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

September 8, 2015

Motivation

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

08:49
WLAN
Authentication error occurred

dlink-nju	Secured (WPS available)
Hiwifi611	Open
Node2	Open
OpenWrt_5.1	Open
SuperMan	Secured (WPS available)
wlantest	Open (WPS available)
wlantest5G	Open (WPS available)
Xiaomi_4CB9	

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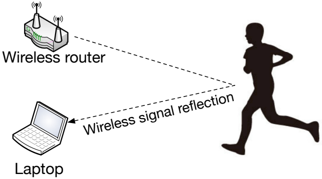
Scan WLAN Direct

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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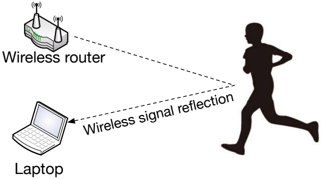

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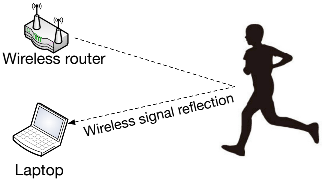

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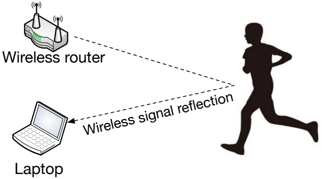

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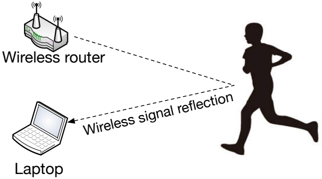

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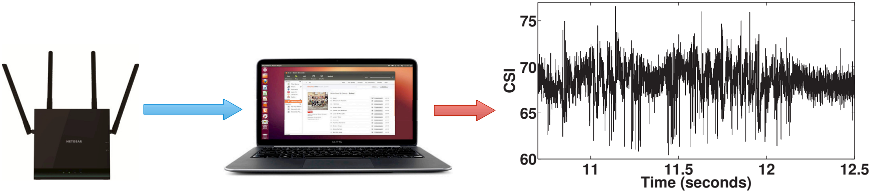
Challenges

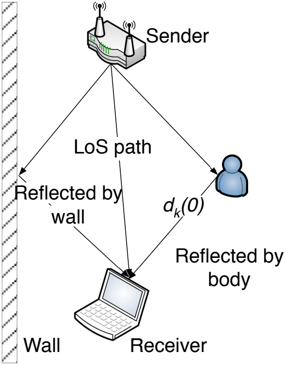
- Measurement from commercial devices are noisy and have unpredictable carrier frequency offsets
- Needs robust and accurate models to extract useful information from measurements



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



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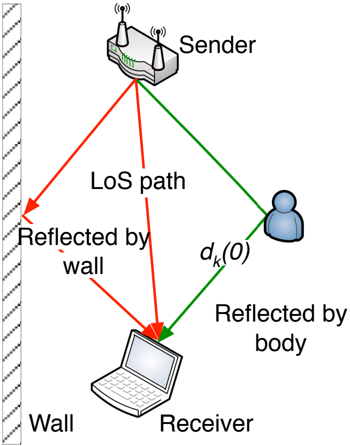

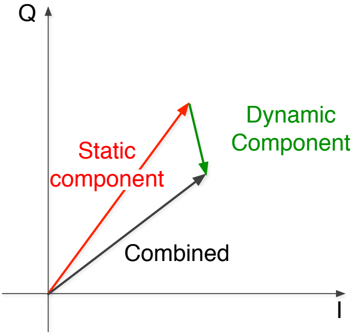

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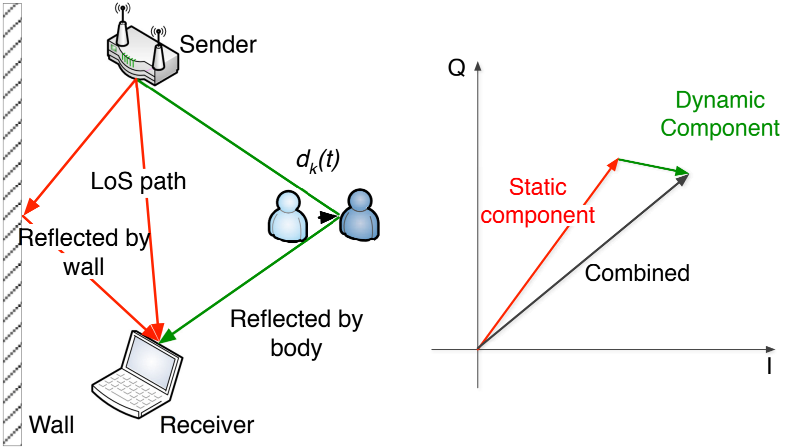

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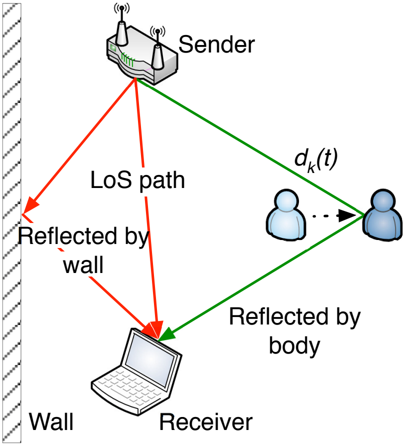
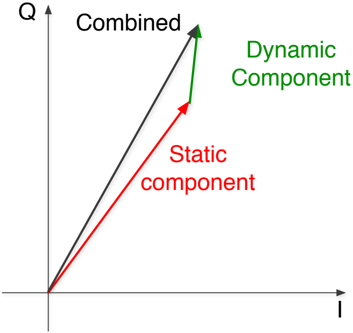
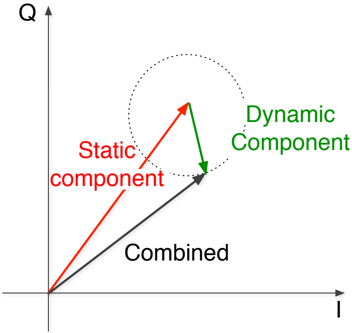




Understanding Multipath

Interpreting CSI amplitude

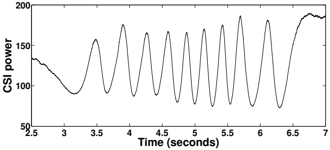
- Phases of paths are determined by path length
- Path length change of one wavelength gives phase change of 2π
- Frequency of amplitude change can be converted to movement speed



CSI-Speed Model

How accurate is it?

- Wave length → $5 \sim 6cm$ in 5 GHz band



Waveform with regular moving speed

CSI amplitude changes are close to sinusoids

CSI-Speed Model

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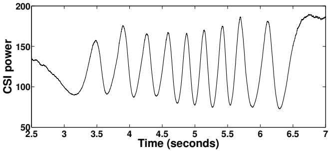

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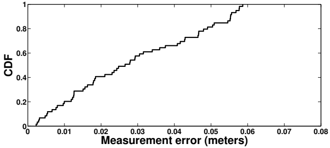


Moving distance measurement error

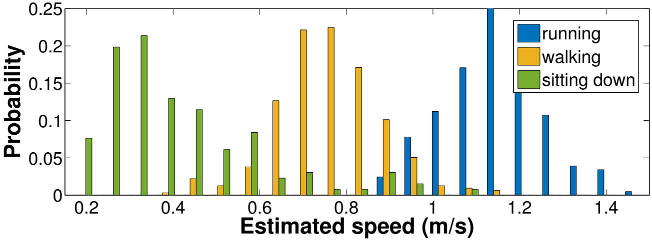
CSI amplitude changes are close to sinusoids

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

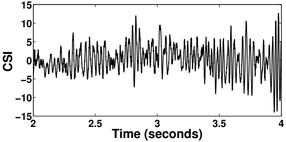


Speed distribution of different activities in different environments

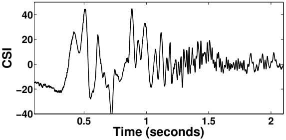
CSI-Activity Model

Activities are characterized by

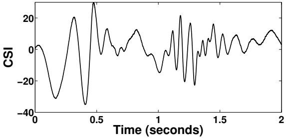
- Movement speeds
- Change in movement speeds
- Speeds of different body components



Walking



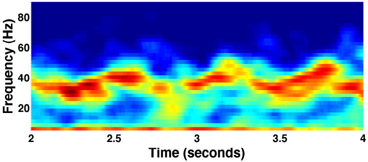
Falling



Sitting down

CSI-Activity Model

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



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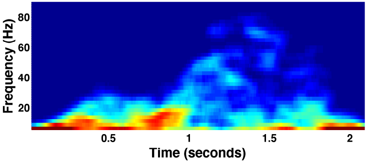
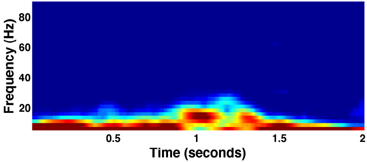


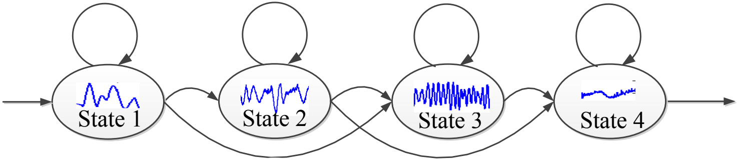
Falling



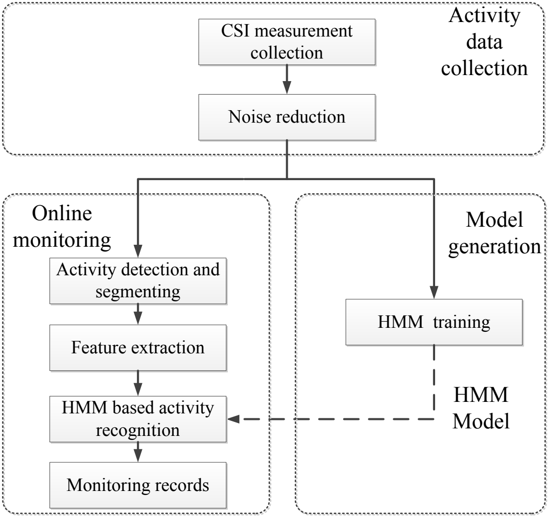
Sitting down

CSI-Activity Model

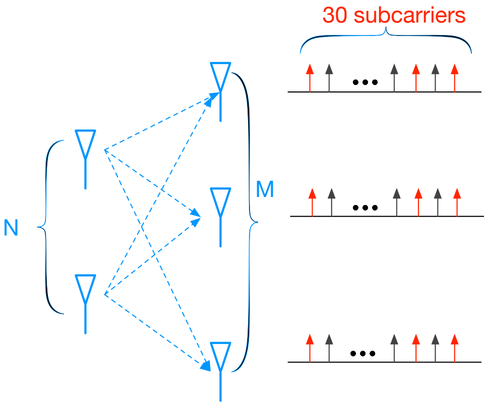
- Build one HMM model for each activity
- Determine states based on observations in waveform patterns
- State durations and relationships are captured by transition probabilities



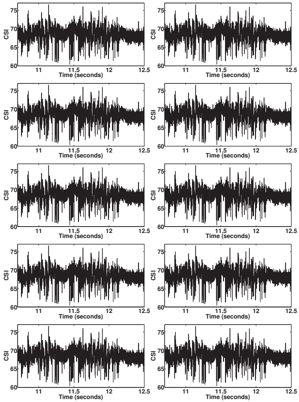
System Architecture



Data Collection



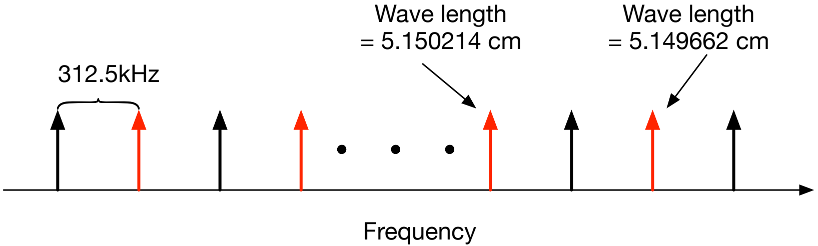
$N \times M \times 30$ CSI streams



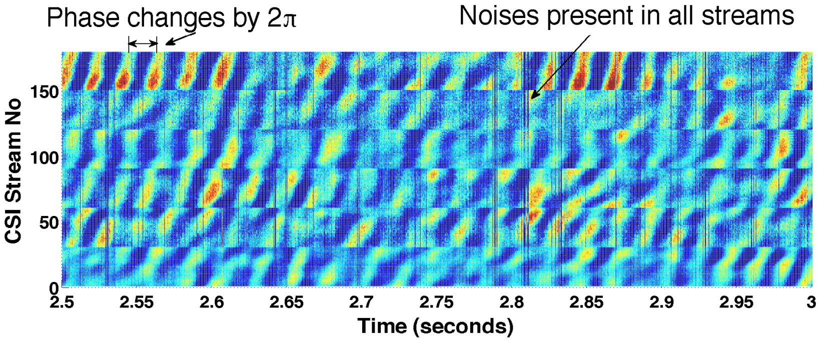
Noise Reduction

Correlation of CSI on different subcarriers

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

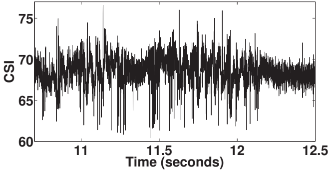


Correlation in CSI Streams

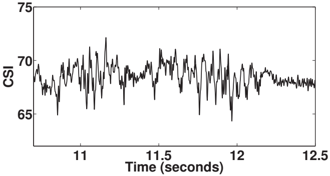


Noise Reduction

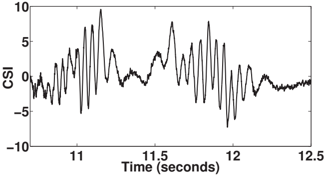
Combines $N \times M \times 30$ subcarriers using PCA to detect time-varying correlations in signal



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

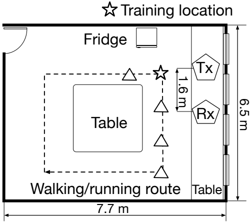
Evaluation Results

		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

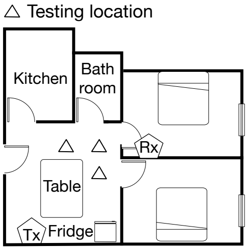
- Ten-fold validation accuracy: 96.5%
- Detects human movements at 14 meters
- Real-time recognition on laptops
- Packet sending rate can be as low as 800 frames per second

Evaluation on Robustness

- Models are robust to environment changes
- Train once, apply to different scenarios
- Training use database collected in lab with different users
- Test in with users not in the training set
    - Open lobby
    - Apartment (NLOS)
    - Small office



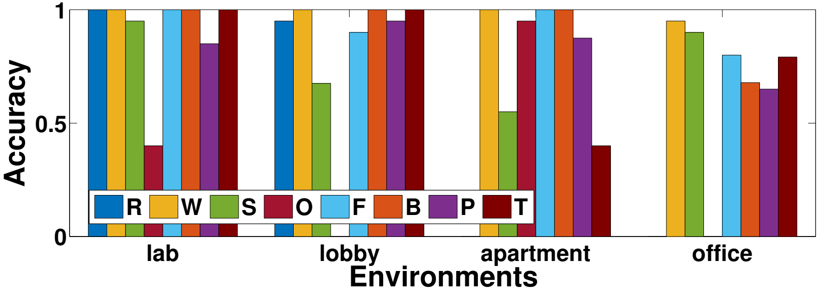
Lab



Appartment

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?