PhaseU

Real-time LOS Identification with WiFi

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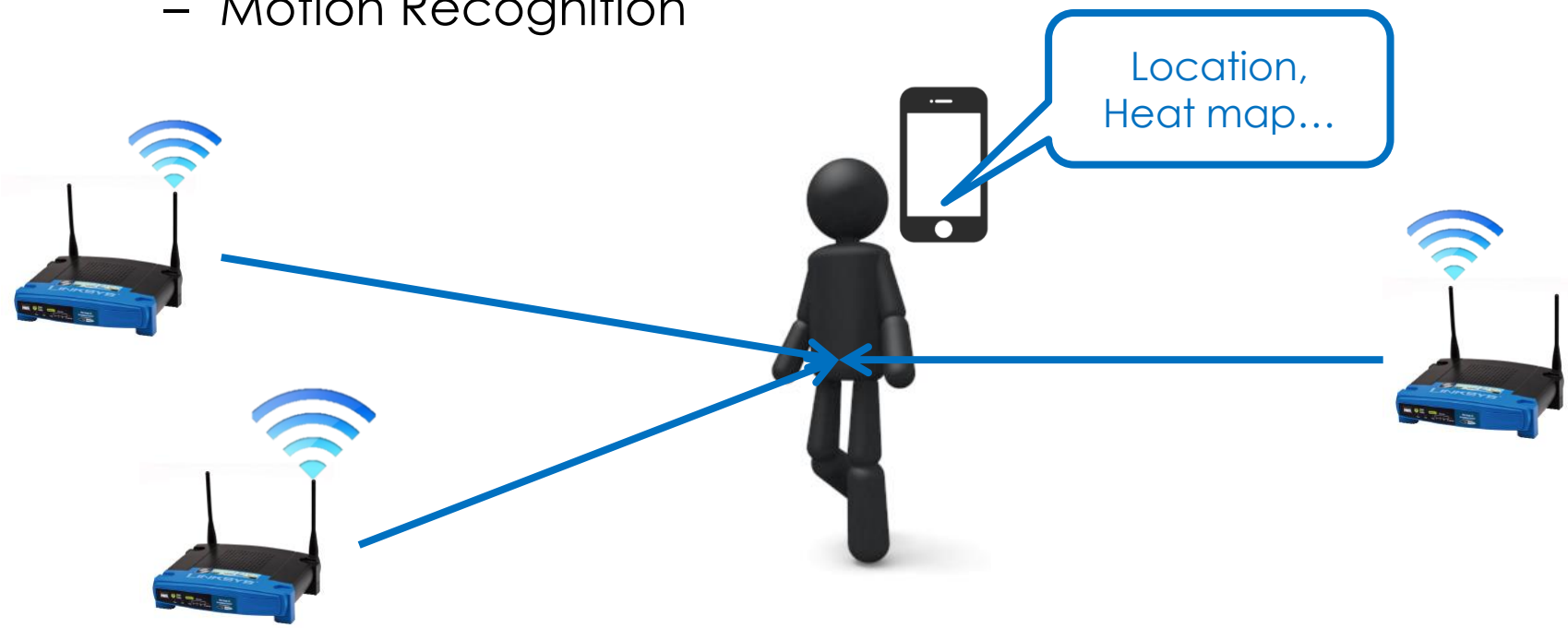
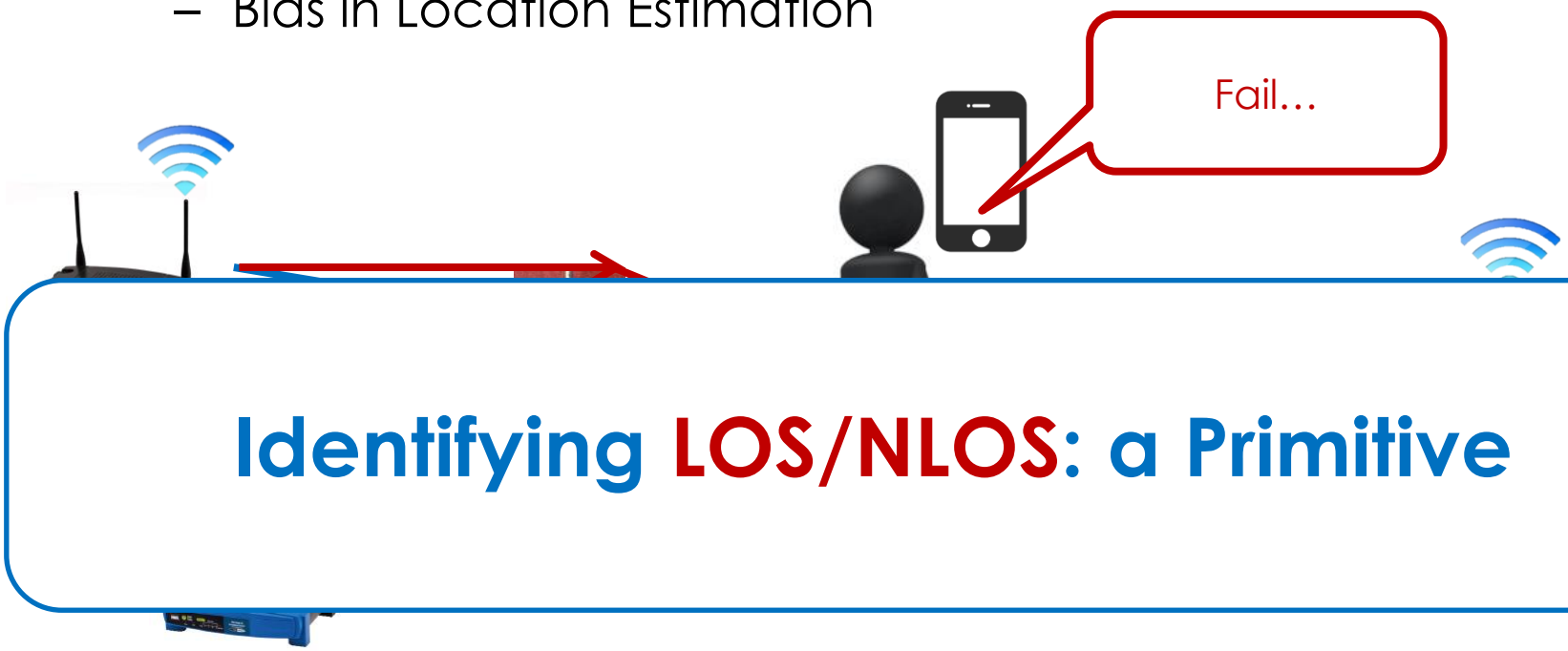
WiFi: More than Communication

- Ubiquitously Deployed **Indoors**
- Emerging Mobile Computing Applications
  - Localization & Tracking
  - Through-wall Imaging
  - Motion Recognition



Non-Line-Of-Sight Propagation

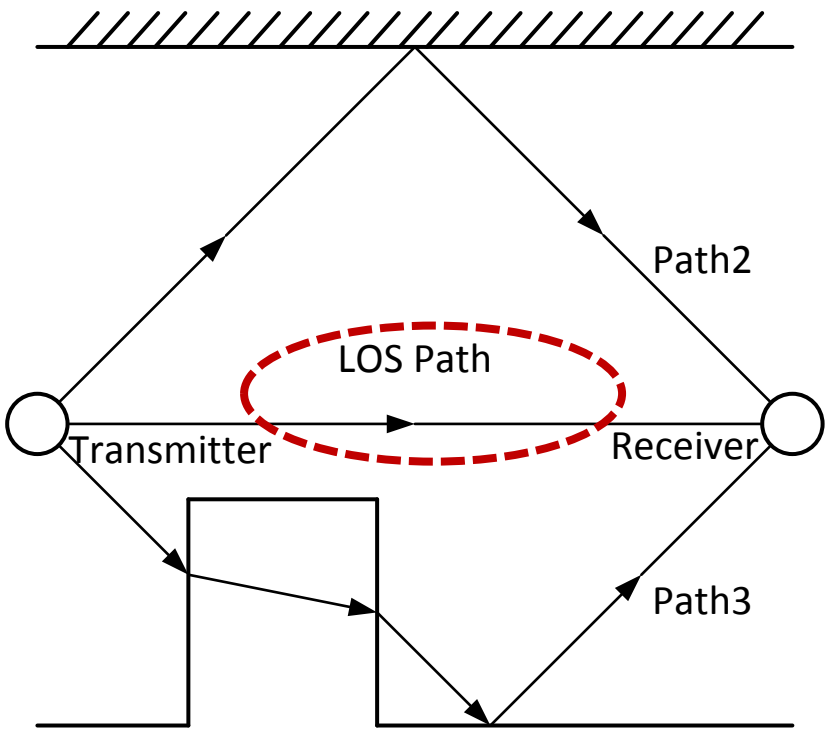
- NLOS Propagation in Cluttered Environment
- Drawbacks:
  - Deteriorate Channel Quality
  - Degrade Propagation Models
  - Bias in Location Estimation



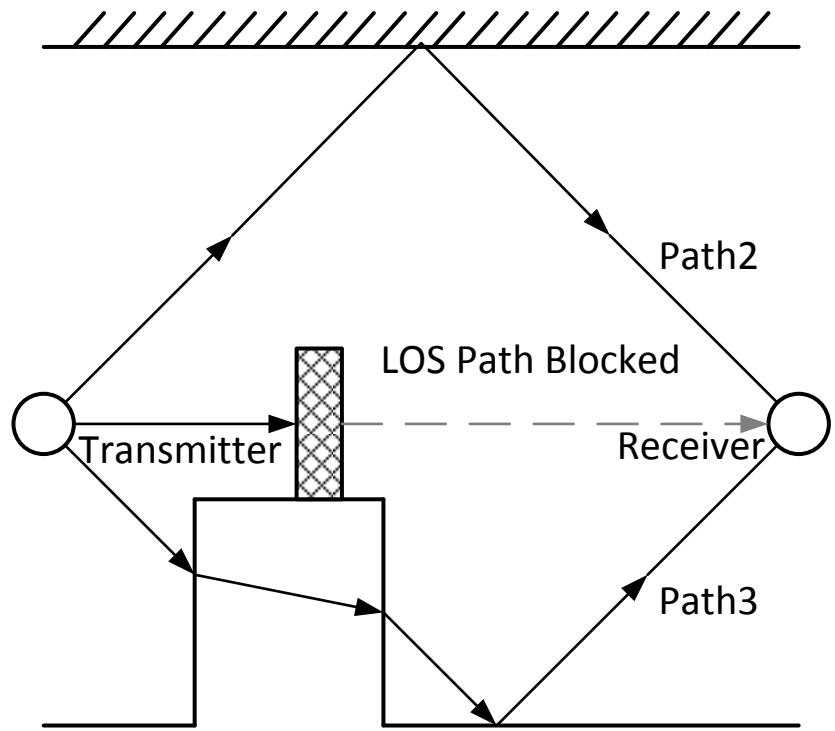
Identifying LOS/NLOS: a Primitive

LOS Identification

- Discern the Availability of a **Strong LOS Path**
- A **Distinctive Feature** is the Core



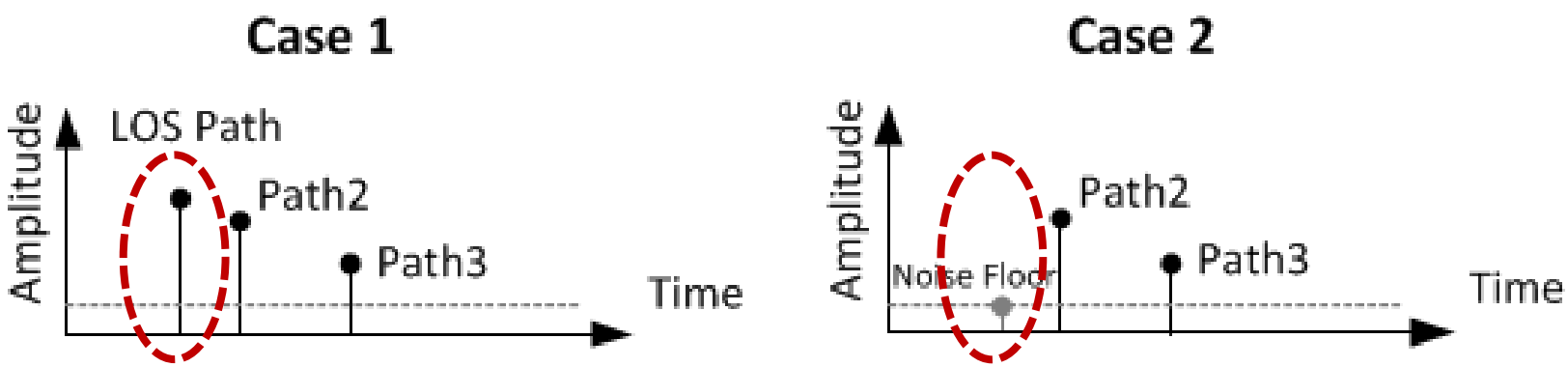
Case 1: With LOS Path



Case 2: Without LOS Path

Existing Approaches

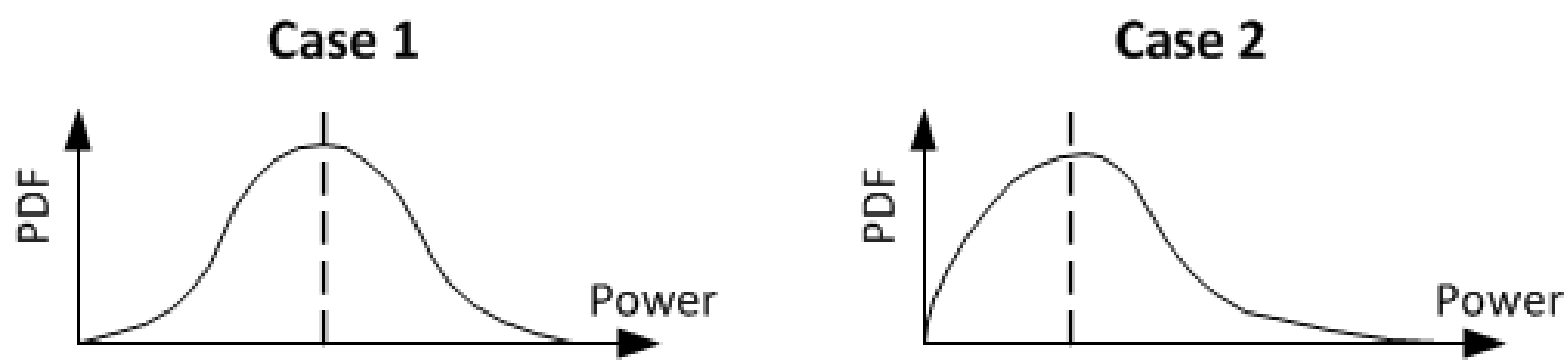
- Channel Impulse Response (CIR) based
  - **Principle:** Delay Characteristics
    - Signals travel through a LOS path arrive first
    - LOS path experiences weaker attenuation
  - **Pros:** **One** Measurement
  - **Cons:** **High-resolution** CIR -> Extremely Wideband Signals



Delay Characteristics of **One** Chanel Impulse Response Measurement

Existing Approaches

- Channel Statistics based:
  - **Principle:** Spatial Randomness
    - More obstacles and uncertainties along NLOS paths
    - Modeling distributions of received signal power
  - **Pros:** Work for even **Narrow band** Signals
  - **Cons:** **More** Measurements, **Model-dependent**



Received Envelope Disrtibutions of **Multiple** Channel Measurements

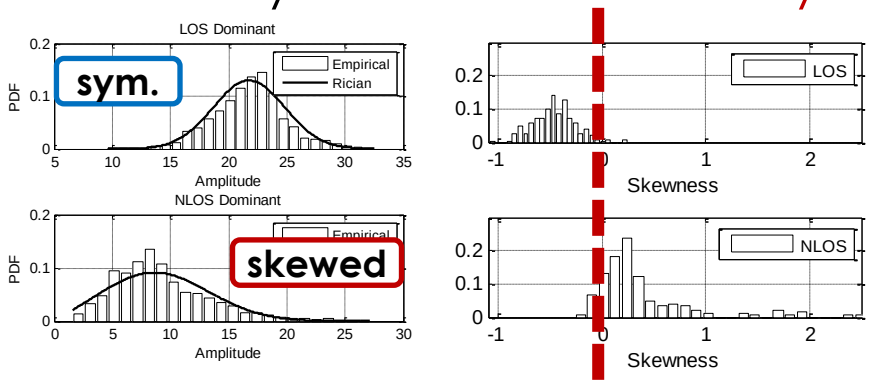
Existing Approaches

Category	Features	Performance	Application
CIR	Mean Excess Delay	74.3%-100%, Simulation	UWB
CIR	Kurtosis	66.3%-98.4%, Simulation	UWB
Channel Statistics	Range Measurements	N/A	Narrow and Wideband
Channel Statistics	K Factor	85%, Simulation	Narrow and Wideband

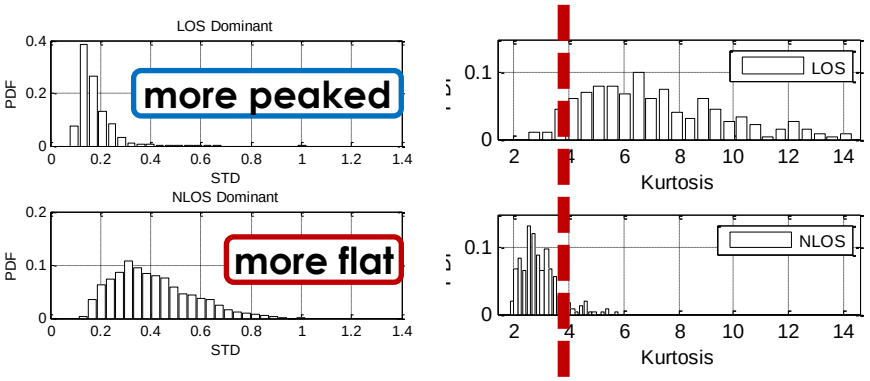
Mostly Simulation
Performance Unknown on WiFi

LiFi: LOS Identification with WiFi

- **Two statistic features:**
  - Skewness of the CSI amplitude distributions
  - Kurtosis of STD distributions of normalized CSI amplitudes
- **Pros: Applicable on COTS WiFi**
- **Cons:**
  - A large amount of measurements (long delay)
  - Rely on contrived movements to increase randomness, yet will fail in naturally mobile scenarios

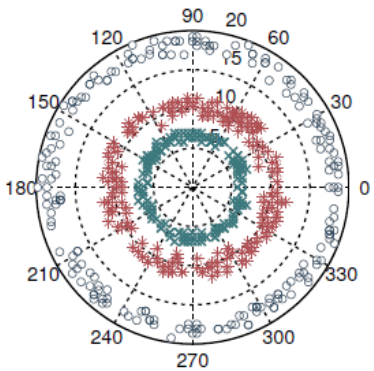


Envelope distributions

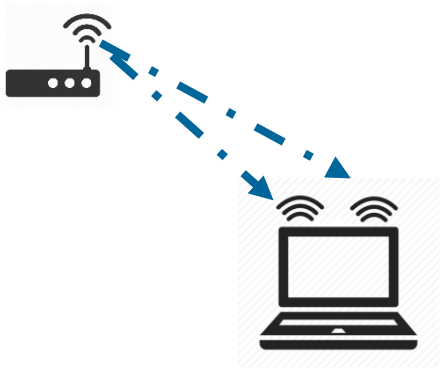


Envelope STD distributions

A step further: PhaseU



Phase information not sufficiently explored



Multiple antennas to support MIMO

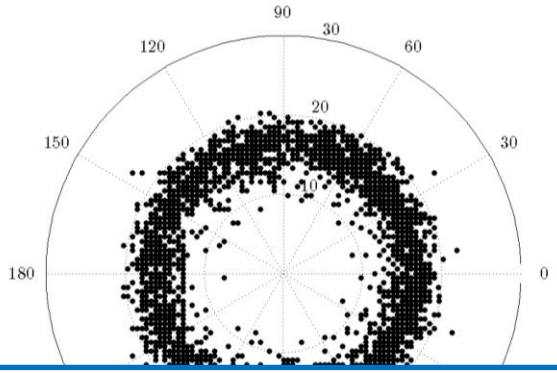
Can we enable Real-time LOS identification on COTS WiFi for both static and mobile scenarios?

Phase Sanitization

Unsynchronized Tx/Rx Pair leads to polluted CSI phase.

Measured Phase

$$\hat{\phi}_i = \phi_i - 2\pi \frac{k_i}{N} \delta + \beta + Z$$



Mitigate the uncertain shifts and random noises to make raw phases meaningful

Phase Sanitization

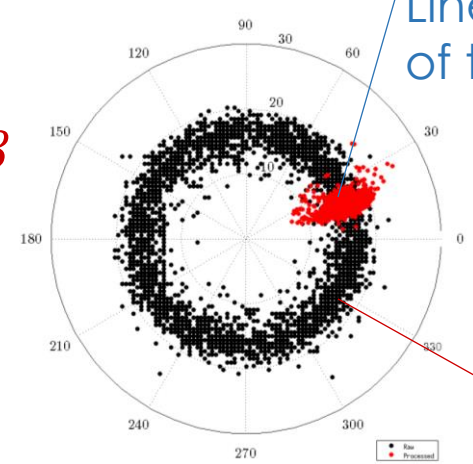
$\boxed{2\pi \frac{k_i}{N}\delta + \beta + Z}$ can be sanitized by linear transformation

$$\tilde{\phi}_i = \hat{\phi}_i - a k_i - b = \phi_i - \frac{\phi_n - \phi_1}{k_n - k_1} k_i - \frac{1}{n}\sum_{j=1}^{n} \phi_j$$

$$\begin{cases} a = \dfrac{\hat{\phi}_n - \hat{\phi}_1}{k_n - k_1} = \dfrac{\phi_n - \phi_1}{k_n - k_1} - \dfrac{2\pi}{N}\delta \\[2ex] b = \dfrac{1}{n}\sum_{j=1}^{n} \hat{\phi}_j = \dfrac{1}{n}\sum_{j=1}^{n} \phi_j - \dfrac{2\pi\delta}{nN}\sum_{j=1}^{n} k_j + \beta \end{cases}$$

Sanitized Phase

Linear combination of true phases $\{\phi_i\}_{i=1}^{n}$

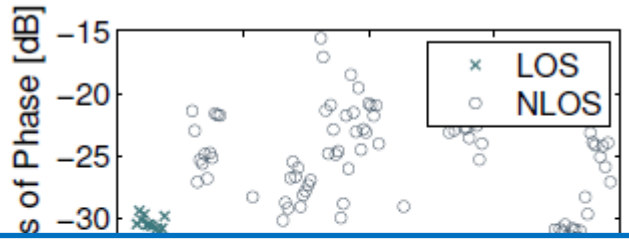


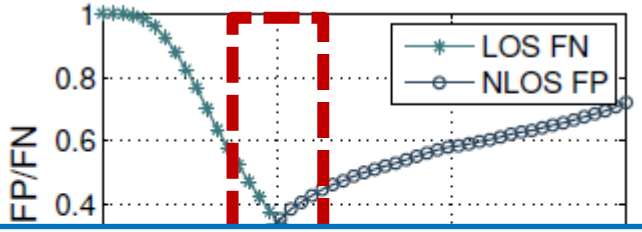
Raw Phase

S. Sen et al ACM MobiSys, 2012.

Variance of Phase as a Feature?

- Signals via NLOS paths often behave more randomly in both signal amplitudes and phases.
- No stable thresholds to discern the two conditions





Fuse the phases of multiple antennas to increase the variance differences and speed up channel statistics calculation

Leveraging Space Diversity

Measured Phase

$$\hat{\phi}_i = \phi_i - 2\pi \frac{k_i}{N}\delta + \beta + Z$$

approaching zero

$$\Delta\hat{\phi}_i = \Delta\phi_i - 2\pi \frac{k_i}{N}\Delta\delta + \Delta\beta$$

Constant over time

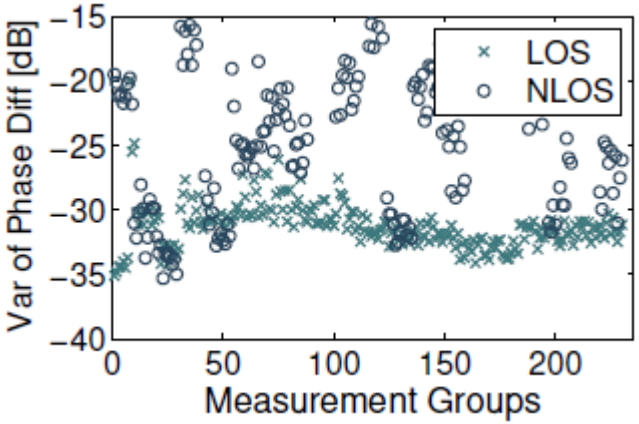
$$\sigma^2_{\Delta\hat{\phi}_i} = \sigma^2_{\Delta\phi_i}$$

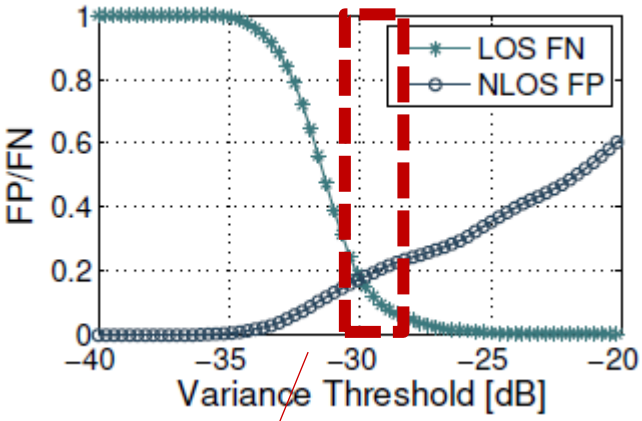
$$\sigma^2_{\Delta\hat{\phi}_i} = \sigma^2_{\phi_{i,1}} + \sigma^2_{\phi_{i,2}}$$

The variance of phase difference of two antennas is the sum of individual variances of true phase on each antenna

Leveraging Space Diversity

- variance of phase difference over two antennas





The variance of phase difference over two antennas proves to be a new feasible feature for LOS identification on WiFi

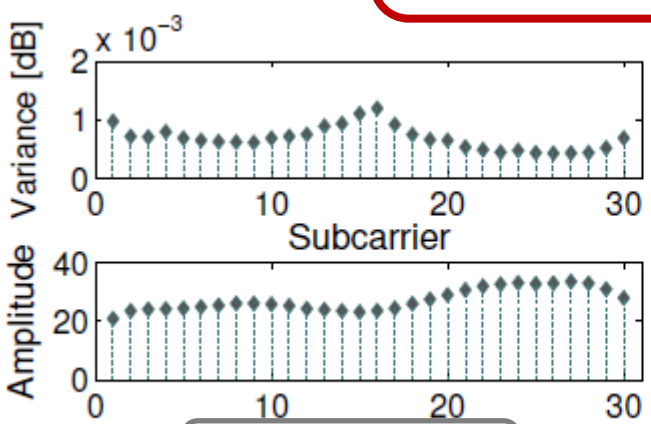
Enhancing via Freq. Diversity

- Signals experience diverse fading at different frequency, especially when penetrating obstacles
- Variances increase with lower amplitudes across the subcarrier frequency in both propagations

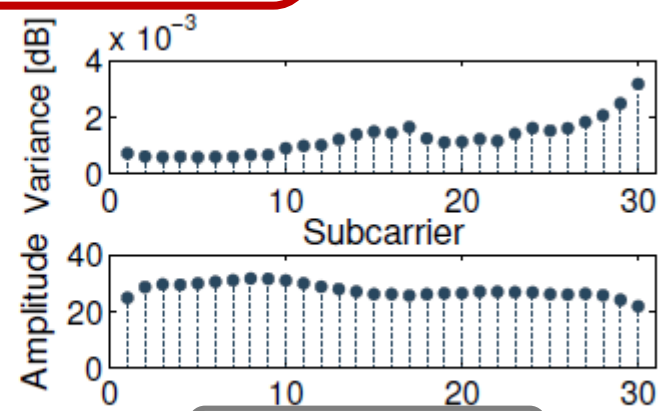
Space Diversity

$$\rho = \frac{\sum_{i=1}^{n} \sigma^2_{\Delta\hat{\phi}_i} |H(f_i)|}{\sum_{j=1}^{n} |H(f_j)|}$$

Freq. Diversity



LOS propagation



NLOS propagation

Real-time Identification

- Binary hypothesis test

Hypothesis test

$$\begin{cases} H_0 : \rho < \rho_{th} \\ H_1 : \rho > \rho_{th} \end{cases}$$

LOS

NLOS

More than 2 antennas

Incorporate all combinations

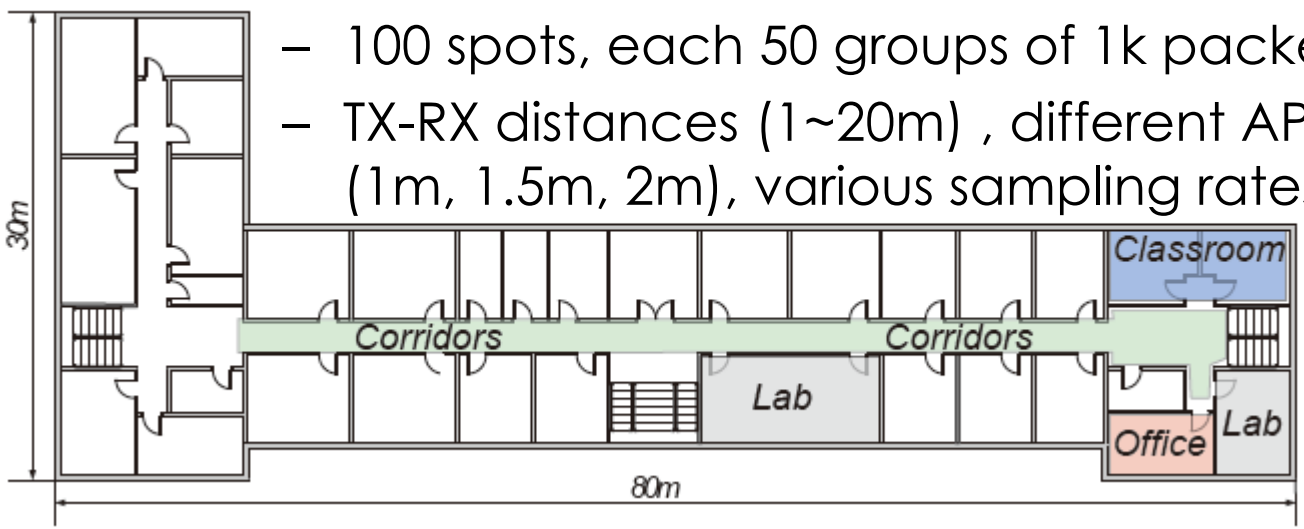
$$\begin{cases} H_0 : \mathrm{med}\left(\rho_{i,j}\right) \leq \rho_{th}, 1 \leq i, j \leq m, i \neq j \\ H_1 : \mathrm{med}\left(\rho_{i,j}\right) > \rho_{th}, 1 \leq i, j \leq m, i \neq j \end{cases}$$

Implementation

- **Transmitter**:
  - one TP-LINK and one Tenda with single antenna, and one Cisco with multiple antennas
  - Operating in IEEE 802.11n AP mode at 2.4GHz
- **Receiver**:
  - A LENOVO laptop with two antennas and a mini desktop with three external antennas
  - Equipped with Intel 5300 NIC and run Ubuntu 10.0

Experimental Setup

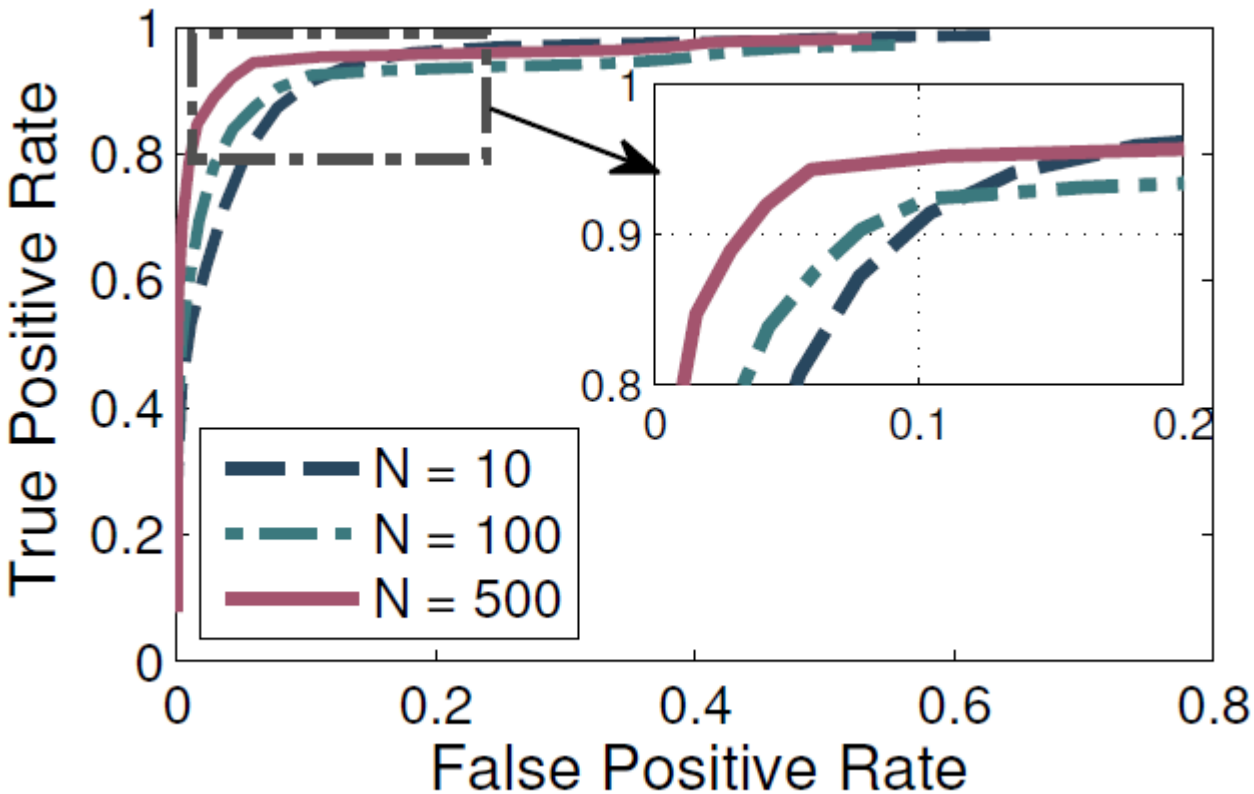
- **Metrics**:
  - LOS Detection Rate
  - False Alarm Rate (NLOS Detection Rate)
- **Comparison Methods:**
  - **Rician-K factor**: The most classical and well-known method
  - **LiFi**: Latest/first work using amplitude features of CSI on WiFi



- 100 spots, each 50 groups of 1k packets
- TX-RX distances (1~20m) , different AP heights (1m, 1.5m, 2m), various sampling rates

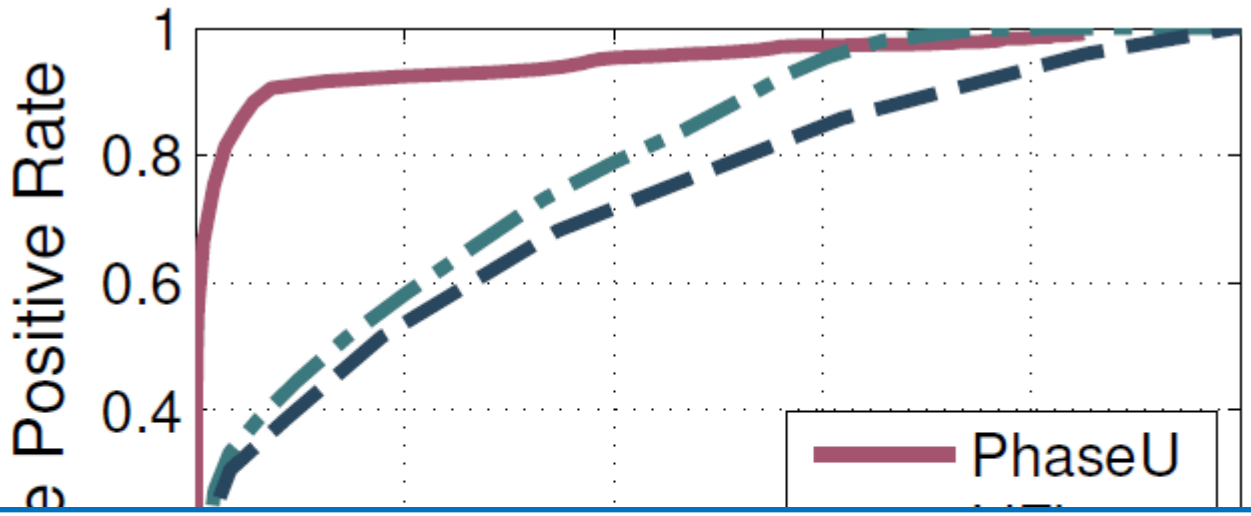
Overall Performance

- Packets #500: 94.35% (LOS) and 94.09% (NLOS)
- Packets #10: 91.61% (LOS) and 89.78% (NLOS)



Performance Comparison

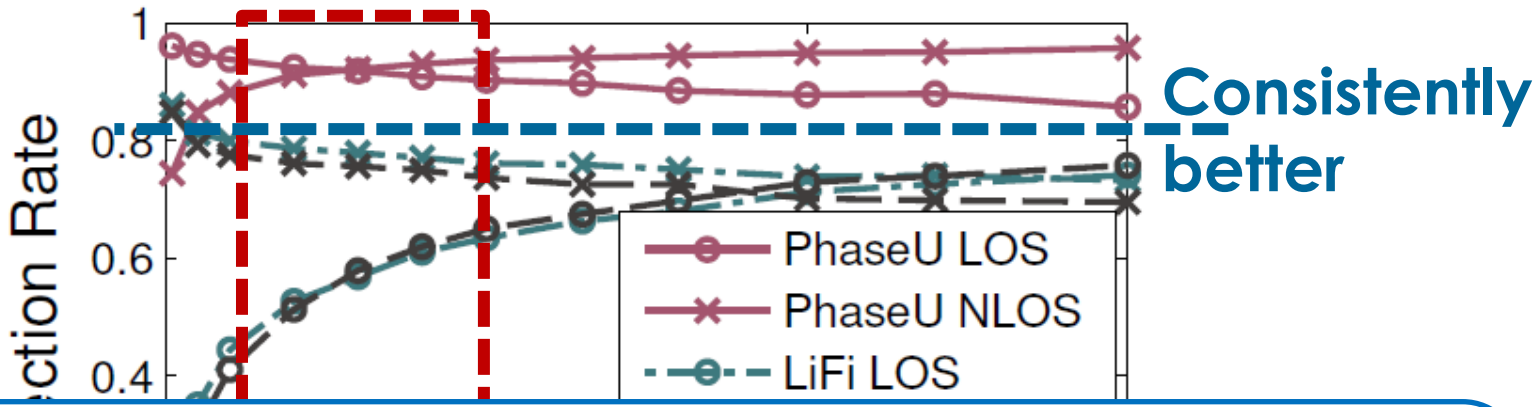
- Using an identical amount of measurements



PhaseU notably better
(up to 20% in both detection rates)

Real-time Capability

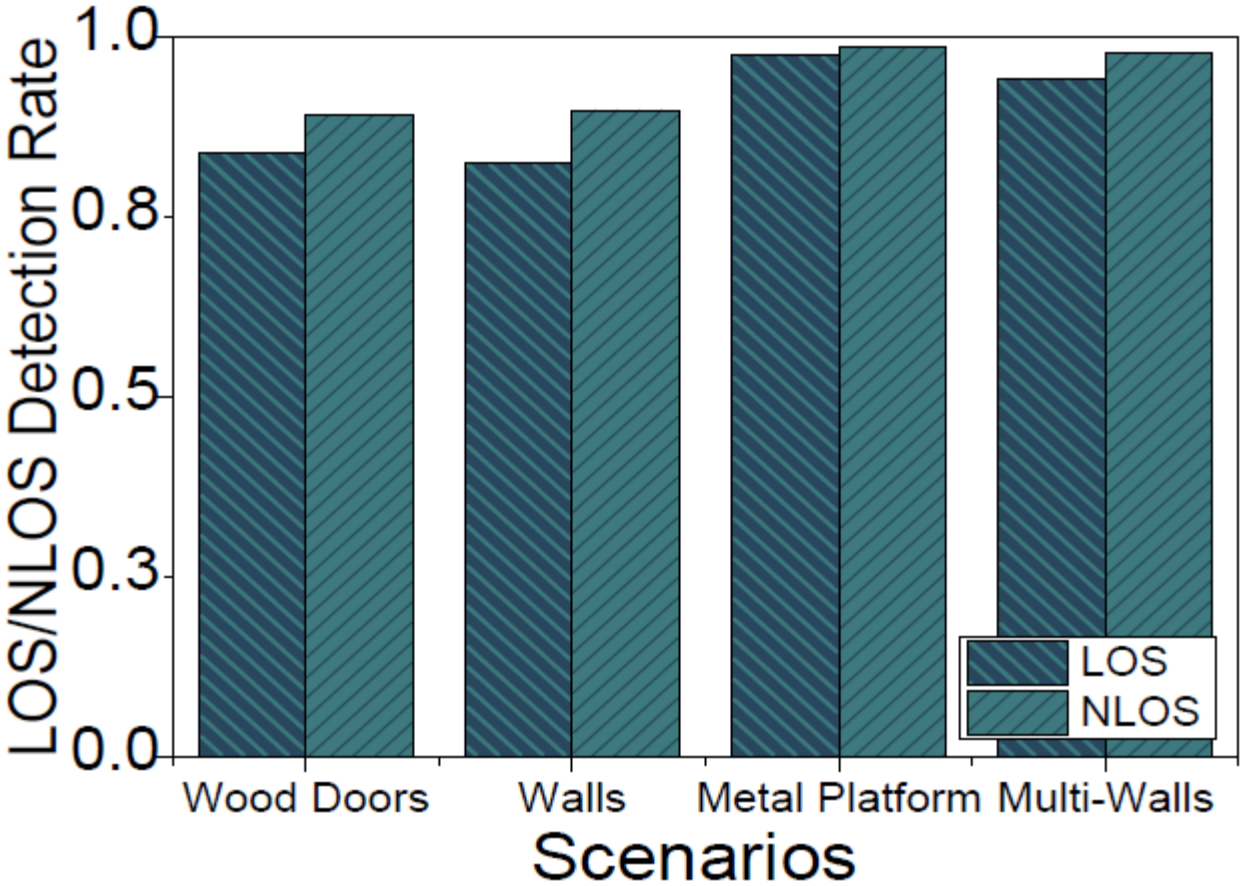
- Average LOS&NLOS detection rates over all cases are 90.84% and 91.01% (with the same threshold)



Millisecond-level real-time identification (depending on the packet rates)

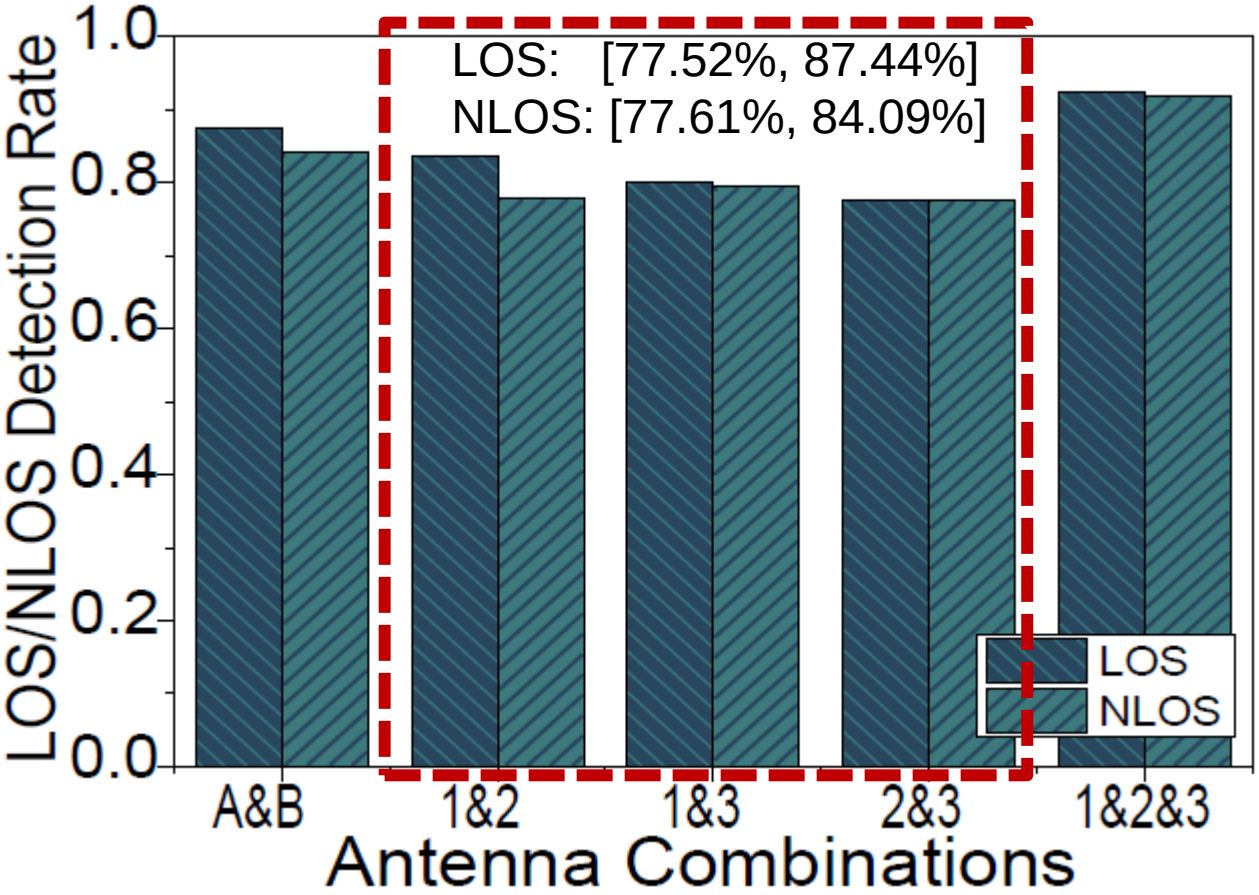
Impact of Obstacle Diversity

No clear performance gap

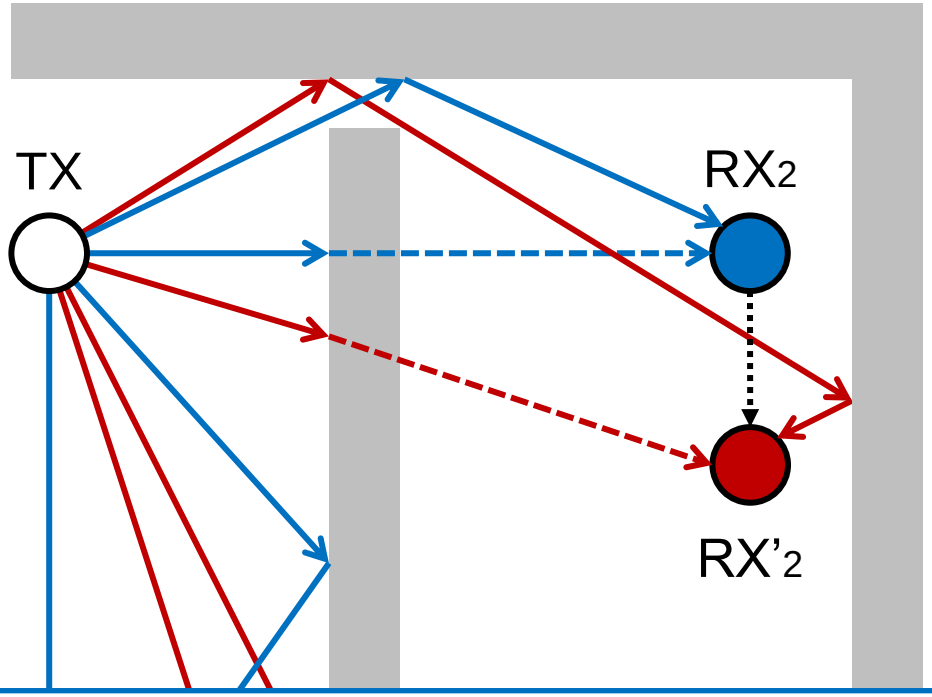


Benefits of Multiple Antenna Combinations

Better with more antennas



Dealing with Mobile Scenario

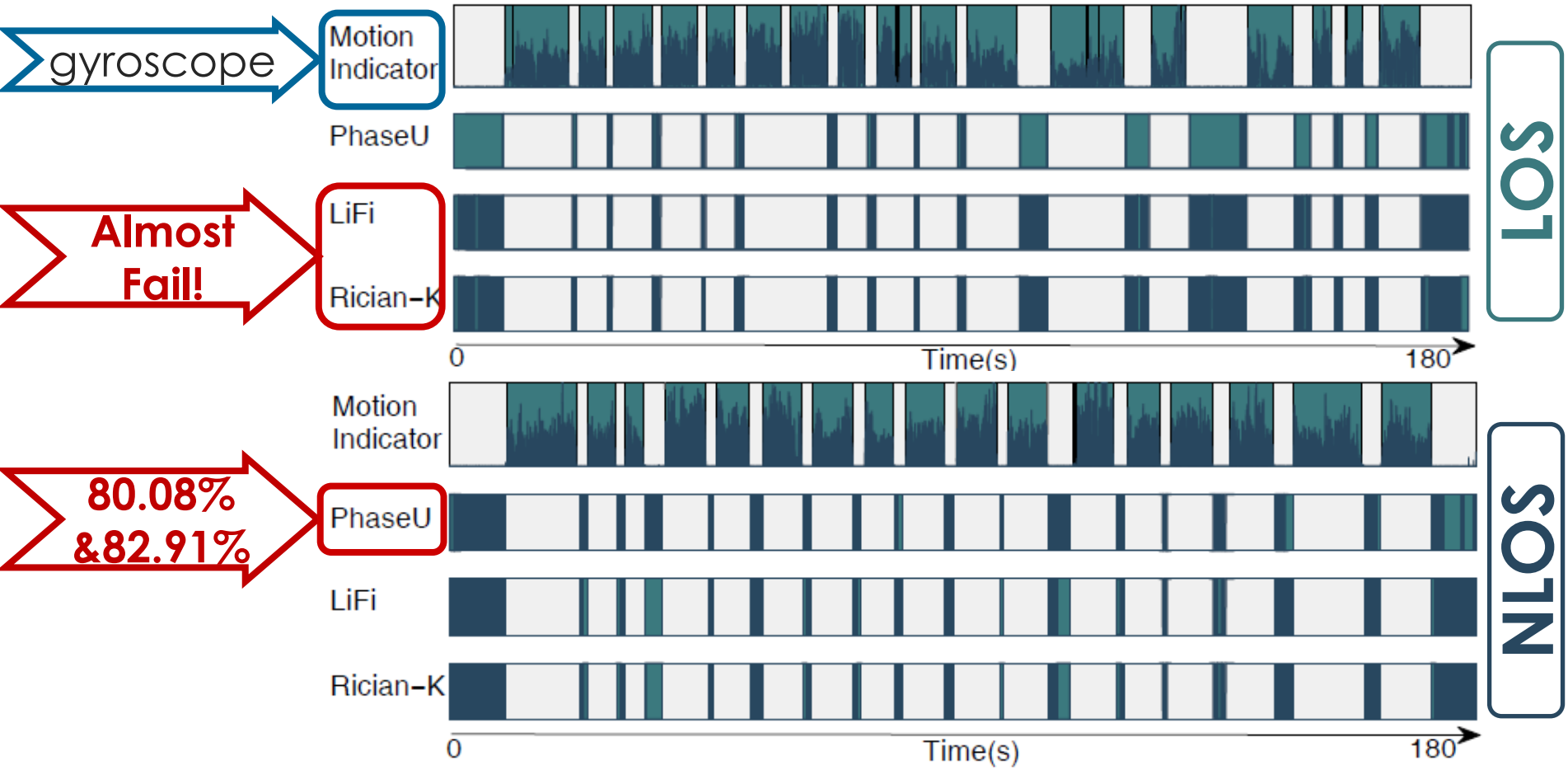


Mobility causes significant randomness, overshadowing the phase variances of both NLOS and LOS propagations!

Insights:

- For a moving user, there are frequent moments when he/she stops for a while to, e.g., look around, greet somebody, or just check a message on the phone.
- The "static" moments can be instantly and accurately captured by inertial sensors embedded on most modern smartphones
- Such immediate "static" moments might be sufficient for millisecond-level identification

Natural Mobile Scenarios



Discussion & Conclusion

- **Discussion:**
  - Pre-calibration for a general threshold
  - Infeasible for fast/continuously moving scenarios
  - Impacts of surrounding moving objects

- **Conclusion:**
  - Enable real-time LOS identification on COTS WiFi devices
  - Exploit phase feature of CSI (Phase difference over antennas, harnessing both space & frequency diversity)
  - Attempts to apply for naturally moving scenarios

Thanks!

Q&A

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