School of Computation, Information and Technology
Technical University of Munich

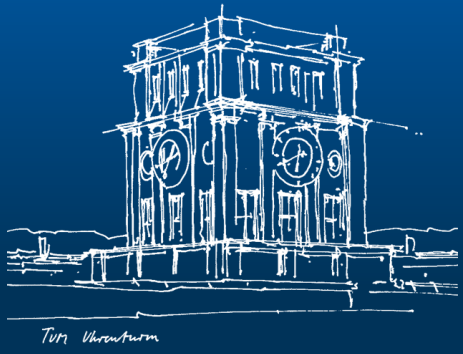
WiSentinel

Detection of humans using Wi-Fi signals

Ilya Nyrkov, Bao Lam Bui, Shivam Singh Chauhan, Max Hufnagel, Muhammad Amir Rafiq Mohd Rafee

Embedded Systems, Cyber-Physical Systems and Robotics
School of Computation, Information and Technology
Technical University of Munich

July 22nd, 2025



Outline

Introduction

- Motivation: Human detection without the usage of cameras.
- Technology: Channel State Information (CSI) data from Wi-Fi with machine learning.

Outline

Project Architecture
Hardware Setup

- Router: TP-Link Archer C7 x2 (red)
- Switch to connect the laptop to the routers (green)
- Laptop: ThinkPad X1 Carbon G10 (blue)

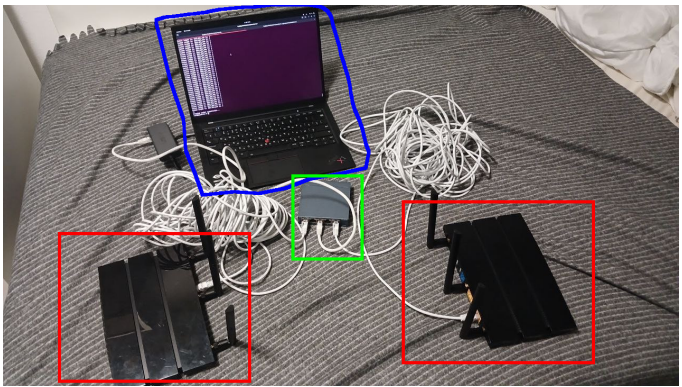


Figure 1 Hardware setup, with different parts highlighted

Project Architecture
Software Setup

- Router: custom-built OpenWrt firmware
  - Patched `ath9k` driver to allow CSI capture
  - Built with Docker, with certain features enabled.
  - Instructions are documented in the repository
- Laptop: Ubuntu
- Data capturing tool: Atheros CSI Tool
- Codebase: pure Python libraries
  - `NumPy`, `Matplotlib` and `csiread` for the main data processing.
  - `FastAPI` for communication between the backend and the frontend (Telegram bot)

Outline

WiSentinel Demonstration

Data Collection & Model Training
Data Collection

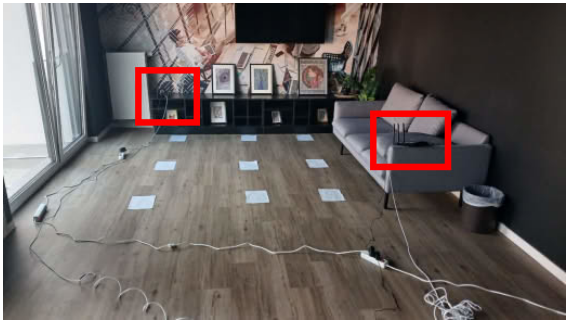


Figure 2 Front side view

Figure 3 Right side view

Data Collection & Model Training
Data Collection

- The room is set up with the routers in the positions in the figure.
- Laptop initiates an SSH connection into the receiver to capture the packets.
- Packets are saved in `.dat` format from the capturing tool.
- Different poses (standing, T-pose) and environments are captured (with a person, with no person).

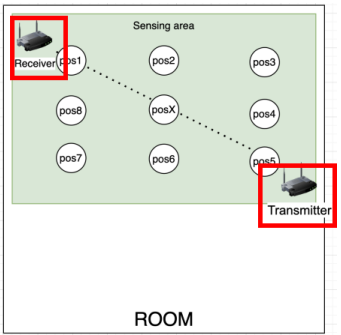


Figure 4 Diagram for router layout

Data Collection & Model Training

Data Format and Presence Model

Data format: 4-dimensional tensor with dimensions
$(packet\_count,\ subcarrier\_count,\ receiving\_antennas,\ ltf\_count)$.

- 56 subcarriers in total, 60 packets per training window.
- 3 transmitting antennas (Tx)+ 3 receiving antennas (Rx).
- "Instability Footprint" is used to determine human presence.

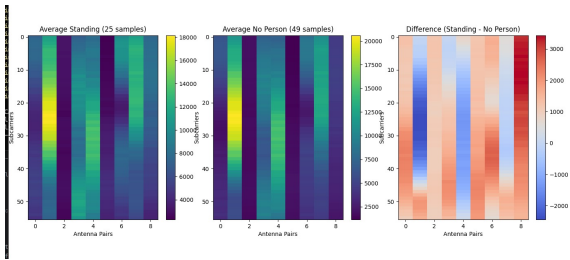


Figure 5 Standard Deviation across time for 56 subcarriers and 9 antenna pairs.

Data Collection & Model Training

Features, Pose Model and Location Model

- Vector of 9 features are extracted from the data, not every model uses all to prevent overfitting.
- Physics-based: tof_mean (Time of Flight), aoa_peak (Angle of Arrival)
- Statistical: std_amp (Amplitude Standard Deviation), $skew\_amp$ (Skewness)
- CNN is used in all models to recognize patterns and identify changes over time.

```
[[-193.+226.j    6.+207.j    0.  +0.j]
 [  19.+112.j   76. -24.j    0.  +0.j]
 [ 230. -64.j  139.-157.j    0.  +0.j]]
```

Figure 6 2D tensor with amplitude and phase values per $Tx + Rx$ pair

Data Collection & Model Training

Model Training

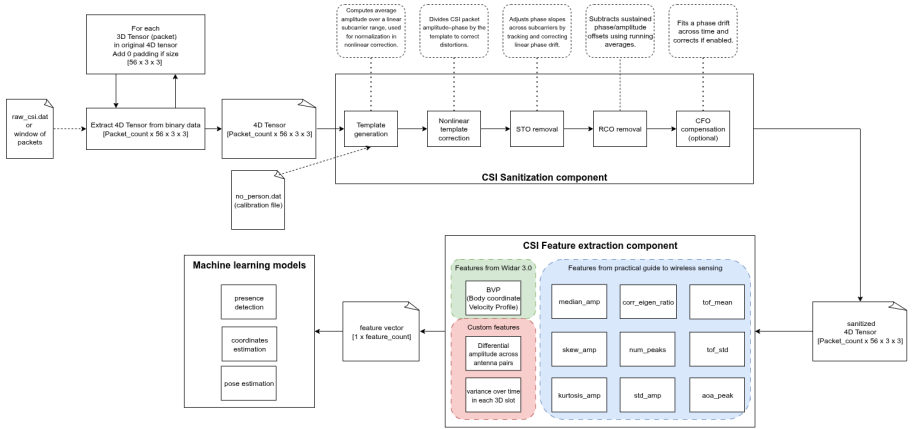


Figure 7 Training pipeline

Outline

Difficulties & Improvements

- Lack of & potential inaccuracy of data.
  - Data must be labelled manually.
  - Lack of available time & locations for data gathering.
  - Environment interference (people walking, different materials, signal degradation)
- Hardware capabilities & cost considerations.
- Lack of experience in different fields (ML, signal processing, etc.).
- Differences in data model compared to existing ones.
- Lack of existing tools for use.

Outline

Practical Applications
Example: Home intrusion detection

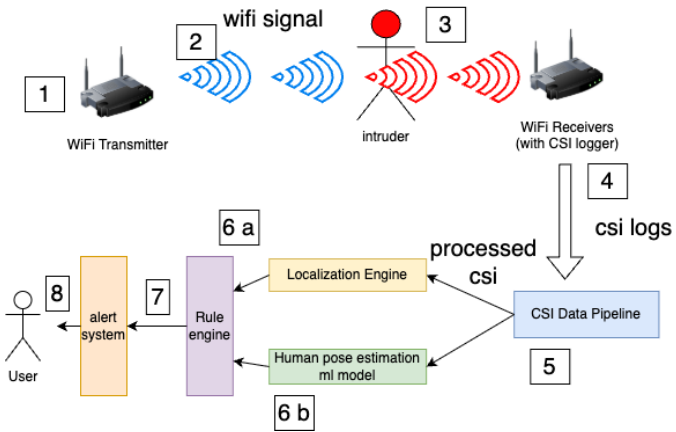


Figure 8 Demonstrative workflow

Outline

Conclusion