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

Location, Heat map...
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

![Diagram showing LOS and Non-LOS Paths]

**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
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**
# Existing Approaches

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<tr>
<td>Channel Statistics</td>
<td>K Factor</td>
<td>85%, Simulation</td>
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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
A step further: PhaseU

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

Phase information not sufficiently explored

Multiple antennas to support MIMO
Phase Sanitization

Unsynchronized Tx/Rx Pair leads to polluted CSI phase.

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

\[ \hat{\phi}_i = \phi_i - 2\pi \frac{k_i}{N} \delta + \beta + Z \]
Phase Sanitization

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

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

\[ a = \frac{\phi_n - \phi_1}{k_n - k_1} = \frac{\phi_n - \phi_1}{k_n - k_1} - \frac{2\pi}{N} \delta \]

\[ b = \frac{1}{n} \sum_{j=1}^{n} \tilde{\phi}_j = \frac{1}{n} \sum_{j=1}^{n} \phi_j - \frac{2\pi\delta}{nN} \sum_{j=1}^{n} k_j + \beta \]

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

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

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

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

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

\[ \sigma^2_{\Delta \phi_i} = \sigma^2_{\phi_{i,1}} + \sigma^2_{\phi_{i,2}} \]
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.

\[ \rho = \frac{\sum_{i=1}^{n} \sigma_i^2}{\sum_{j=1}^{n} |H(f_j)|} \]

Space Diversity  Freq. Diversity

LOS propagation  NLOS propagation
Real-time Identification

- Binary hypothesis test

Hypothesis test

\[ \begin{align*}
H_0 : \rho &< \rho_{th} & \text{LOS} \\
H_1 : \rho &> \rho_{th} & \text{NLOS}
\end{align*} \]

More than 2 antennas

Incorporate all combinations

\[ \begin{align*}
H_0 : \text{med} (\rho_{i,j}) &\leq \rho_{th}, 1 \leq i,j \leq m, i \neq j \\
H_1 : \text{med} (\rho_{i,j}) &> \rho_{th}, 1 \leq i,j \leq m, i \neq j
\end{align*} \]
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)

Consistently better

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

LOS: [77.52%, 87.44%]
NLOS: [77.61%, 84.09%]
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

- gyroscope
- Motion Indicator
- PhaseU
- LiFi
- Rician-K

Almost Fail!

80.08% & 82.91%
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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