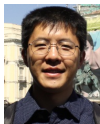


Understanding and Modeling of WiFi Signal Based Human Activity Recognition



Wei Wang[†], Alex X. Liu^{†‡}, Muhammad Shahzad[‡], Kang Ling[†], Sanglu Lu[†]

[†]Nanjing University, [‡]Michigan State University

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Motivation

- WiFi signals are available almost everywhere and they are able to monitor surrounding activities.

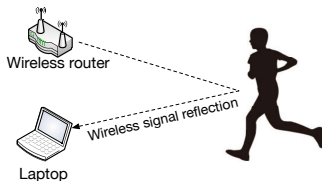




Problem Statment

WiFi based Activity Recognition

- Using commercial WiFi devices to recognize human activities.



Advantages

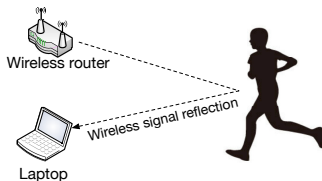
- ✓ Work in dark
- ✓ Better coverage
- ✓ Less intrusive to user privacy
- ✓ No need to wear sensors



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Limitations of Prior Arts

Limitations of Prior Arts: no model (signal, activity)

- So, have to rely on statistical characteristics of WiFi signals
- So, sensitive to environmental changes signals

Our Approach: model(signal, speed)+model(signal, activity)

- Robust to environmental changes
- High recognition accuracy



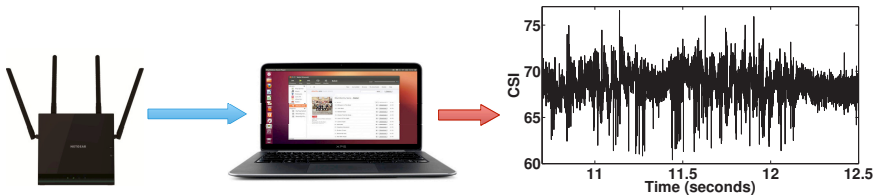
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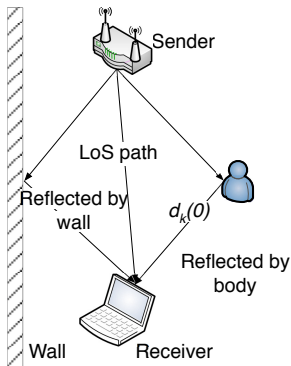




Understanding Multipath

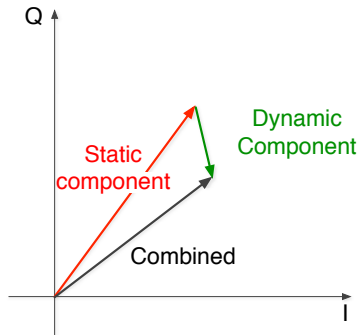
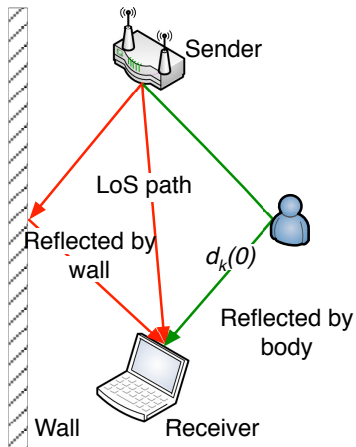
Key observations

- Multipaths contain both static component and dynamic component
- Each path has different phase
- Phases determine the amplitude of the combined signal



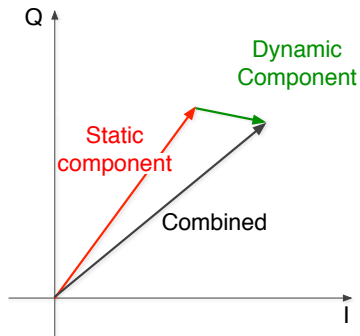
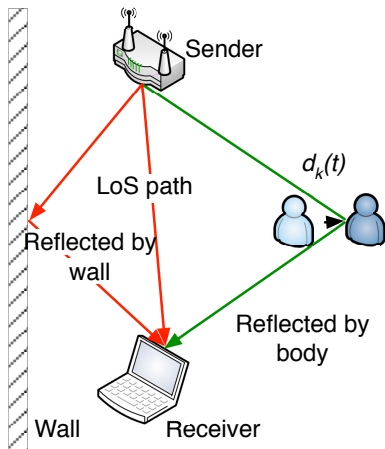


Understanding Multipath



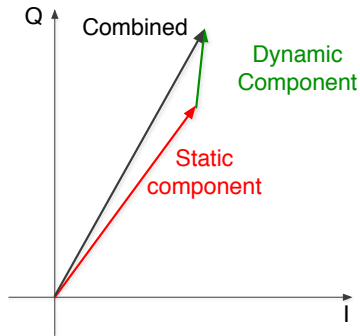
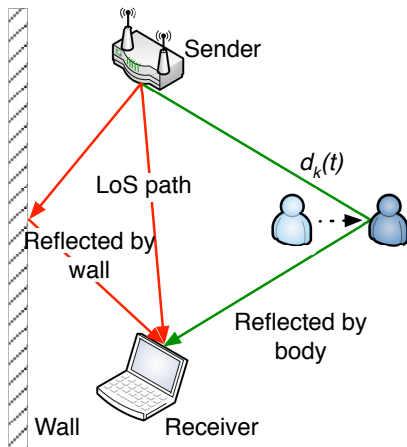


Understanding Multipath





Understanding Multipath

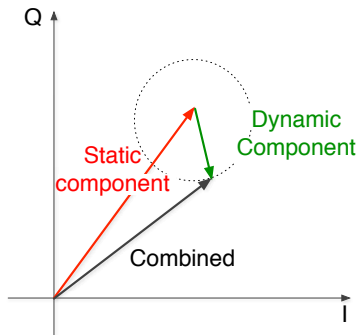




Understanding Multipath

Interpreting CSI amplitude

- Phases of paths are determined by path length
- Path length change of one wavelength gives phase change of 2π
- Frequency of amplitude change can be converted to movement speed

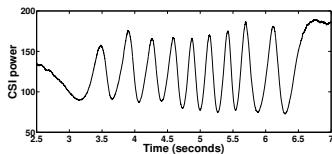




CSI-Speed Model

How accurate is it?

- Wave length \rightarrow 5 ~ 6cm in 5 GHz band



Waveform with regular moving speed

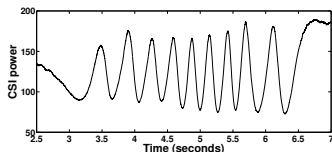
CSI amplitude changes are close to sinusoids



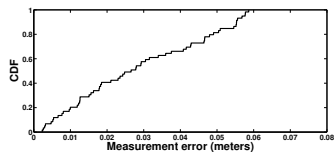
CSI-Speed Model

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- Wave length $\rightarrow 5 \sim 6\text{cm}$ in 5 GHz band



Waveform with regular moving speed



Moving distance measurement error

CSI amplitude changes are close to sinusoids

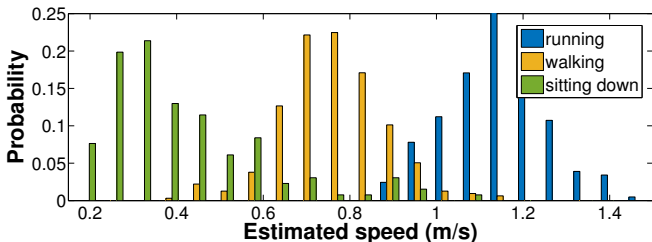
Average distance measurement error of **2.86** cm



CSI-Speed Model

How robust is it?

- Robust over different multipath conditions and movement directions
- Linear combination of multipath do not change frequency



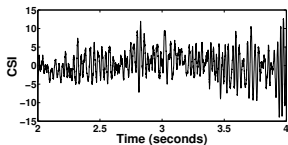
Speed distribution of different activities in different environments



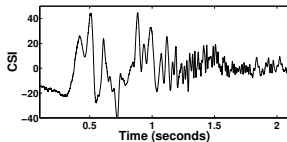
CSI-Activity Model

Activities are characterized by

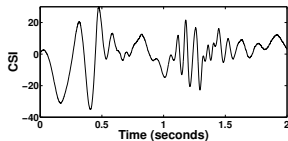
- Movement speeds
- Change in movement speeds
- Speeds of different body components



Walking



Falling

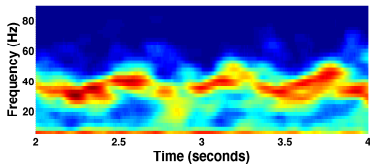


Sitting down

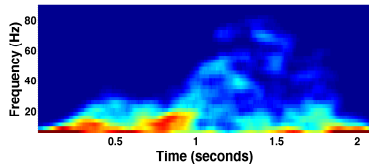


CSI-Activity Model

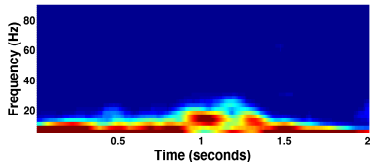
- Use time-frequency analysis to extract features
- Use HMM to characterize the state transitions of movements



Walking



Falling

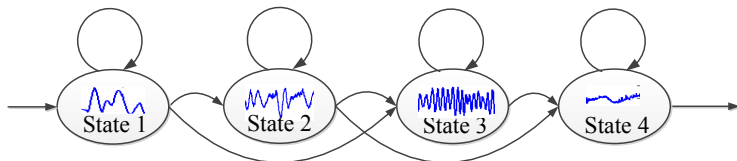


Sitting down



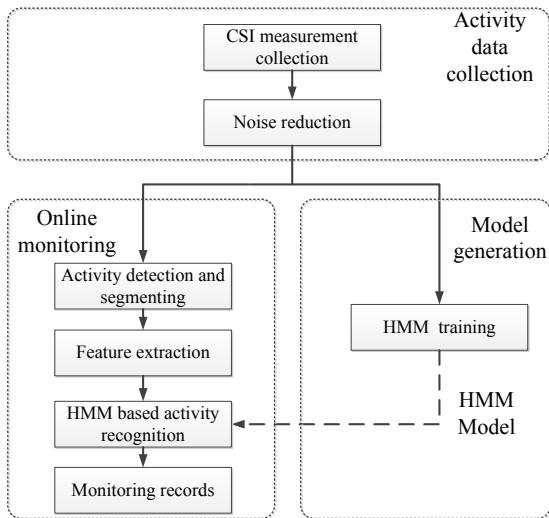
CSI-Activity Model

- Build one HMM model for each activity
- Determine states based on observations in waveform patterns
- State durations and relationships are captured by transition probabilities



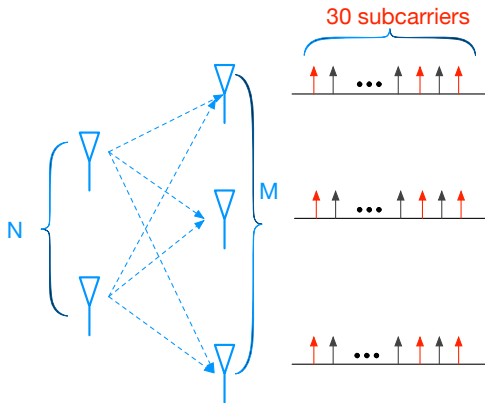


System Architecture

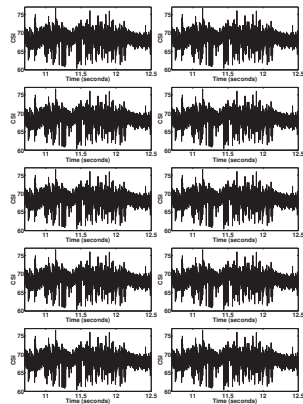




Data Collection



$N \times M \times 30$ CSI streams

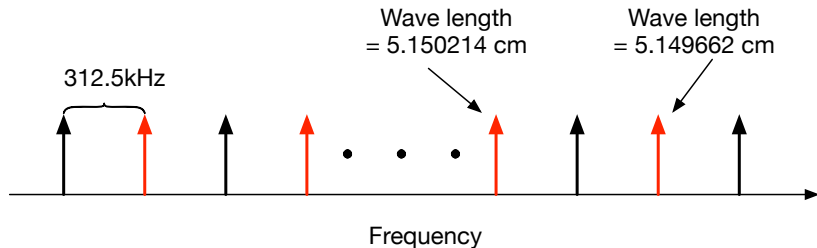




Noise Reduction

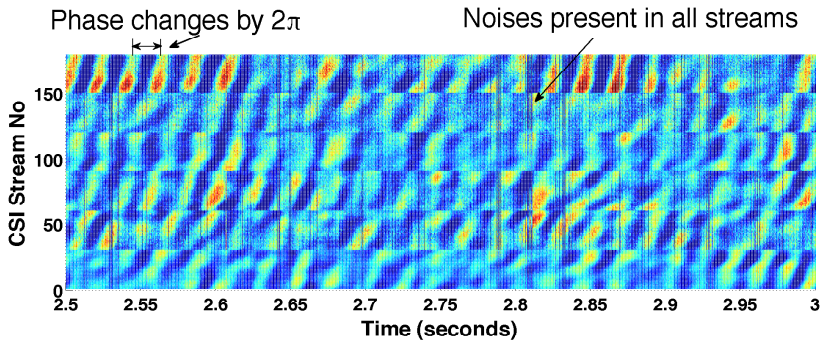
Correlation of CSI on different subcarriers

- Subcarriers only differ slightly in wavelength
- Subcarriers have the same set of paths, with different phases





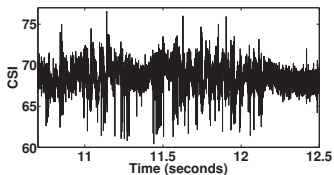
Correlation in CSI Streams



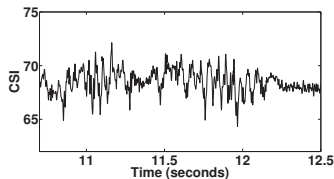


Noise Reduction

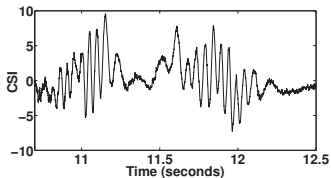
Combines $N \times M \times 30$ subcarriers using **PCA** to detect time-varying correlations in signal



Original



Low-pass filter



PCA



Real-time Recognition

- Activity detection
 - Use both the signal variance and correlation to detect presence of activities
- Feature extraction
 - Time-frequency analysis (DWT)
- HMM model building
 - Eight activities
Walking, running, falling, brushing teeth, sitting down, opening refrigerator, pushing, boxing
 - More than 1,400 samples from 25 persons as the training set



Evaluation Setup

- Commercial hardware with no modification
 - Transmitter: NetGEAR JR6100 Wireless Router
 - Receiver: Thinkpad X200 with Intel 5300 NIC
- A single communicating pair is enough to monitor 450 m^2 open area
- Measurement on UDP packets sent between the pair
- Sampling rate 2,500 samples per second





Evaluation Results

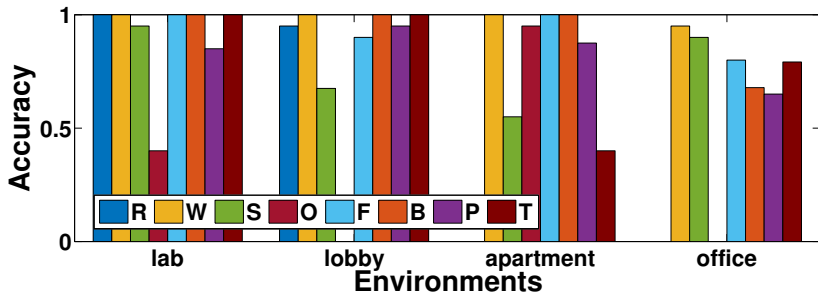
| | | Activity recognized | | | | | | | | |
|---------------|----------|---------------------|-------|-------|-------|-------|-------|-------|-------|-------|
| | | R | W | S | O | F | B | P | T | E |
| True activity | Running | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | Walking | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | Sitting | 0.000 | 0.000 | 0.947 | 0.030 | 0.011 | 0.000 | 0.012 | 0.000 | 0.000 |
| | Opening | 0.000 | 0.005 | 0.150 | 0.803 | 0.042 | 0.000 | 0.000 | 0.000 | 0.000 |
| | Falling | 0.000 | 0.010 | 0.041 | 0.010 | 0.939 | 0.000 | 0.000 | 0.000 | 0.000 |
| | Boxing | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 |
| | Pushing | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 |
| | Brushing | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | 0.000 |
| | Empty | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |

- Ten-fold validation accuracy: **96.5%**
- Detects human movements at **14** meters
- Real-time recognition on laptops
- Packet sending rate can be as low as 800 frames per second



Evaluation on Robustness

- Consistent performance in unknown environments, with more than 80% average accuracy





Conclusions

- CSI measurements contains fine-grained movement informations
- CSI-Speed model
quantifies the correlation between CSI value dynamics and human movement speeds
- CSI-Activity model
quantifies the correlation between the movement speeds of different human body parts and a specific human activity
- Our models are robust to environment changes



Q & A

Thank you!
Questions?