Towards Reproducible Wireless Experiments Using R2lab

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General Outline

1. Context and Motivation
2. Orion:

   Use case
3. Using R2lab for system design and validation
4. Reproducibility Considerations
5. Conclusion

Motivation for Reproducibility

Learning	Extending	Reusing
Learning with a hands-on experience	Extending scientific work	Reusing tools for other scientific projects

Orion: Context

- Position and orientation estimation using Fingerprinting is inaccurate and inefficient[1][2].
- Position estimation using MIMO techniques is accurate (decimeter level precision)[3][4][5].
- Is it possible to estimate accurately the true heading of a terminal using MIMO?

REFERENCES

[1] H. Mohd et al. Indoor Human Localization with Orientation Using WiFi Fingerprinting. ACM ICUIMC, New York, NY, USA, 2014.

[2] C. Rohrig and F. Kunemund. Estimation of position and orientation of mobile systems in a wireless LAN. IEEE Decision Control, Dec 2007.

[3] D. Vasisht et al. Decimeter-Level Localization with a Single WiFi Access Point. In *ACM NSDI*, Santa Clara, CA, 2016.

[4] Y. Xie et al. Precise Power Delay Profiling with Commodity WiFi. In *ACM Mobicom*, pages 53–64, New York, NY, USA, 2015.

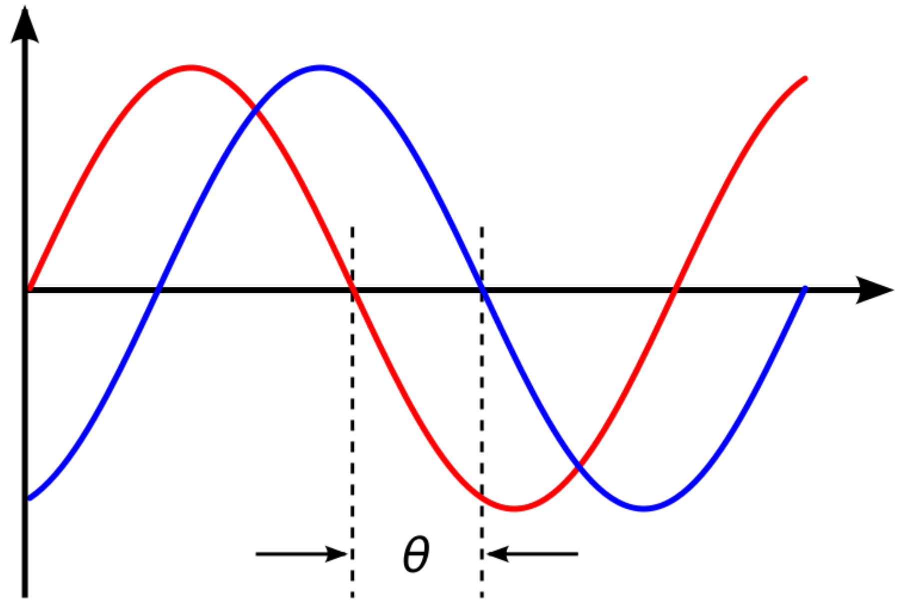
[5] M. Kotaru et al. SpotFi: Decimeter Level Localization Using WiFi. In *ACM SIGCOMM*, London, UK, Aug 2015.

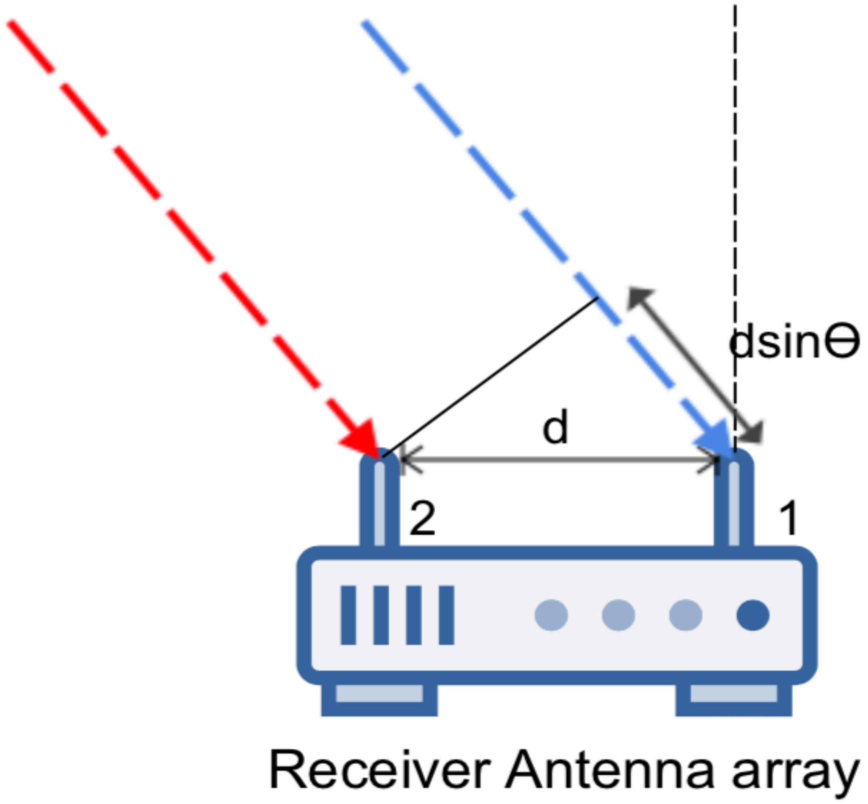
Orion: Motivation

- Enable an Access Point to measure the orientation of a client w/o soliciting IMU measurements (passive approach).
- Enhance low-cost IMU orientation estimation indoor by using Wi-Fi signal for calibration reference (Gyroscope drifts and magnetometer perturbation).

Primer: MIMO and Signal Angle Estimation

- Measure the phase difference between the signal copies received by each antenna.





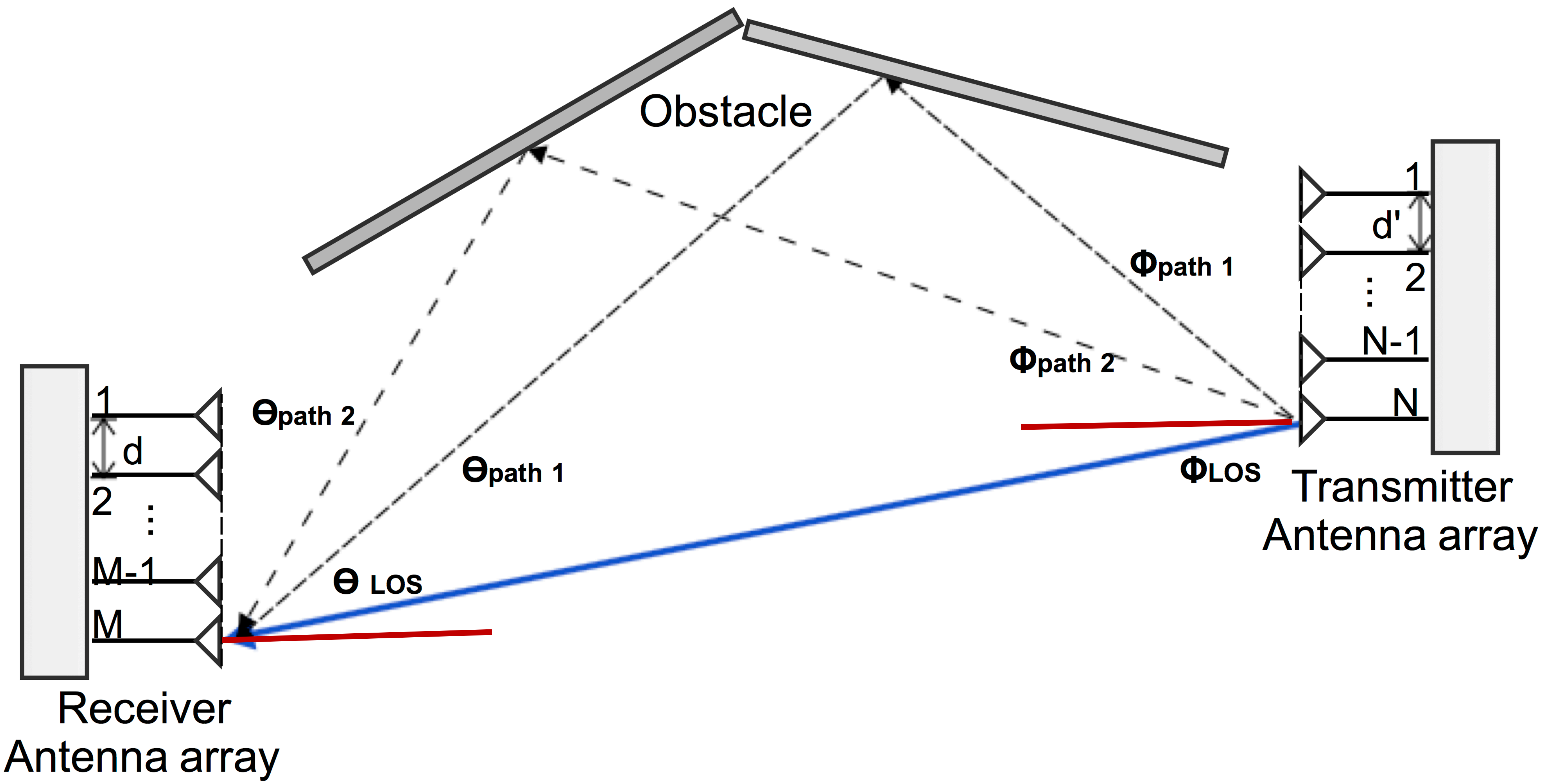
Orion: Data Model

Matrix representation of the received signal vector:

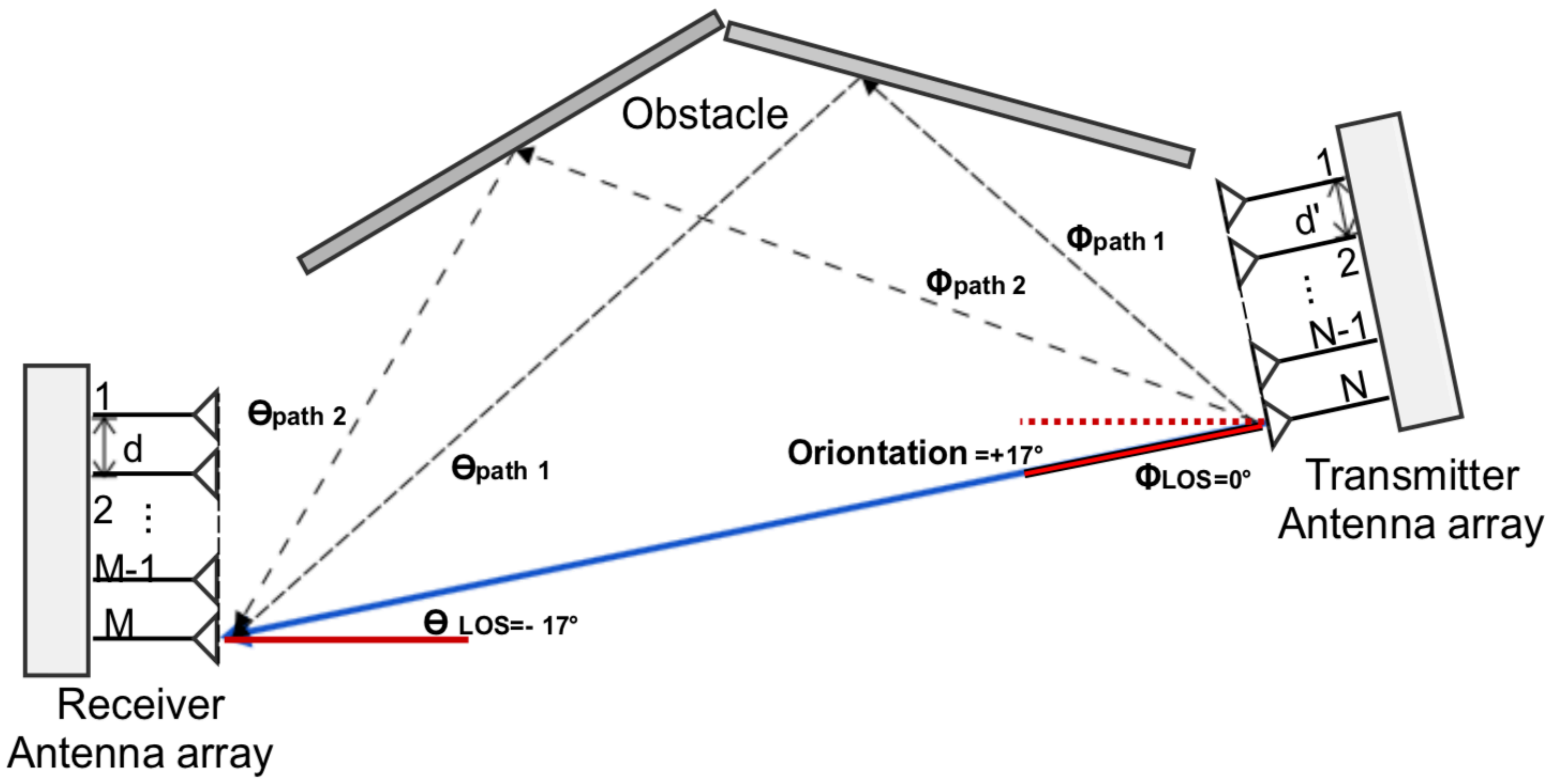
$$\mathbf{x} = [\mathbf{a}_r(\theta_0) \otimes \mathbf{a}_t(\phi_0), \quad \mathbf{a}_r(\theta_1) \otimes \mathbf{a}_t(\phi_1), \quad \cdots, \quad \mathbf{a}_r(\theta_{p-1}) \otimes \mathbf{a}_t(\phi_{p-1})] \cdot \mathbf{s} + \mathbf{n}$$

x is the $MN \times 1$ received signal vector, $\mathbf{a}_t(\phi)$ and $\mathbf{a}_r(\theta)$ are the transmit and receive steering vectors, **s** is the vector representing the complex gain of the p paths, **n** is the white noise Gaussian vector with zero mean.

Orion: Schema



Orion: Schema



2D-MUSIC (Multiple Signal Classification)

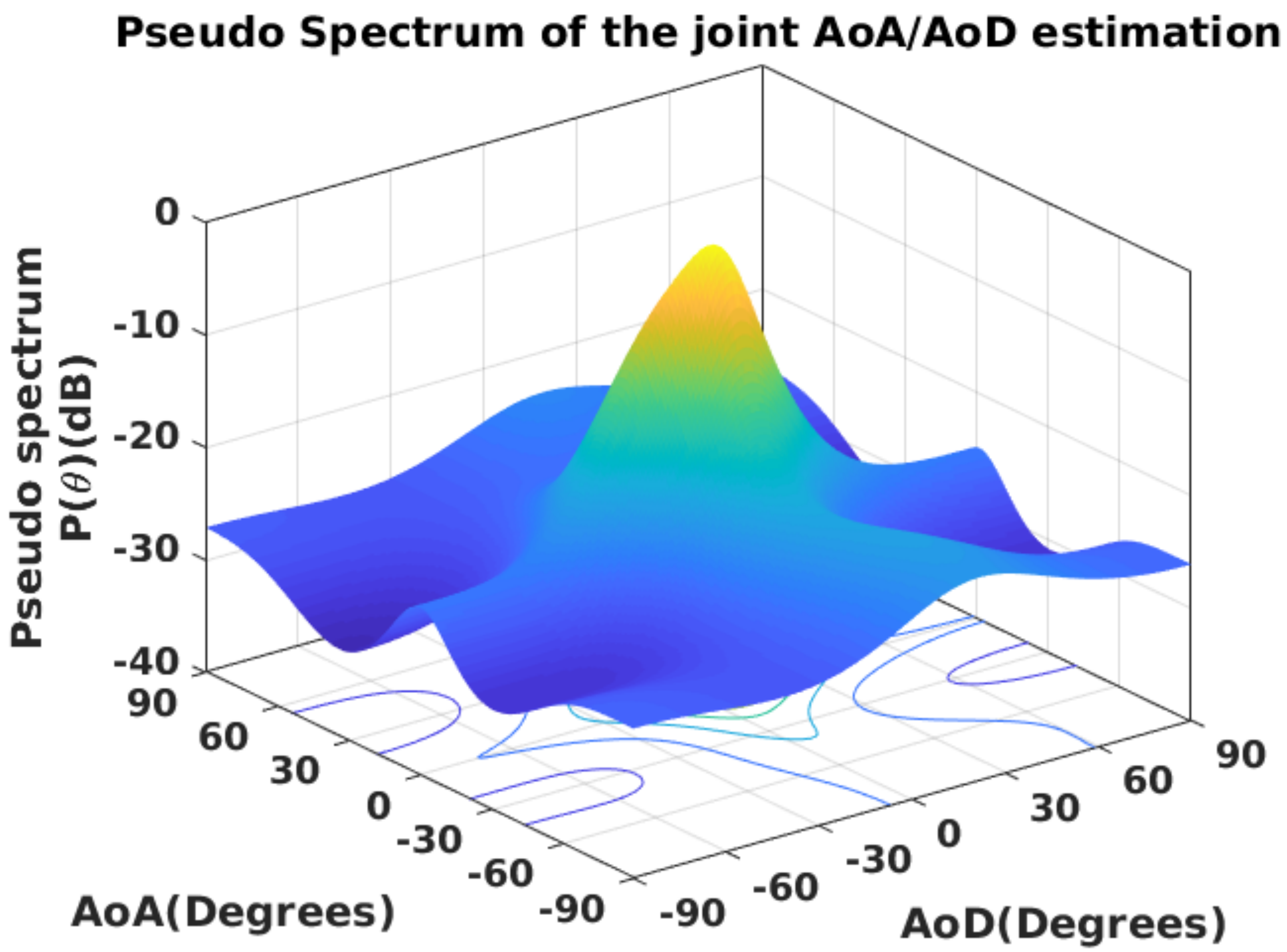
The matrix Qn is estimated from the Eigen-decomposition of the auto covariance matrix Rxx.

$$\mathbf{R}_{xx} = \mathbf{QDQ}^{\mathrm{H}} = \left[\mathbf{Q}_s \mathbf{Q}_n\right] \begin{bmatrix} \mathbf{D}_s & 0 \\ 0 & \sigma^2 \mathbf{I} \end{bmatrix} \left[\mathbf{Q}_s \mathbf{Q}_n\right]^{\mathrm{H}}.$$

We define a quadratic function with steering vectors that span on several angles.

$$\mathbf{P}(\theta_i, \phi_i) = \frac{1}{(\mathbf{a}_r(\theta_i) \otimes \mathbf{a}_t(\phi_i))^H \; \mathbf{Q}_n \; \mathbf{Q}_n^H (\mathbf{a}_r(\theta_i) \otimes \mathbf{a}_t(\phi_i))}$$

2D-MUSIC (Multiple Signal Classification)



Channel State Information (CSI)

Channel State Information :

- Matrix with complex Channel gain for each antenna at the reception.
- Used for computing precoding matrices (beamforming).

The phase difference between the CSI of adjacent antennas is related to an angle (departure or arrival).

- Intel 5300 AGN [8]Provides CSI

[6] D. Halperin et al. Tool Release: Gathering 802.11n Traces with Channel State Information. *ACM CCR*, 41(1):53–53, Jan 2011.

ORION: Challenges using COTS Hardware

- Channel state information (CSI), i.e., the output matrix used for antenna array signal processing, suffers from phase shifts.
- Estimating a signal's AoD relies on the measurement of the phase difference between transmitted synchronized signals.
- Tracking orientation requires a series of AoAs and AoDs estimations. These measurements usually suffer from statistical noise and could translate in a jerky observation of actual monitored orientation.

Using R2lab for calibration: Testbed presentation

- 90m^2 insulated anechoic chamber at INRIA, Sophia Antipolis.
- 37 Wi-Fi nodes nodes on the ceiling.
- 24 nodes feature an SDR board.

Using R2lab for calibration: Testbed presentation

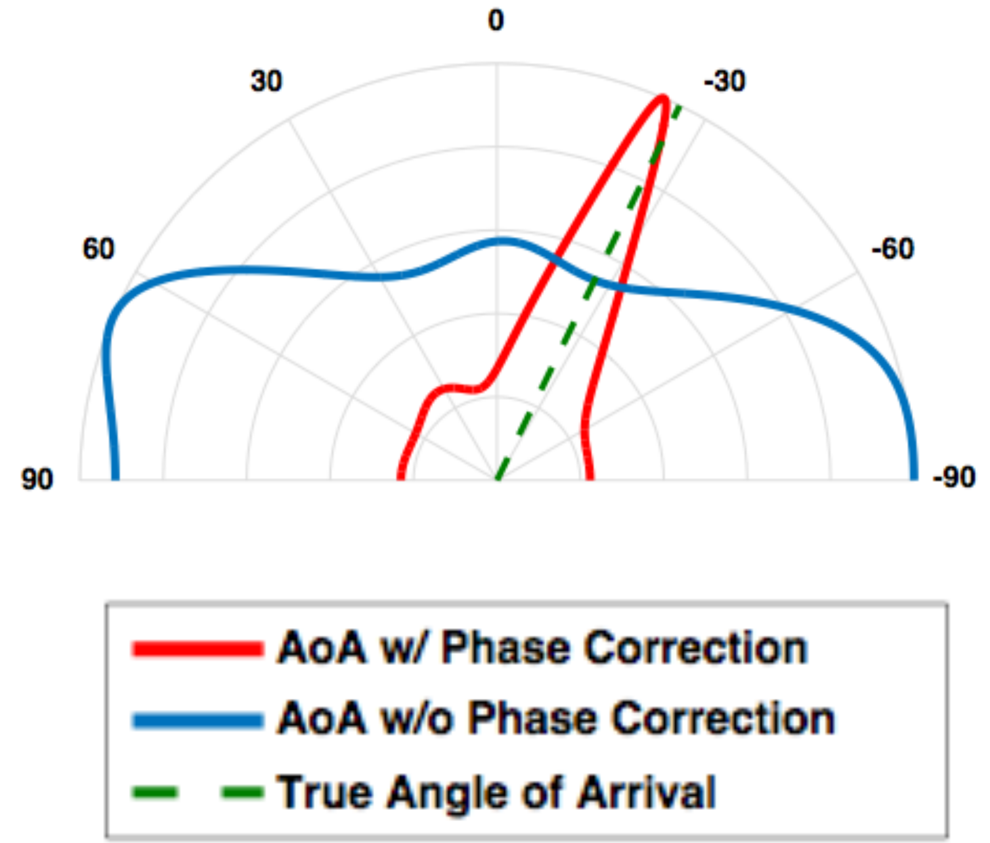
- 2 Wi-Fi MIMO cards (Atheros 802.11 93xx a/b/g/n ,Intel NIC 5300 AGN [6])
- Each card is has 3 dual-band 5dBi antennas, operating on both 2.4GHz and 5GHz.
- Antennas are spaced of 2.8cm

[6] D. Halperin et al. Tool Release: Gathering 802.11n Traces with Channel State Information. *ACM CCR*, 41(1):53–53, Jan 2011.

Using R2lab for calibration: Angle of Arrival Estimation

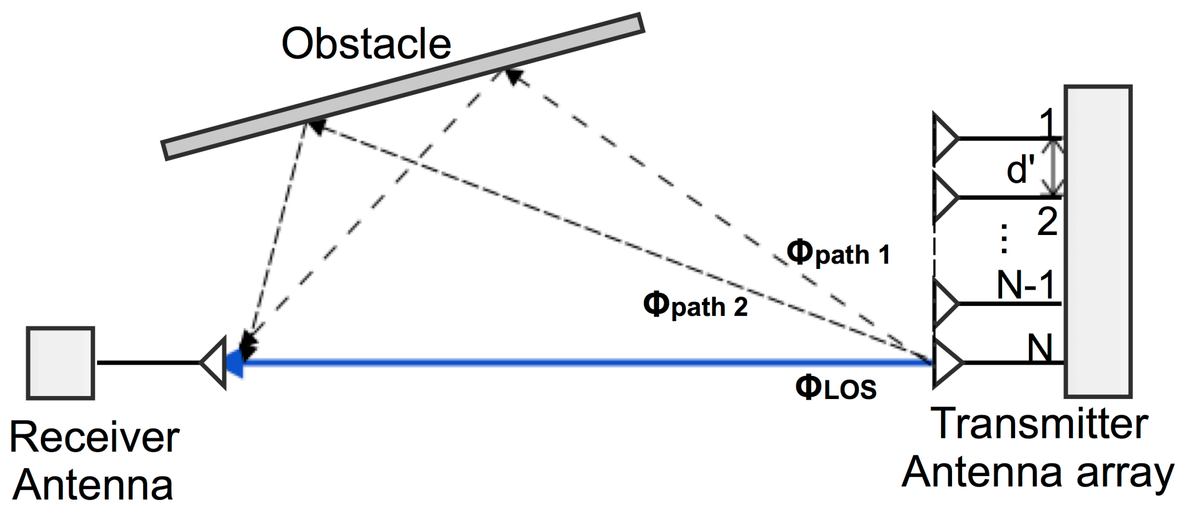
Phase inconsistency due to RF oscillator offset:

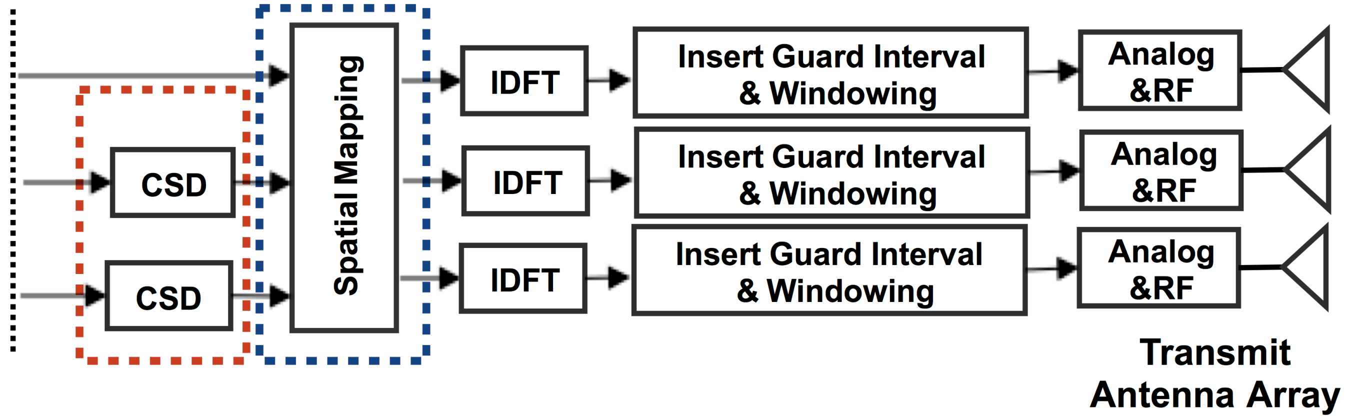
- Random but fixed phase shift throughout a session. Changes at each restart or recalibration.
- Correction by applying a phase rotation according to a reference signal.



Using R2lab for calibration: Angle of Departure Estimation

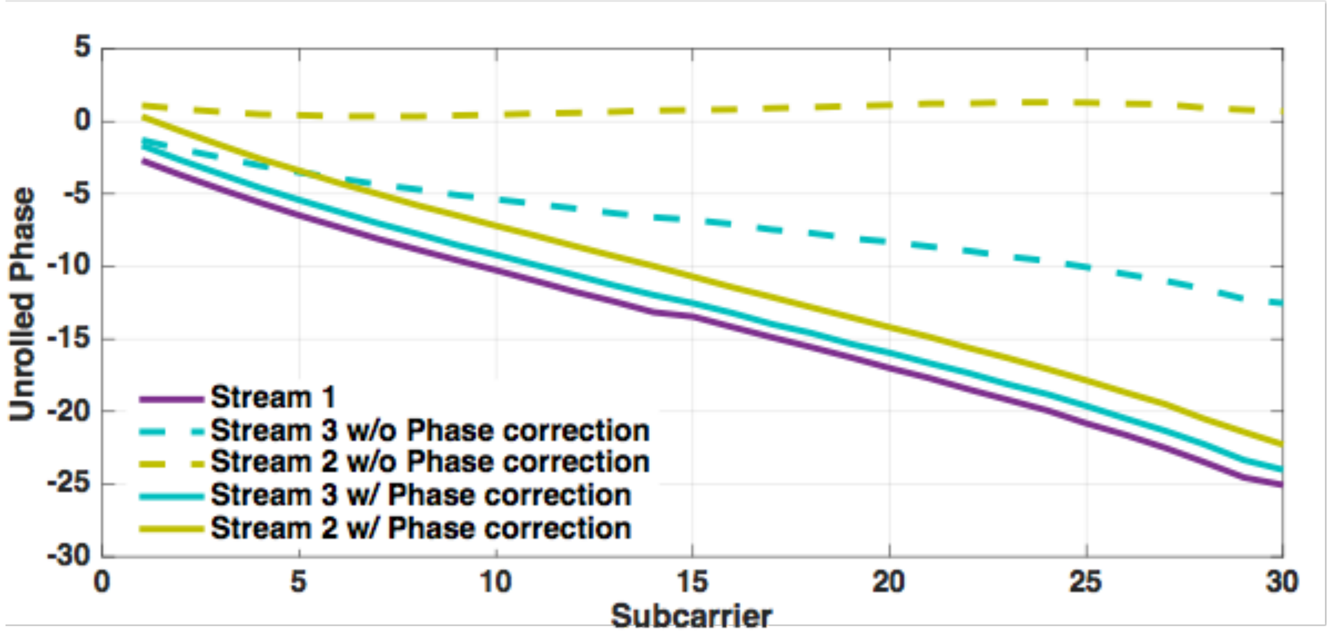
- Send a Stream on each of the Tx RF chain.
- Measure CSI from each Rx antenna for Each (Stream) Tx antenna.
- Compute the phase difference b/w the signals.

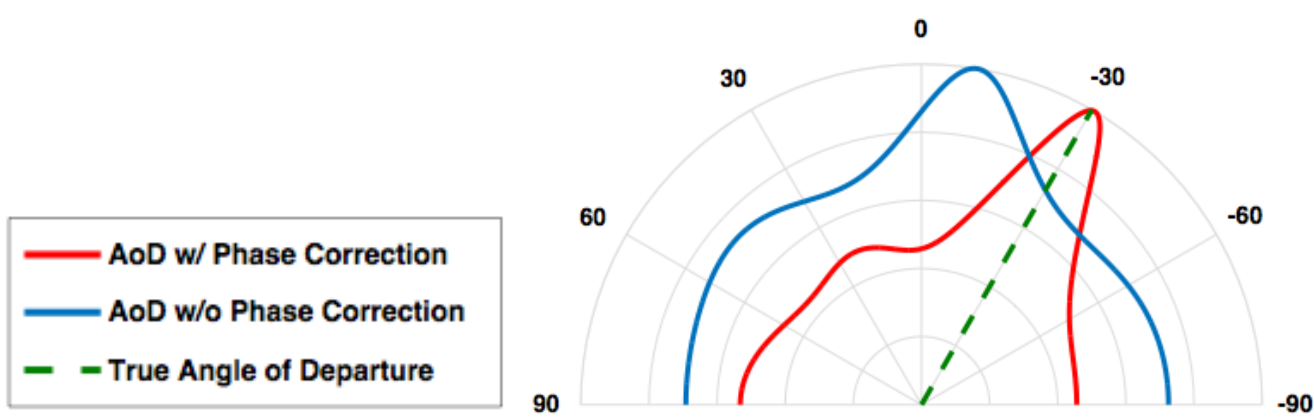




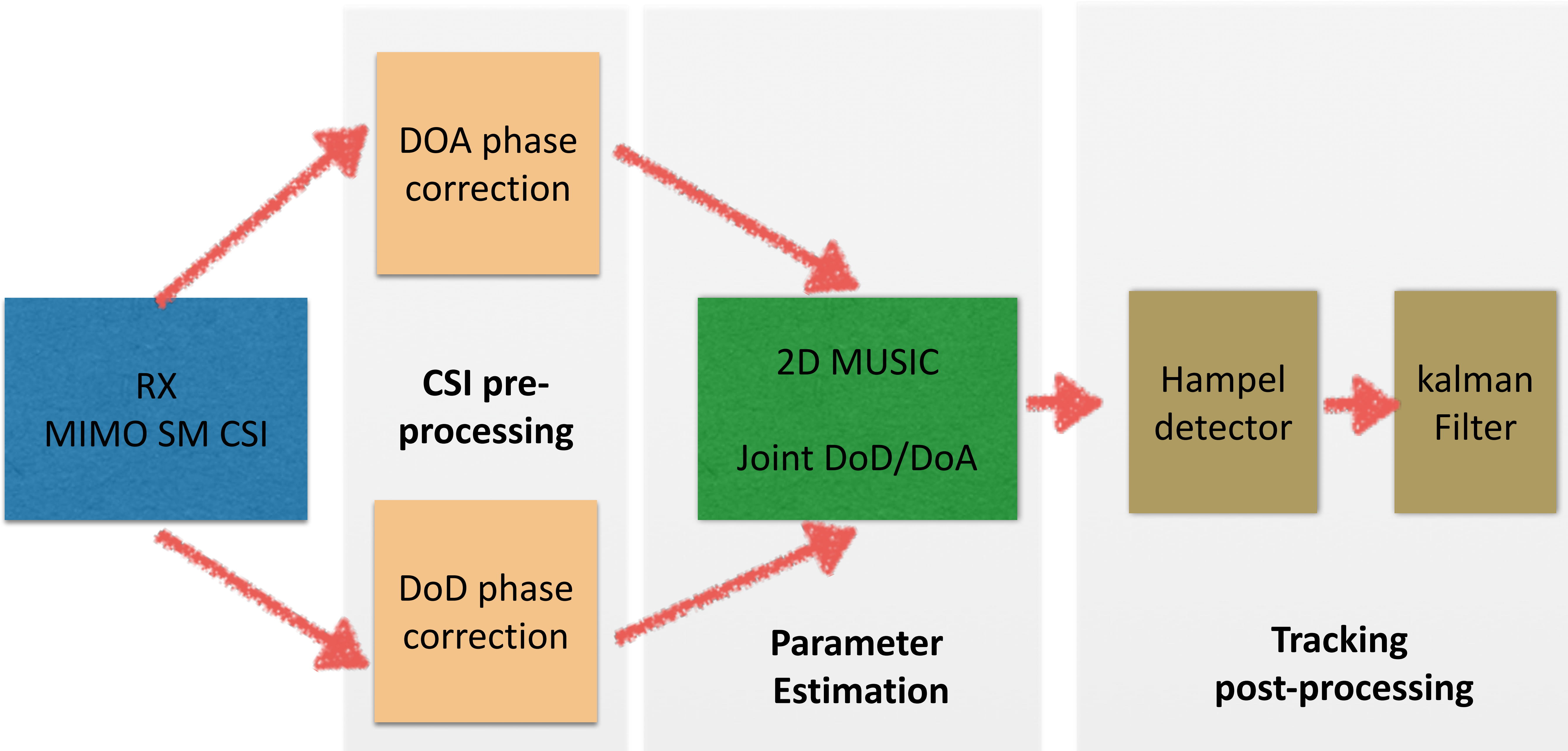
Using R2lab for calibration: Angle of Departure Estimation

- Cyclic shift delay: delay between signal streams.
- Spatial mapping: multiplication by a specific matrix for assigning a stream to a transmission RF chain. Introduces a phase shift.





System Design for Orientation Tracking

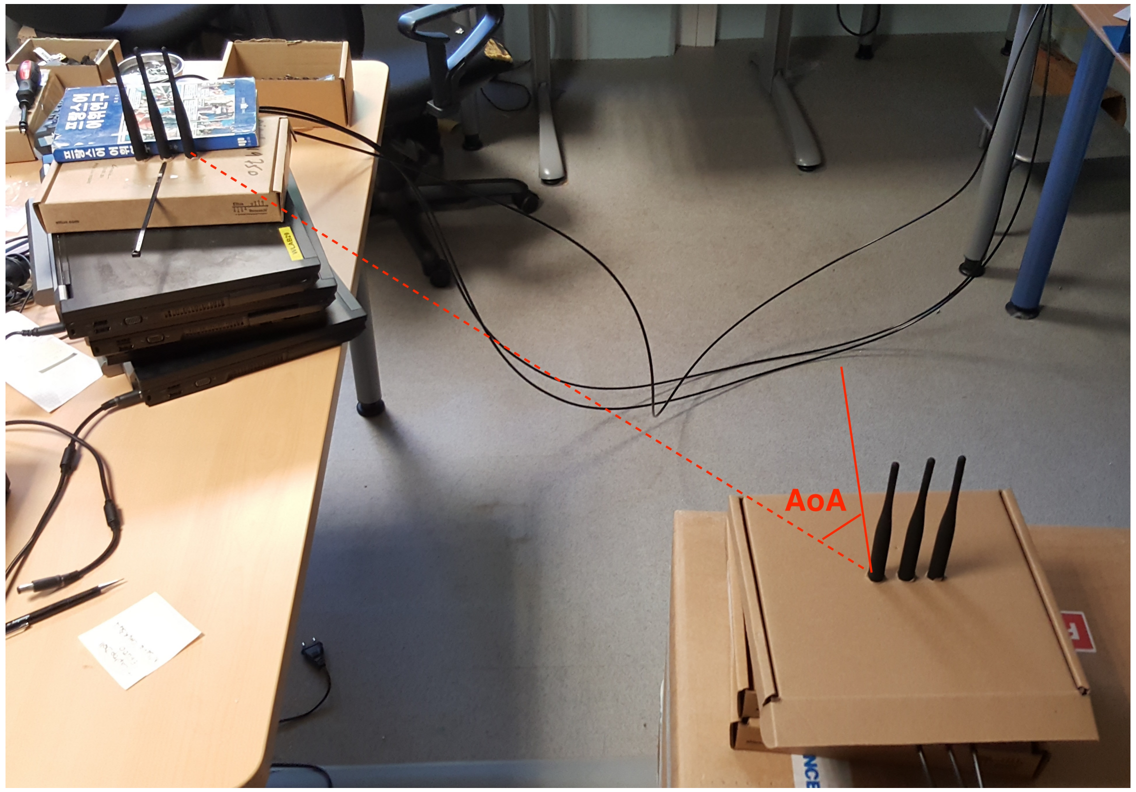


Method Validation : nepi-ng

- Used for running and orchestrating network experiments that involve several tens of target hosts.
- Used to efficiently automate and control our experiment scenario.

Running in a different environment

- Test system in an open, realistic, and non-controlled wireless environment.
- Reproduce the same experiment in an office room (Several multipath clusters).
- Use the same type hardware as in R2lab, including antennas cables and antennas spacing.



Experimental material in a git repository

- Detailed description of the system setup and of the hardware involved, with illustrations*.
- Avoid any licensing problems related MATLAB by a python version of our code for data post-processing.**
- Jupyter notebook that allows running all the steps of our angle estimation technique.

*Description: https://www-sop.inria.fr/teams/diana/orion/
** Code : https://github.com/naoufal51/Orion

Discussion

- R2lab allowed the Design and Validation of our System Design by:
  - Acquiring an extensive knowledge and greater understanding of COTS hardware along with a thorough understanding of its capabilities and limitations
  - Controlling the experiment environment and scenario (avoid interference, …)
  - Automate experiments to have fine-grained control over the design of experiments (nepi-ng)

Conclusion

- Reproducibility is tied to information accessibility
- Reproducibility should be accounted as a part of the research project's activities