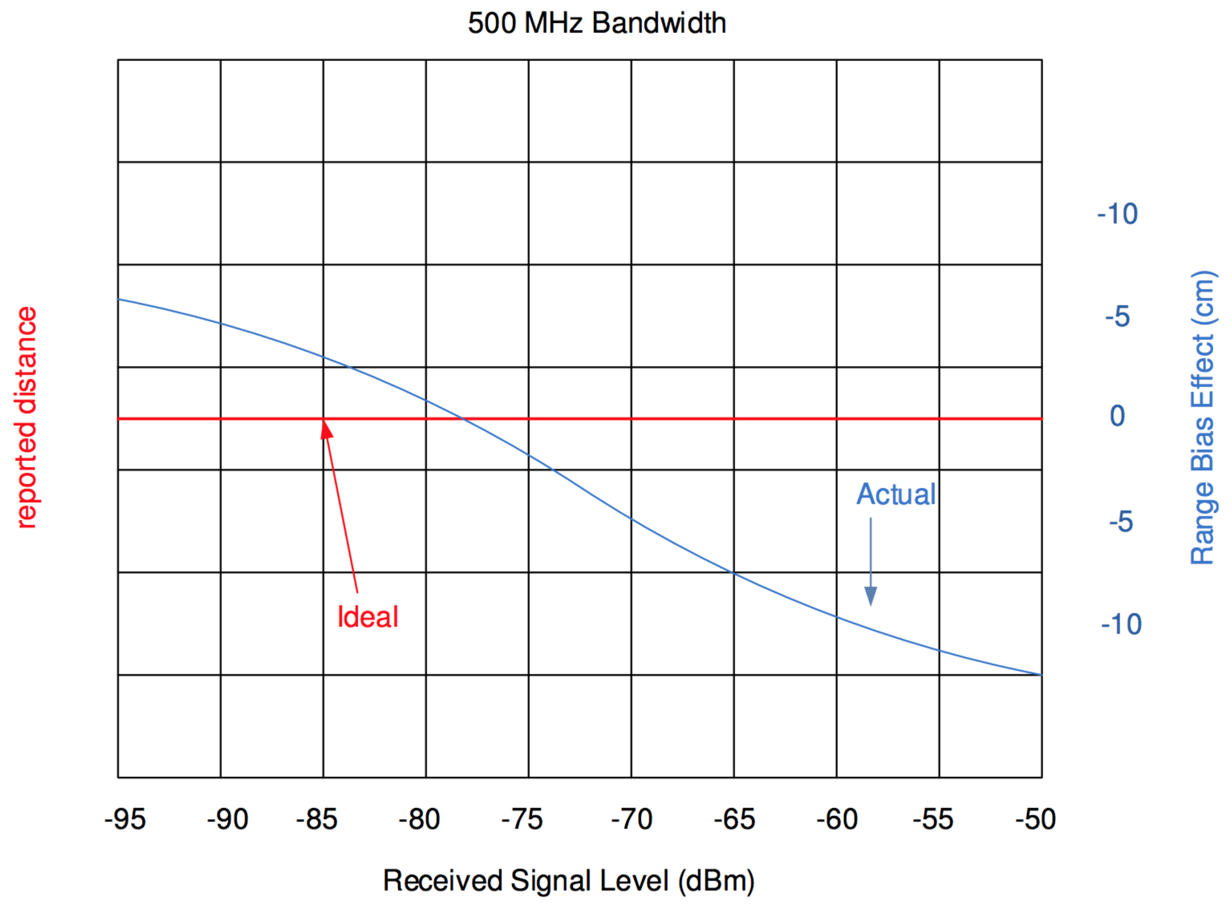
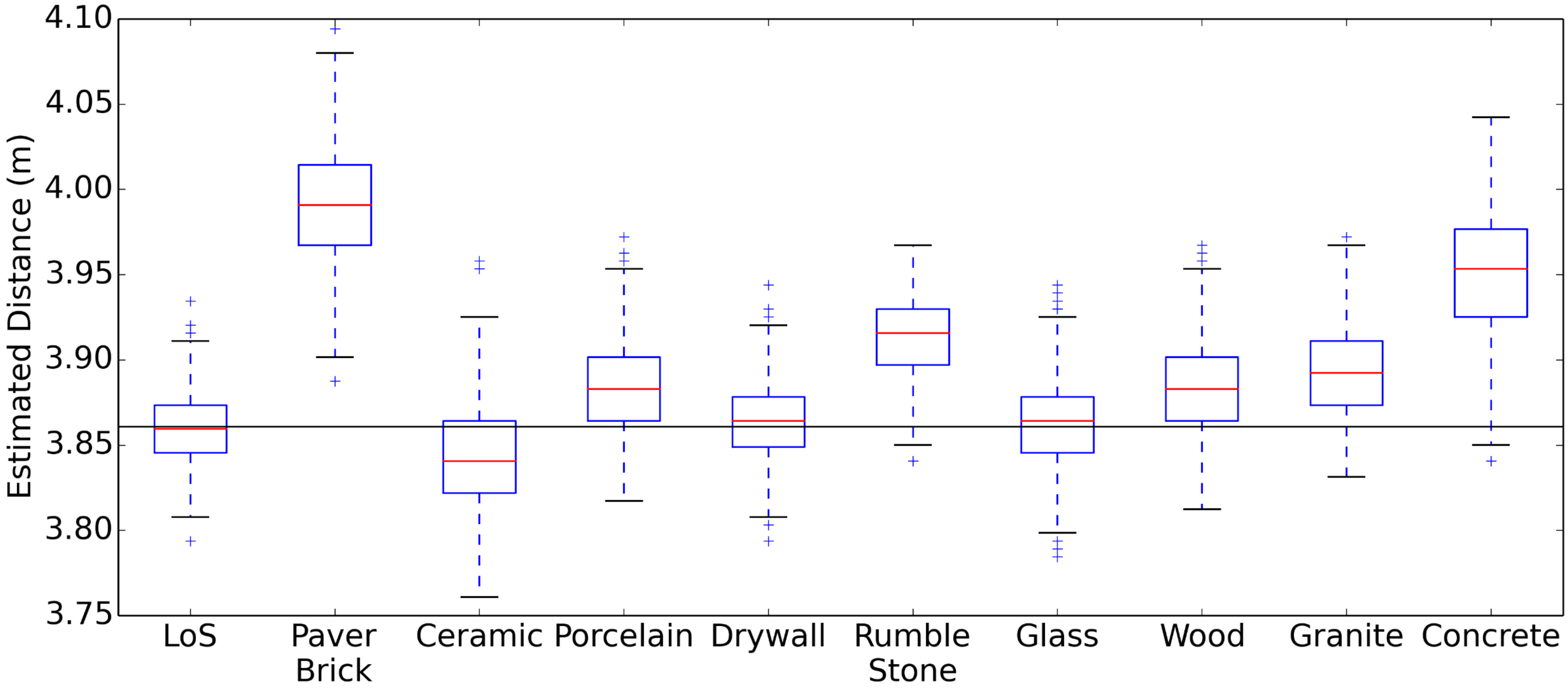


Figure 10: Diagram illustrating the effect of range bias on the reported distance

Ranging accuracy depends on RSS. Ranging bias can be either positive or negative.

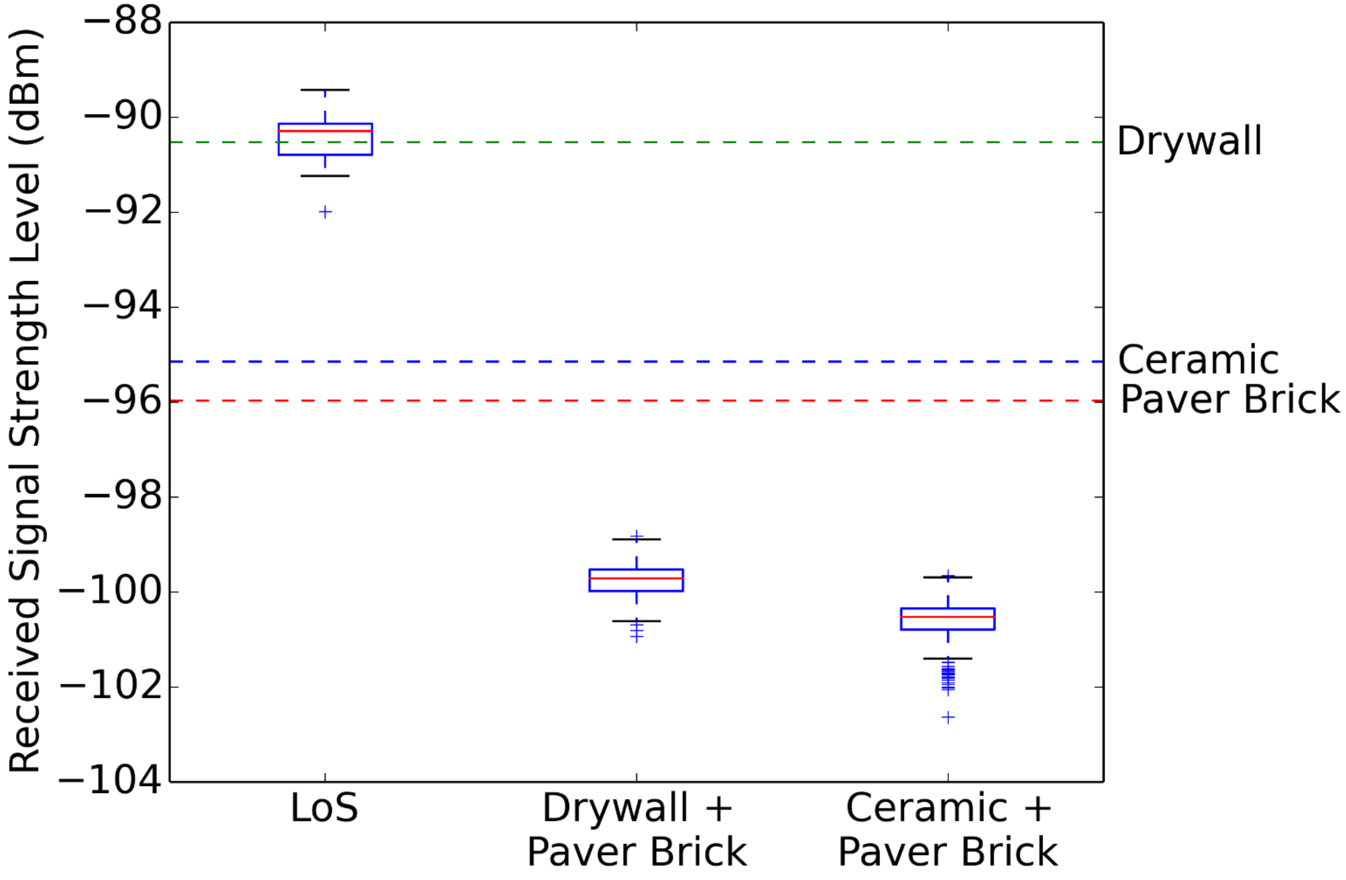
Figure borrowed from https://www.decawave.com/sites/default/files/aps011_sources_of_error_in_twr.pdf

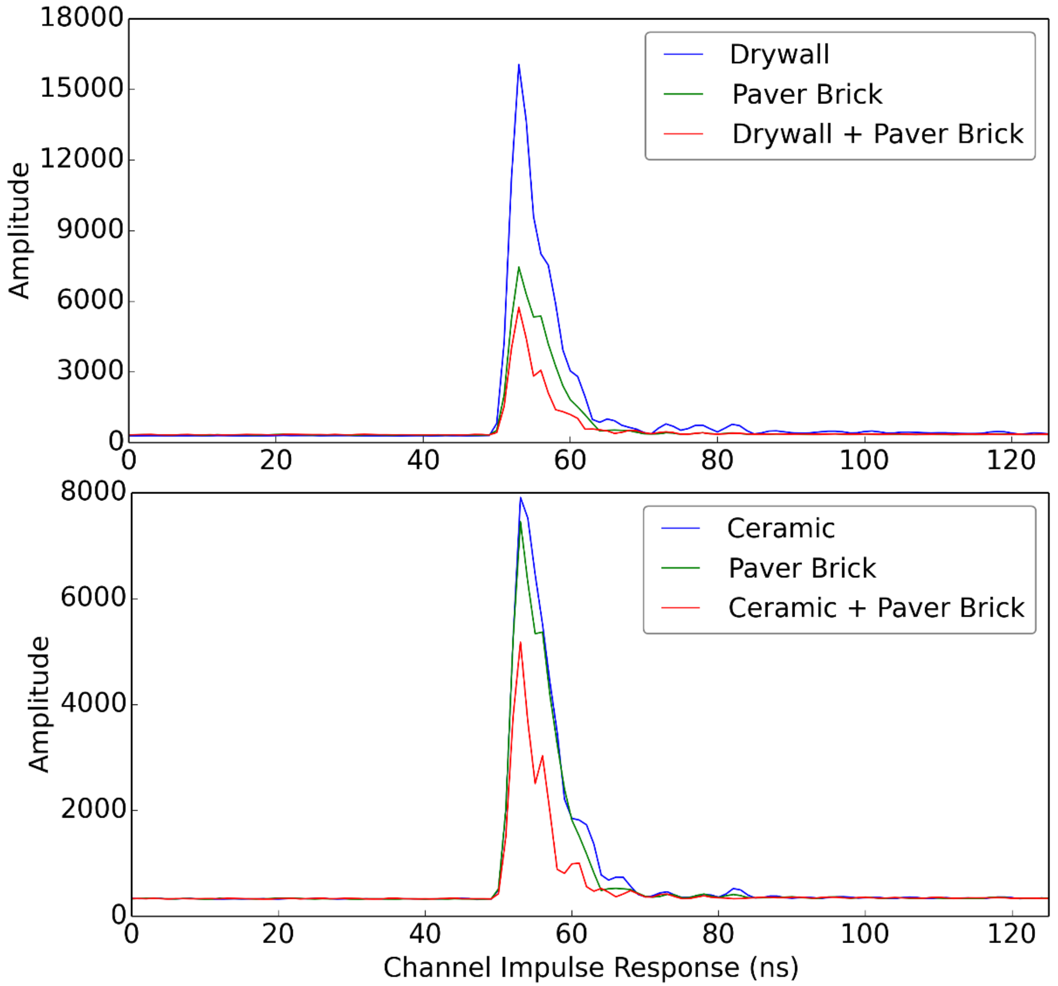
Results – Ranging Bias



Drywall has the least impact and Paver Brick has the most impact on ranging

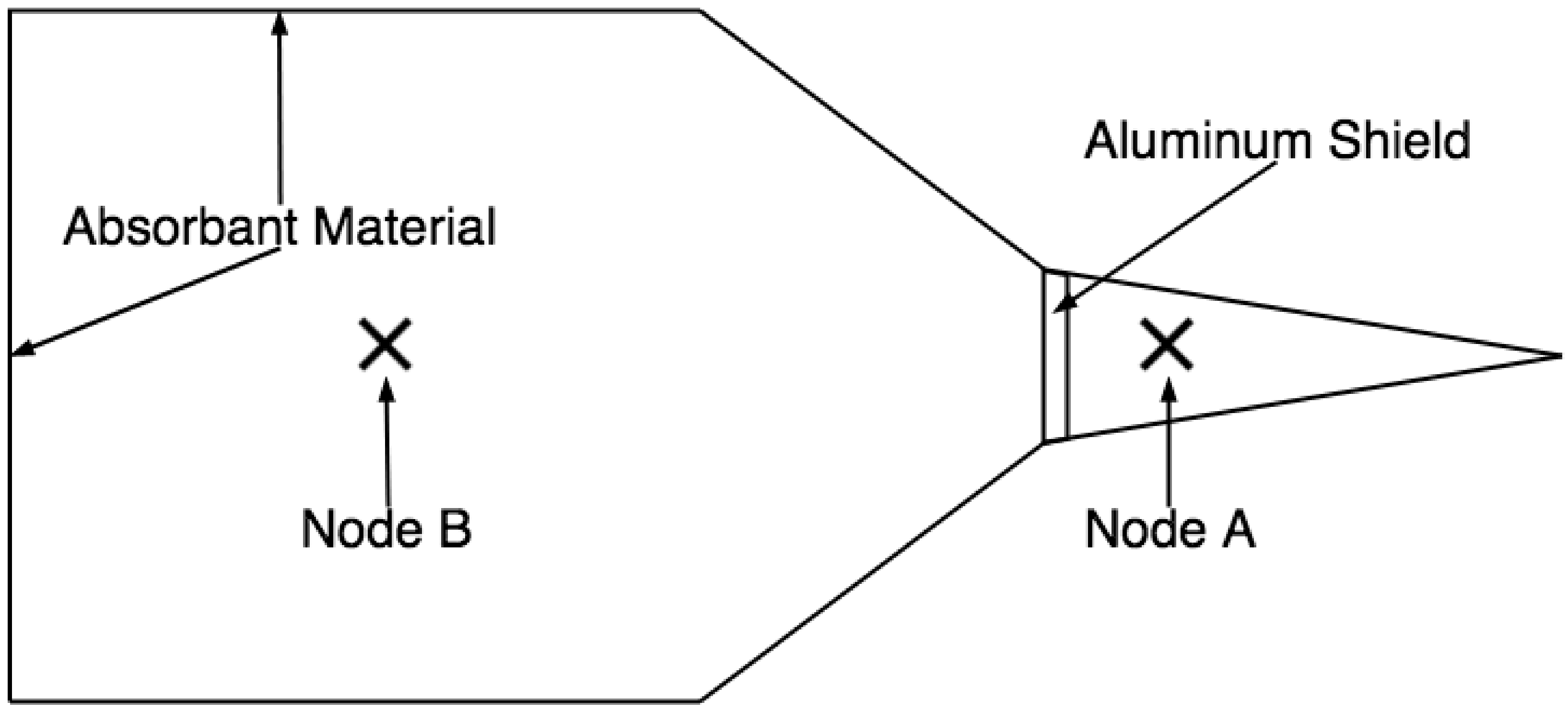
Results – Multiple Layers of Obstruction





More impact on RSS and CIR with multiple layers of obstruction

Diffraction Experiment



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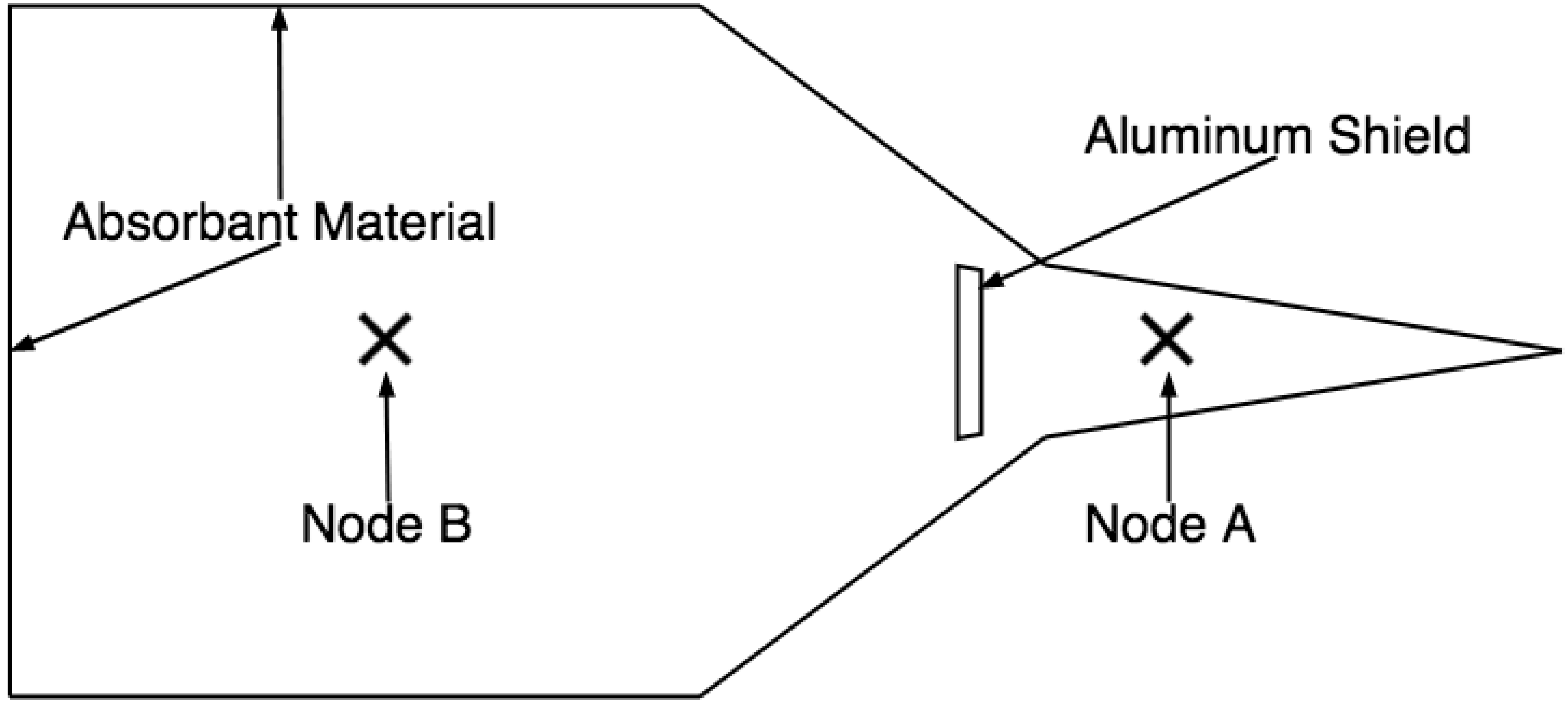
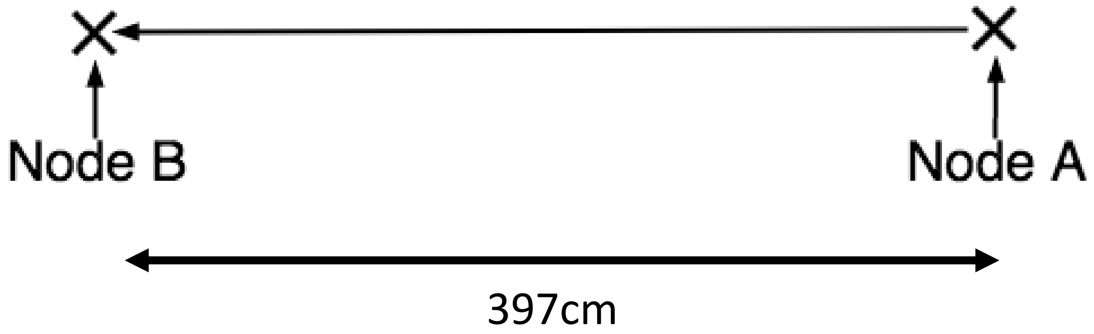
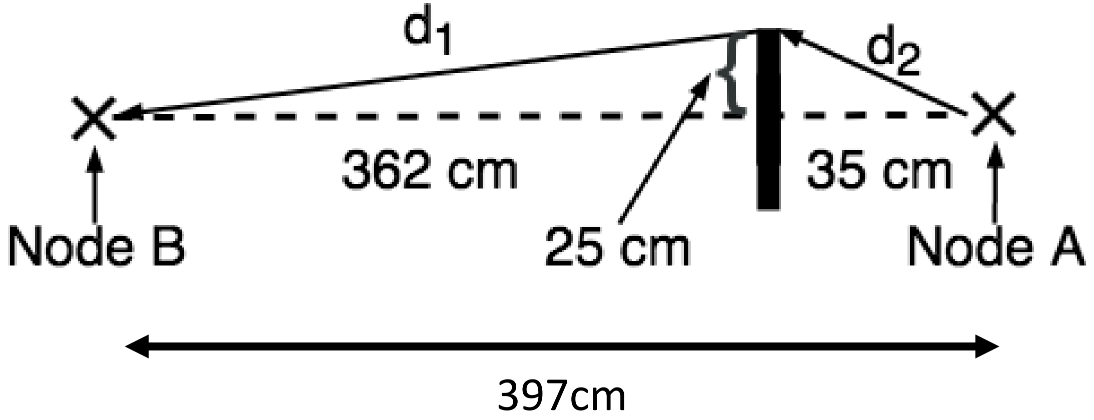


Results – Diffraction



Results – Diffraction

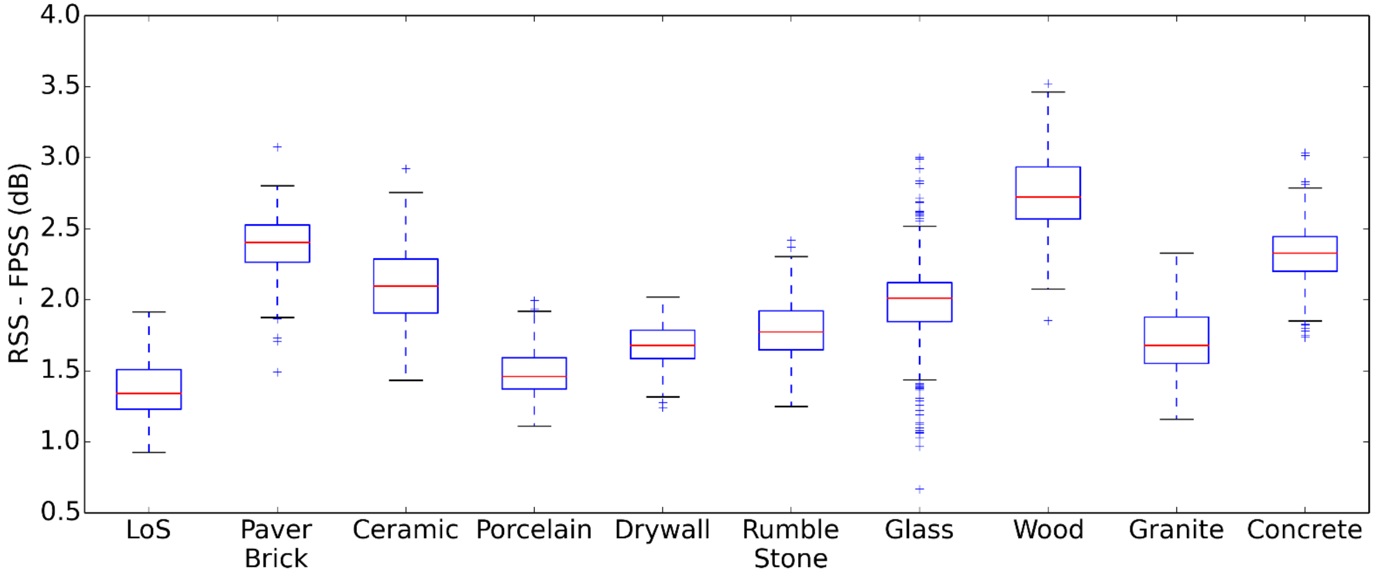
$d_1 + d_2 \cong 405.87\ cm$



Longer path for signals due to diffraction

Measured Distance using UWB $= 405.18$ cm

NLoS Detection Implications



Difference between received signal strength and first path signal strength is less than 3 dB. State-of-the-art NLoS identification requires 6 dB difference.

Repeatibility of Our Observations

Repeated selected experiments after 40 days

Similar results

Conclusions and Discussions

NLoS RF propagation impacted by materials.

Neglecting the difference between Visual NLoS and RF NLoS makes it difficult to compare the results from different studies.

Questions for UWB-Based Localization Benchmarking

- Environments for LoS and NLoS for UWB testing?
- Specification of LoS and NLoS environments for UWB testing?
- How should we deal with dynamic environments?
- Can we characterize attenuation and refraction separately?
- Role of controlled environments?
- Relation to other types of localization technologies?
  - E.g., IMU [no concept of NLoS]