Smokey:

Ubiquitous Smoking Detection with Commercial WiFi Infrastructures

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Motivations

- Smoking ban is put into effect in many countries

Motivations

- However, what do the civilized people do?

How to monitor and detect?

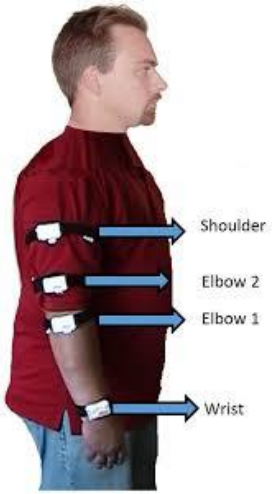
- Fire alarm system
  - Smog sensors
- ***Not sensitive enough*** to detect smoking a cigarette

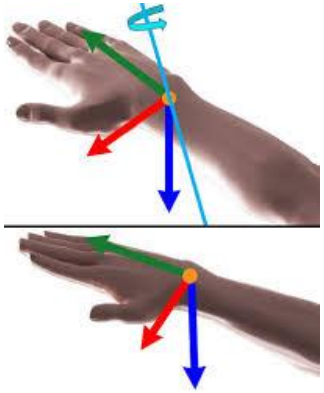
How to monitor and detect?

- Customized sensors
  - carbon monoxide
  - Nicotine
- Impractical to be ***ubiquitously*** deployed
  - Limited sensing range of each sensor
  - Expensive

How to monitor and detect?

- Wearable devices
  - Inertial sensors
  - Analyze: chest motions, wrist motions, arm motions…
- Require targets to ***wear dedicated devices***





How to monitor and detect?

- Computer Vision (CV)
  - Surveillance cameras
  - Detect the cigarette or the body movements
- Require clear and ***line-of-sight (LOS)*** video images

Motivation

- Desired Smoking Detection System
  - **Non-intrusive**: without requirements of wearing devices
  - **Ubiquitous**: without the limitation of LOS scenarios
  - **Accurate**: detect invalid smoking activities

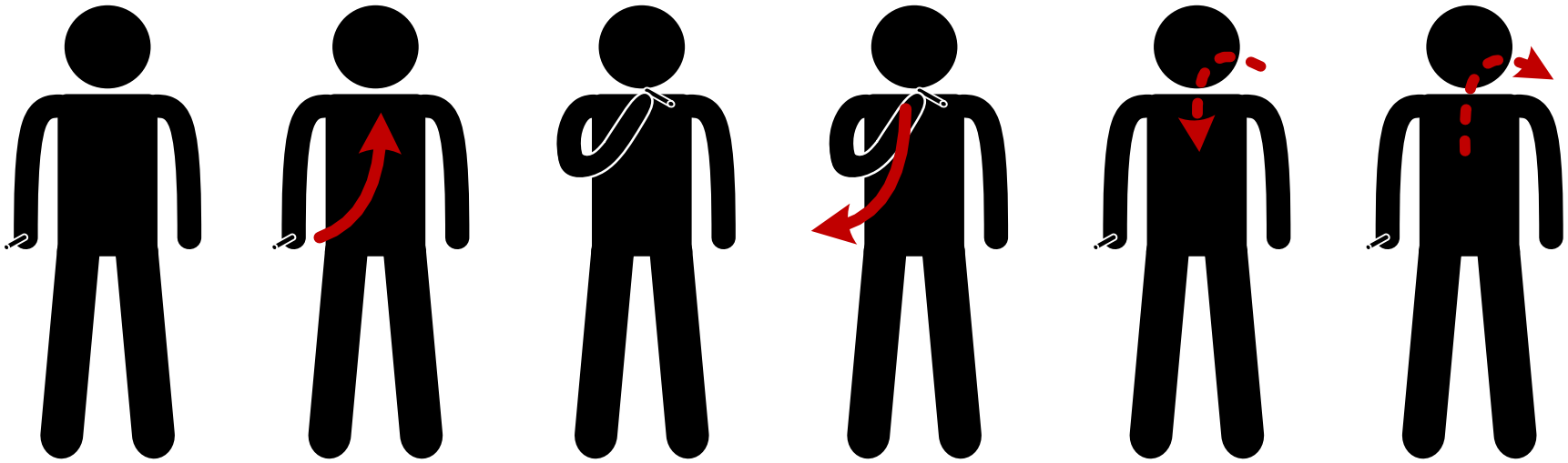
Wireless signal?

- Human motions affect wireless signal
  - Localization & TrackingControl system: virtual mouse, AllSee, WiGesture, et al.
  - Users' involvement and compliance required

- *Is that possible to leverage the affected WiFi signal to infer smoking activities?*
  - Without the requirement of users' compliance
  - Under various dynamic environments

Smoking steps

- *Smoking is a rhythmic activity*



(a) Holding

(b) Put up

(c) Suck into mouth

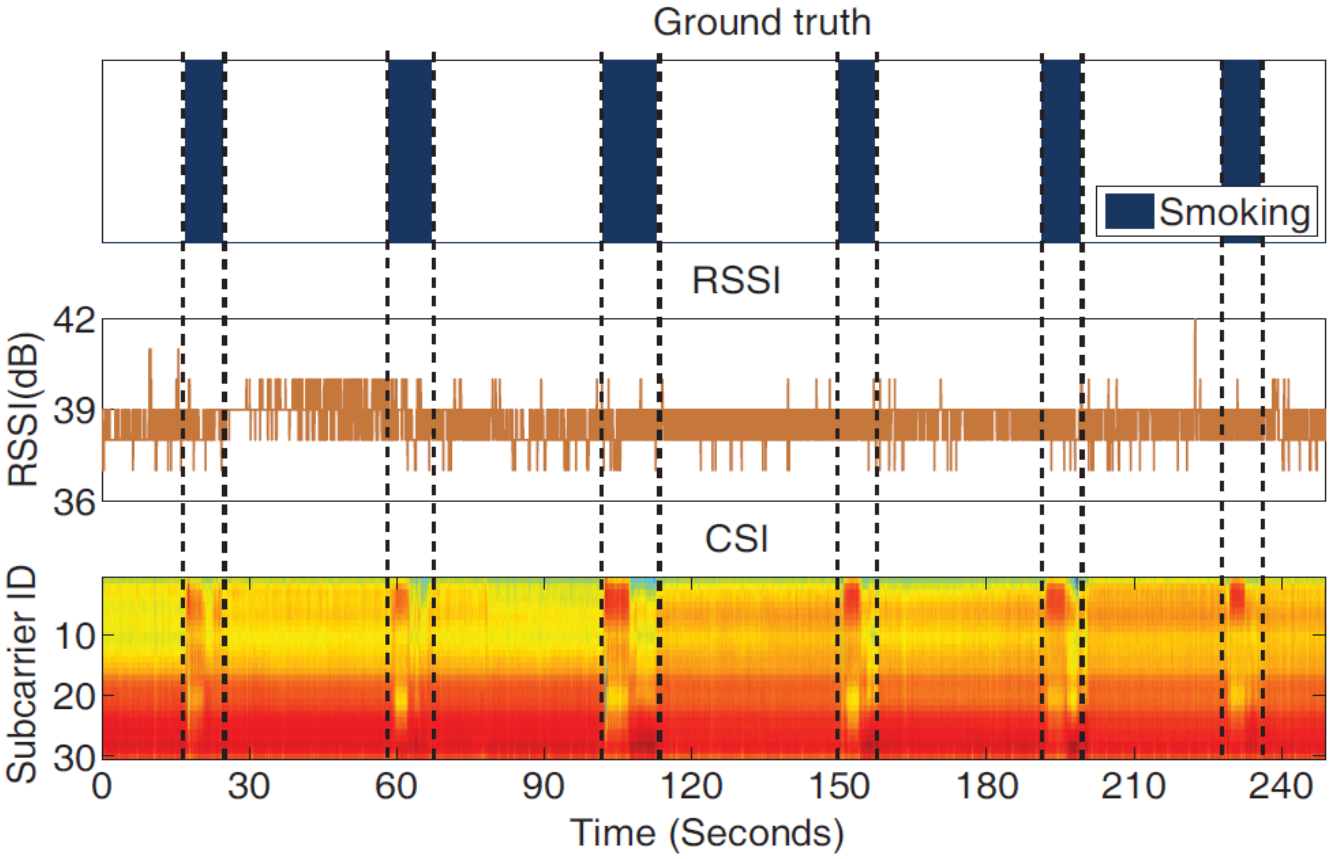
(d) Put down

(e) Inhale

(f) Exhale

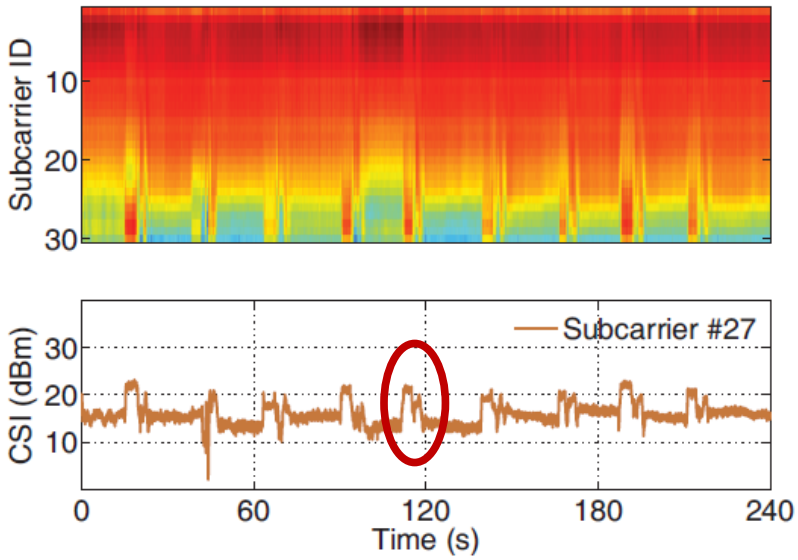
Smoking affects WiFi CSI

- *Channel State Information (CSI)*

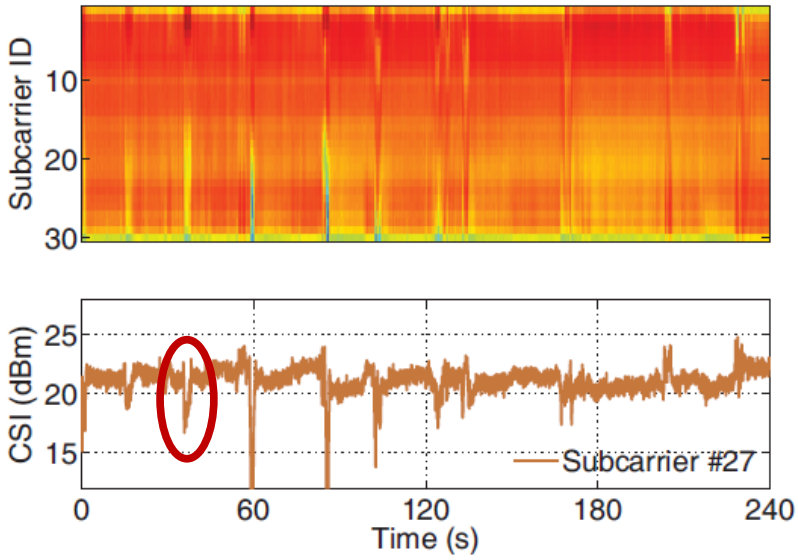


Distinctive smoking

- *Smoking is rhythmic activity*
- *Smoking is a composite activity that contains a series of motions in a certain order*



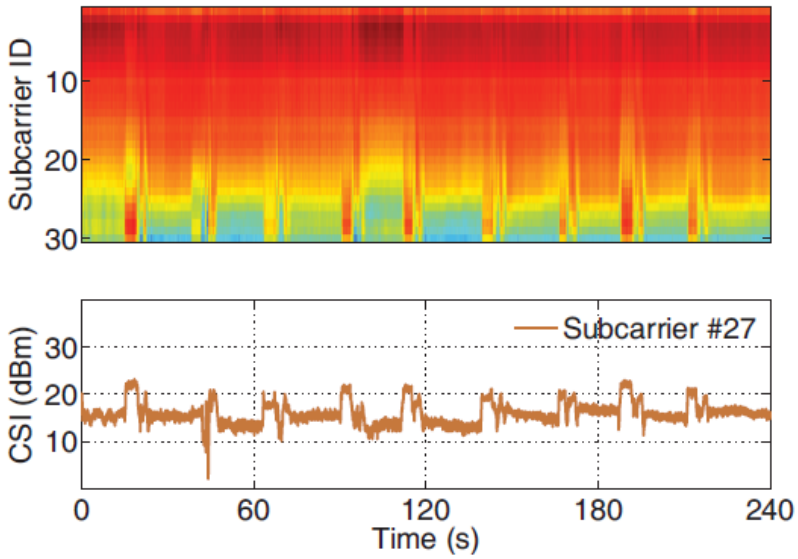
(a) Smoking



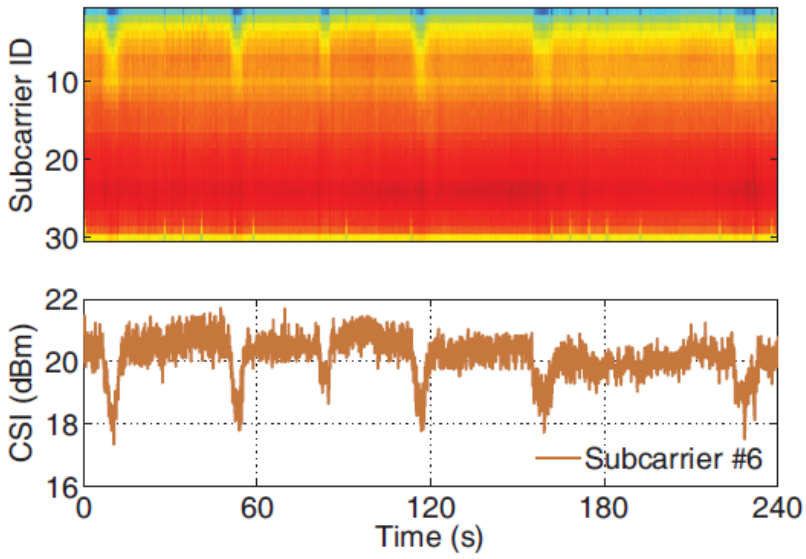
(b) Eating

Distinctive smoking

- *Smoking is rhythmic activity*
- *Smoking is a composite activity that contains a series of motions in a certain order*



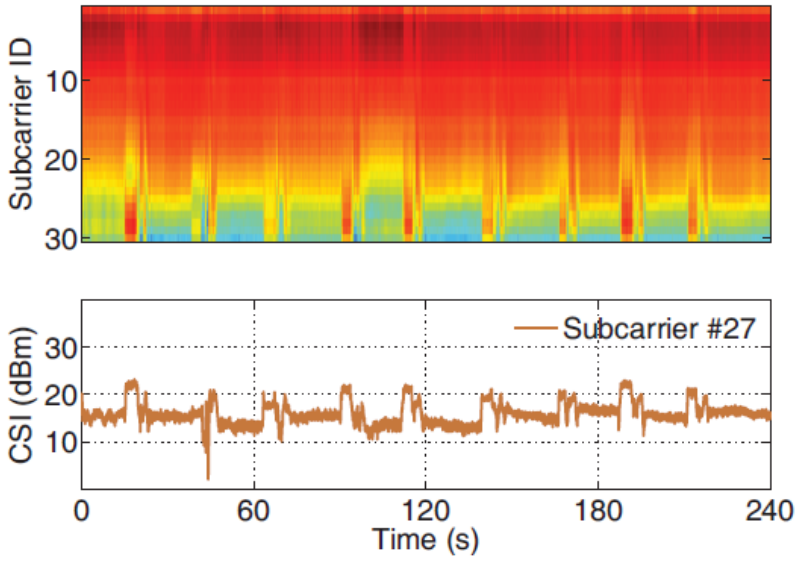
(a) Smoking



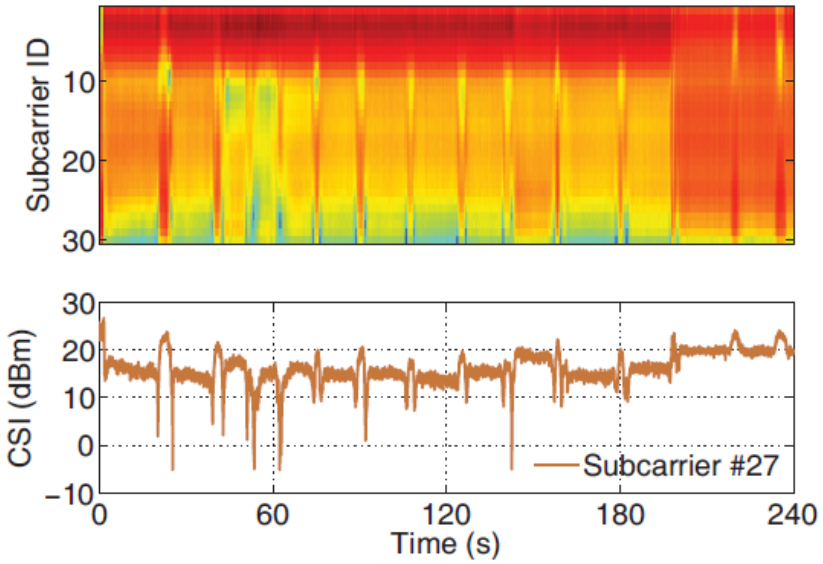
(c) Drinking

Distinctive smoking

- *Smoking is rhythmic activity*
- *Smoking is a composite activity that contains a series of motions in a certain order*



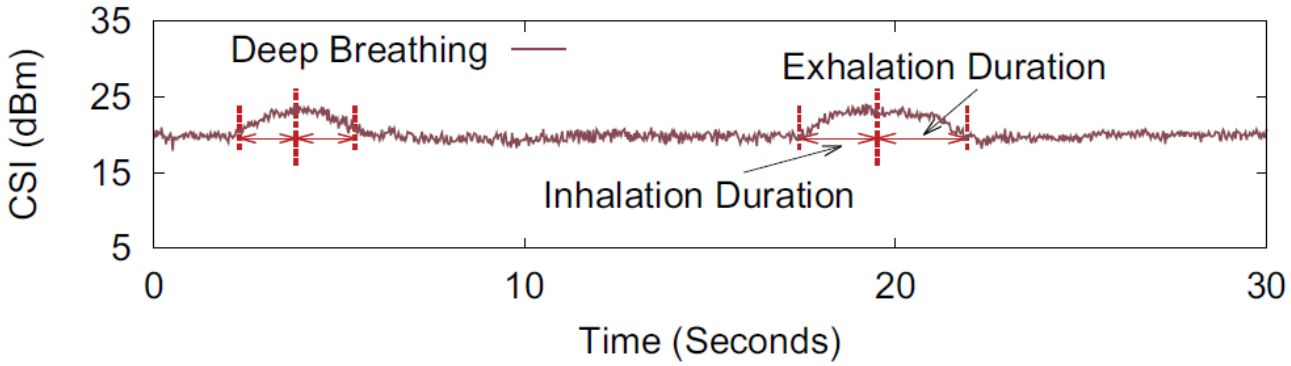
(a) Smoking



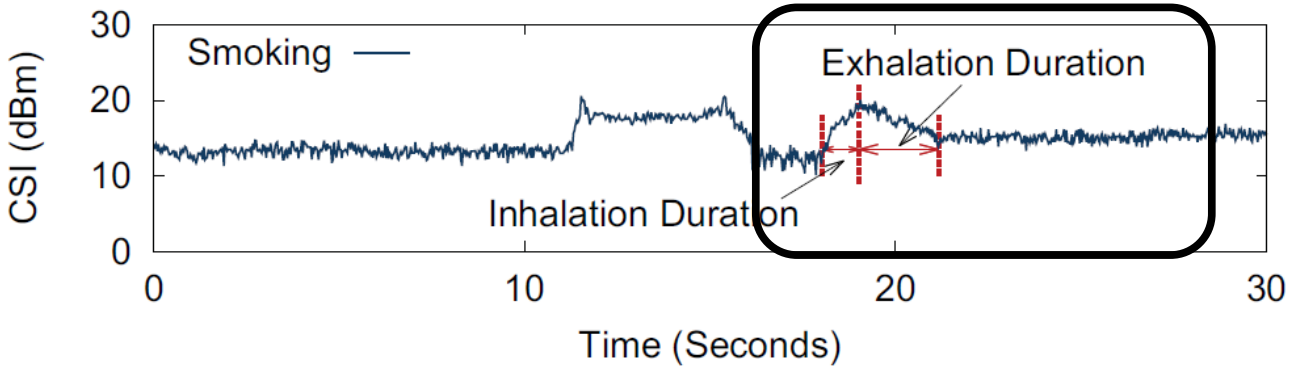
(d) Deep Breathing

Unique chest motion

- *Exhalation is longer than inhalation*



(a) Deep breathing



(b) Smoking

Micro-benchmark

- Desired Smoking Detection System

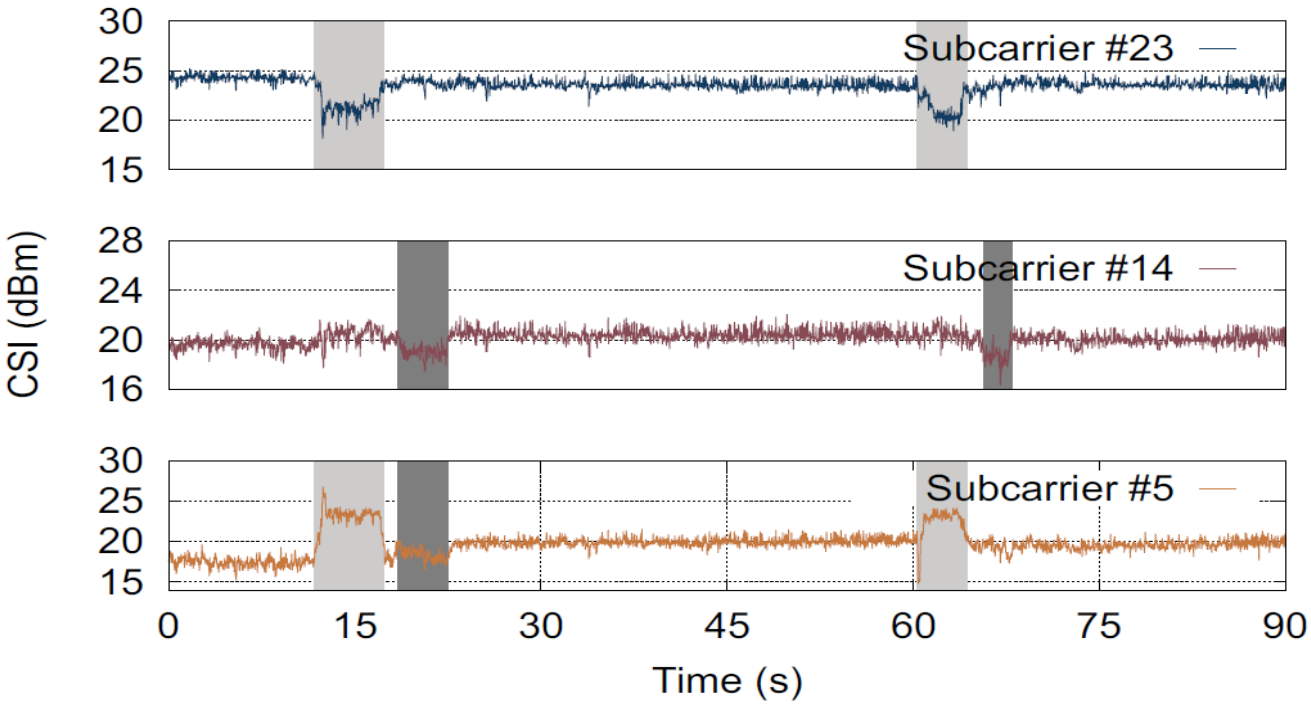
- **Non-intrusive**: without requirements of wearing devices

- **Ubiquitous**: without the limitation of LOS scenarios

- **Accurate**: detect invalid smoking activities

Subcarrier-dependent problem

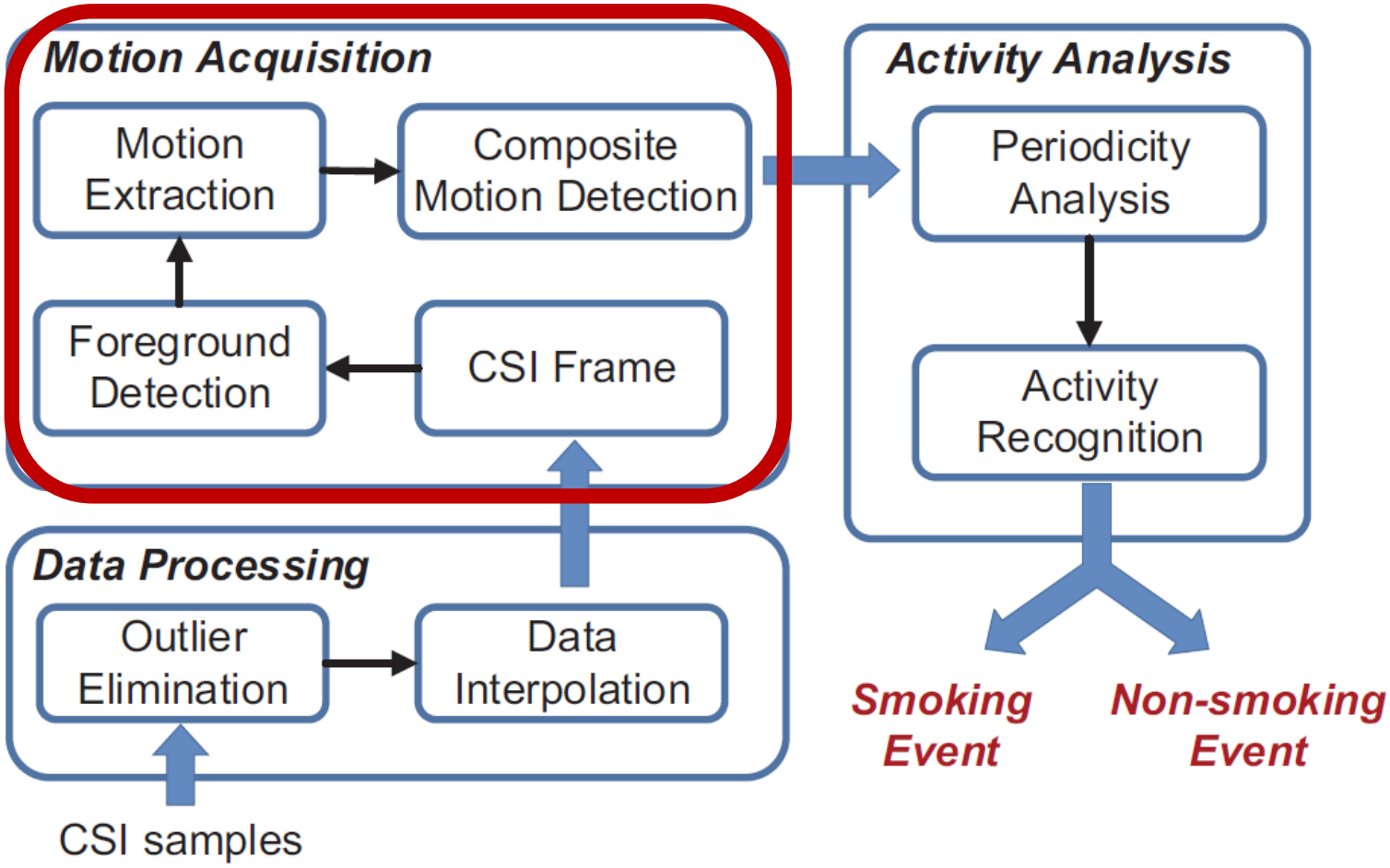
- *The impacts of smoking are subcarrier-dependent*
- *The impacts of smoking on CSI vary dynamically on a single subcarrier*



Outline

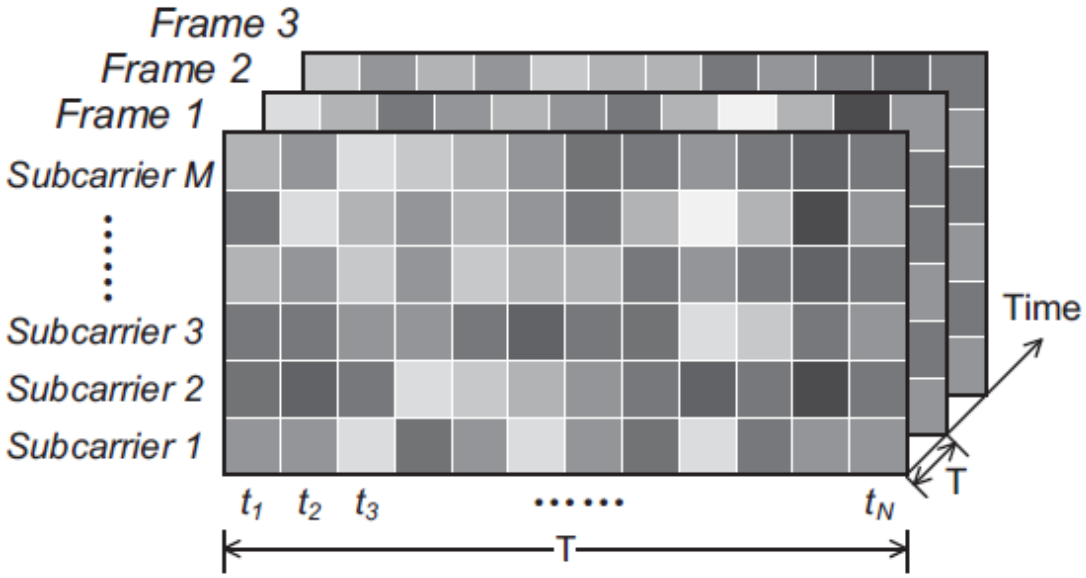
- Motivations
- Preliminary Analysis
- **Design of Smokey**
- Evaluation
- Summary

Smokey Overview



CSI Frame

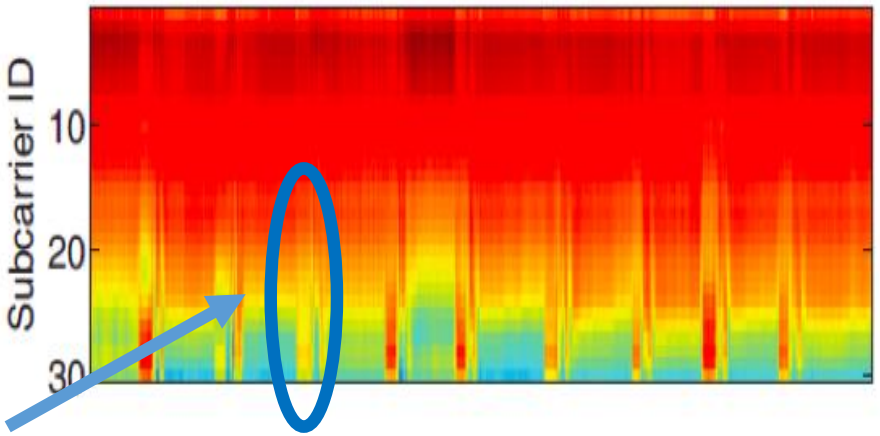
- Construct CSI frames from CSI sequences
  - Each frame contains $M \times N$ pixels
  - $P_{m,n}$: CSI amplitude of subcarrier m collected within the n-th time window (t_n)



Subcarrier-dependent problem

Foreground Detection

Information Extraction



Moving objects

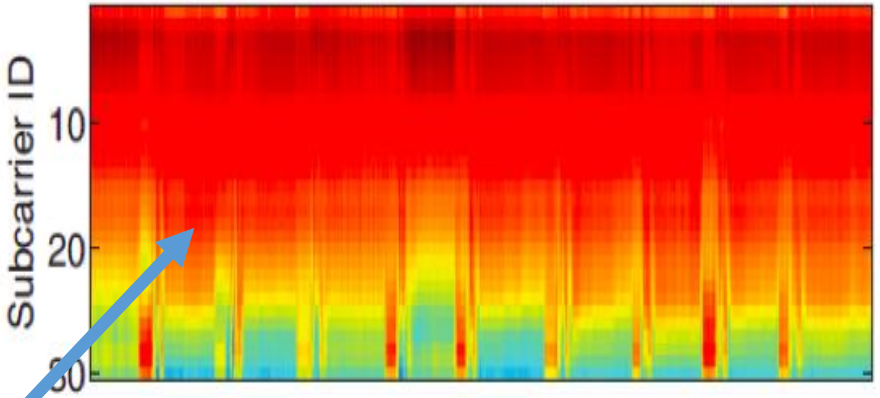
Foreground

CSI changes caused by smoking

Subcarrier-dependent problem

Foreground Detection

Information Extraction



Background model

Adaptive to environment changes such as luminance

Online Update

Background

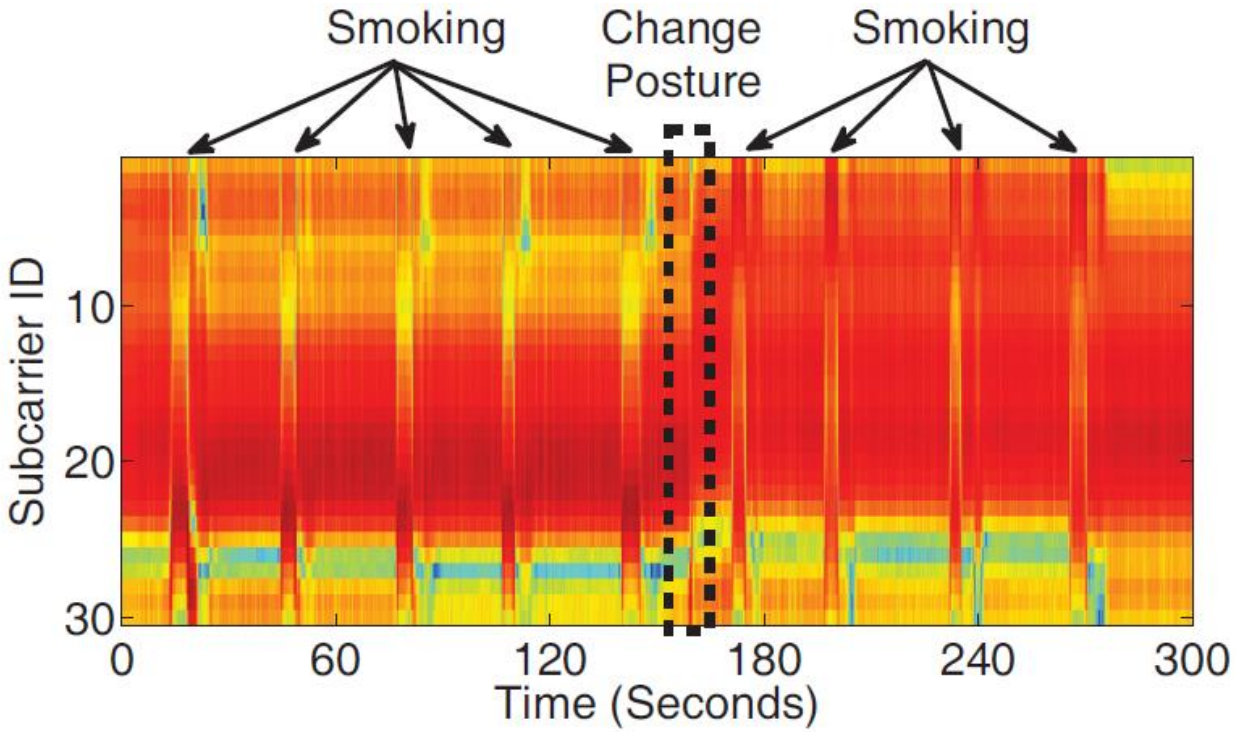
Mixture of Gaussians

Adaptive to time-varying dynamics

Online Update

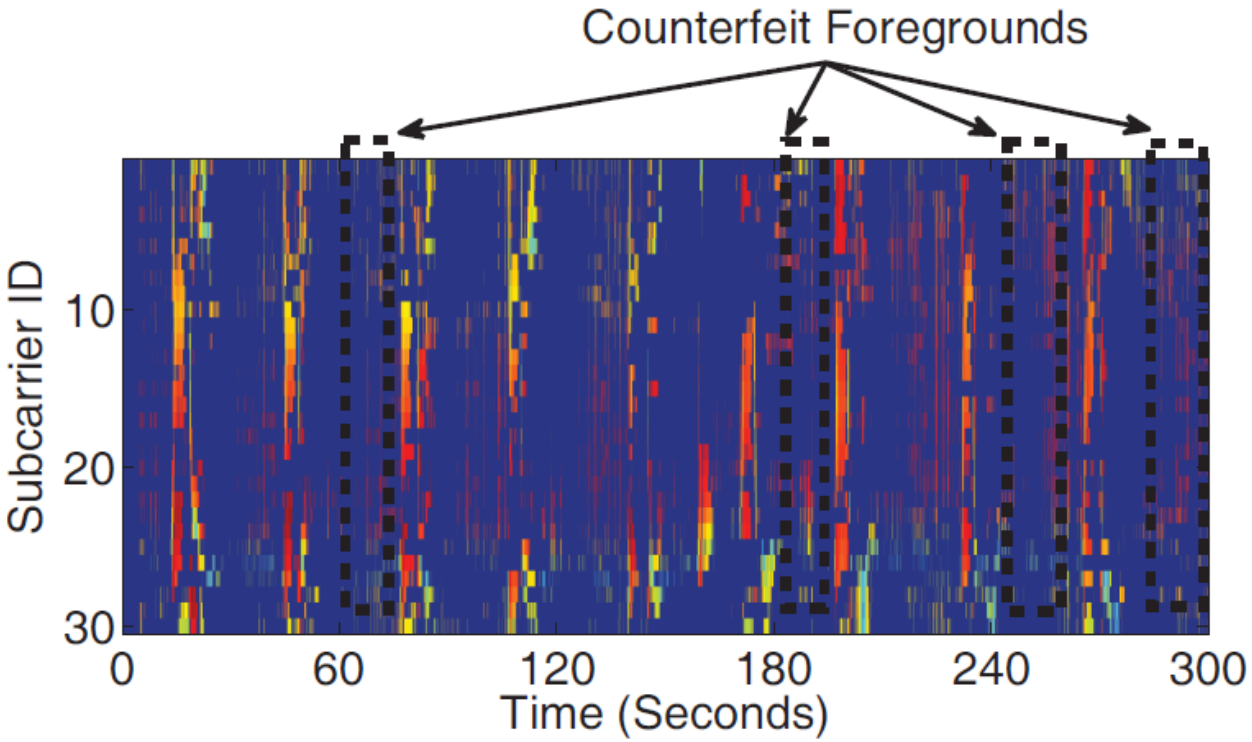
Sample Results

- Original CSI trace



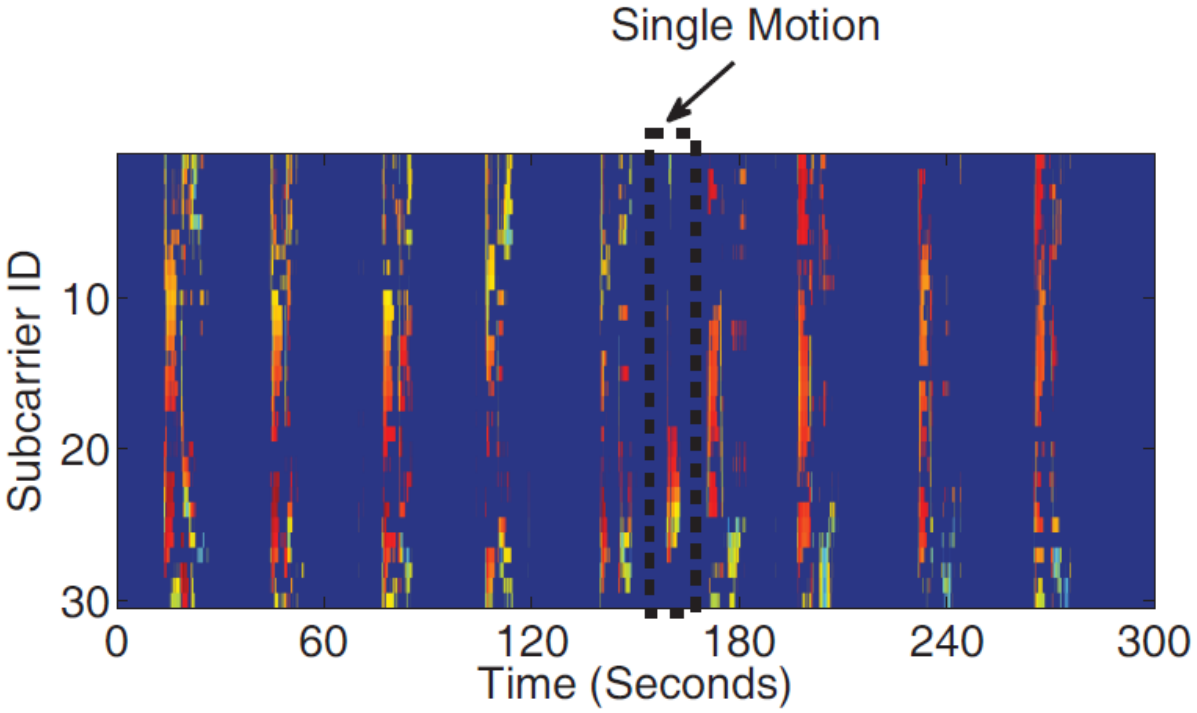
Sample Results

- After foreground detection



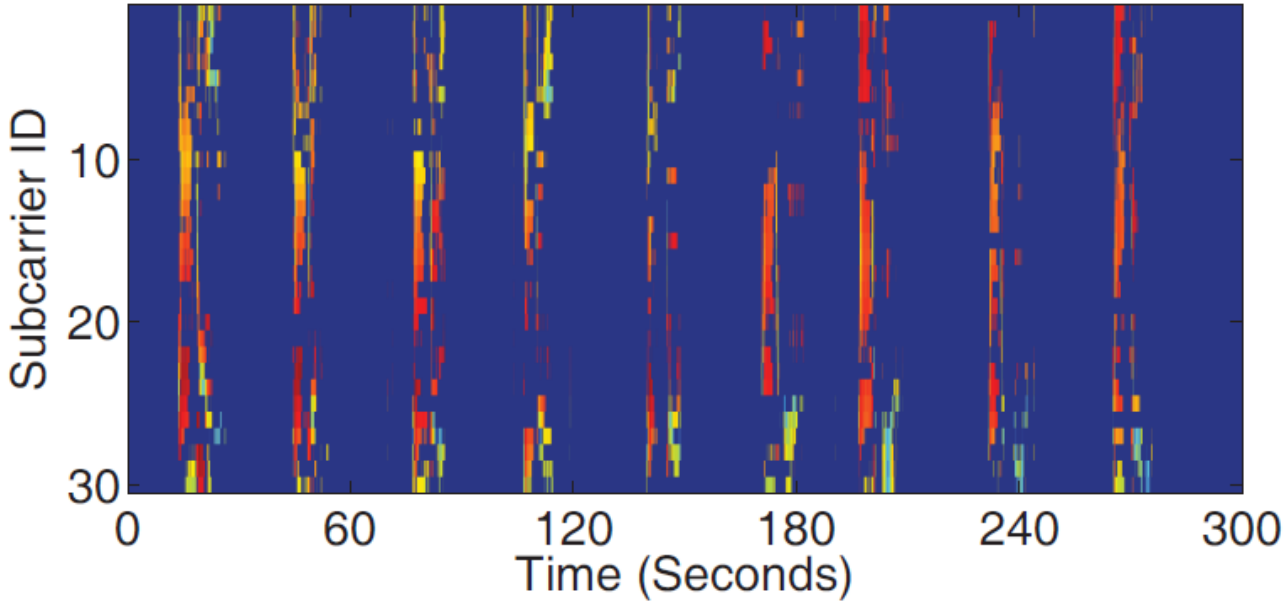
Motion Extraction

- Filter out the counterfeit foregrounds
  - Temporal correlation
  - Frequency correlation

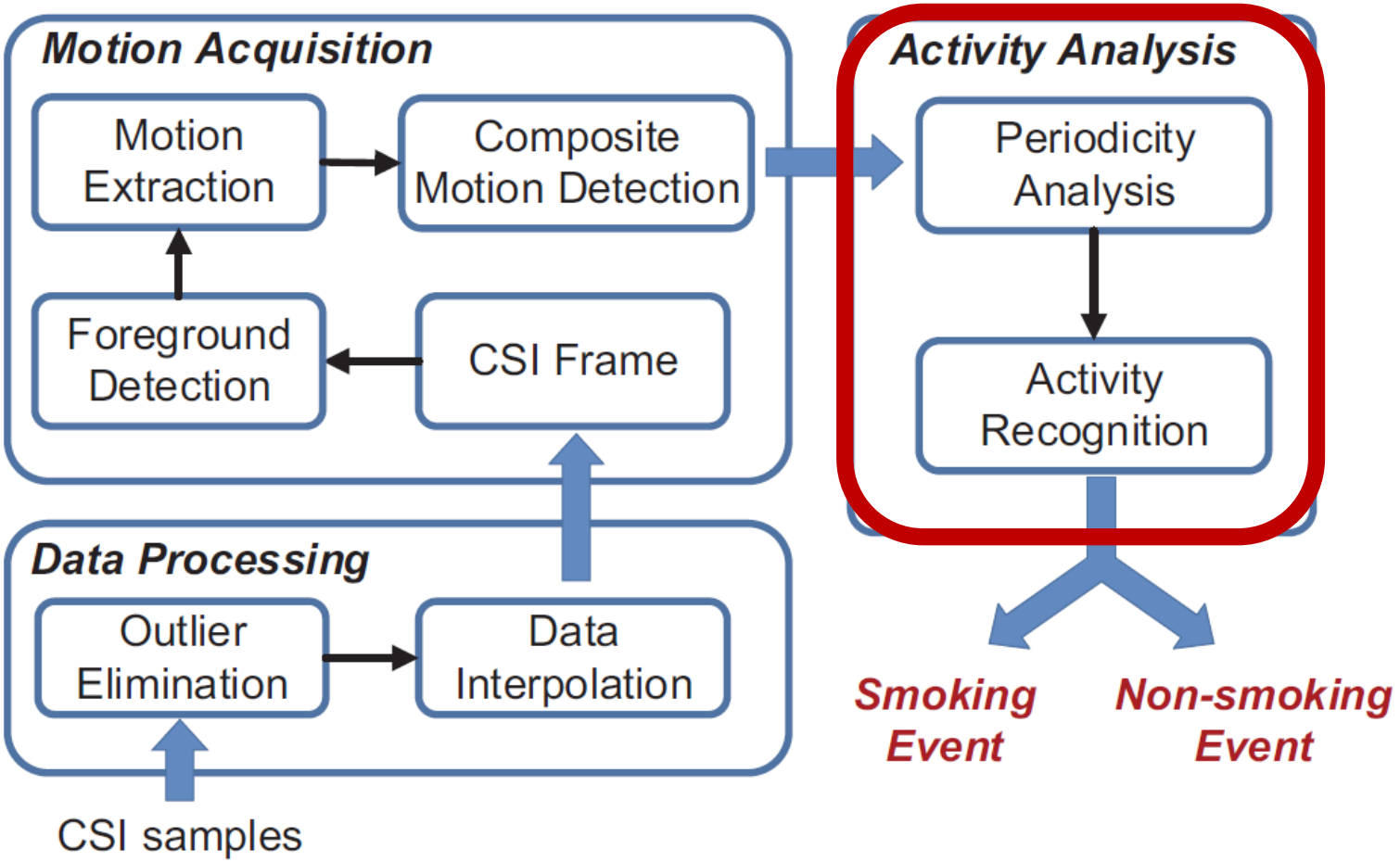


Composite Motion Detection

- Filter out the single motion

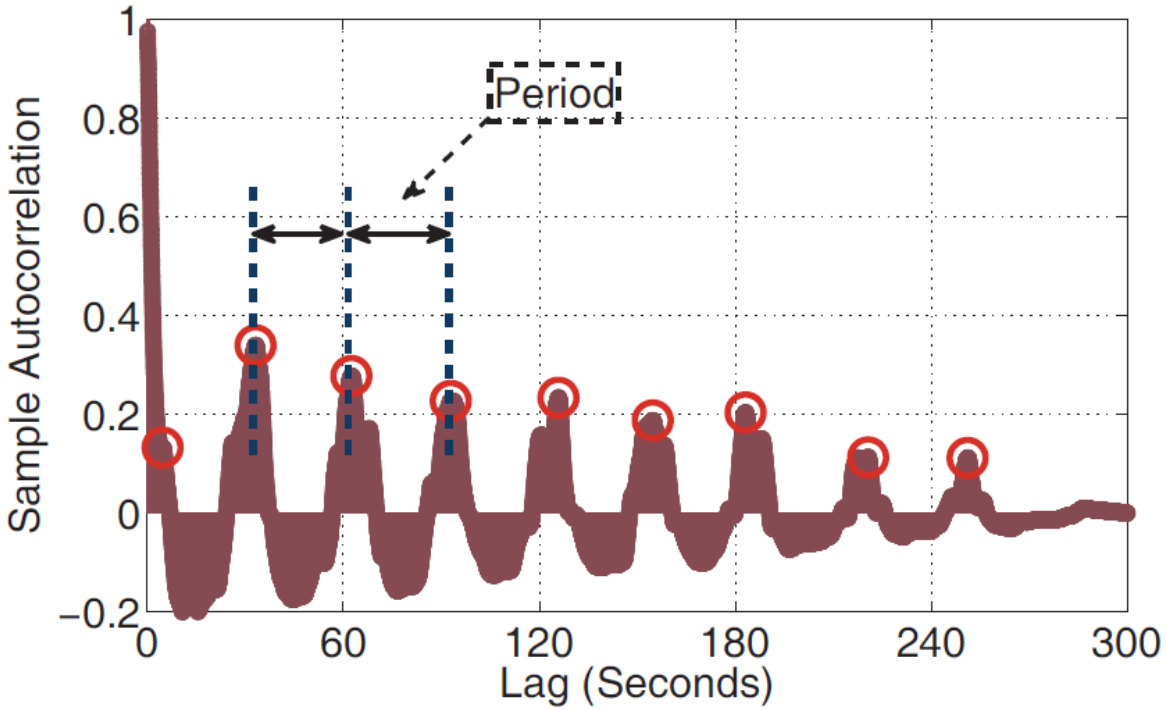


Smokey Overview



Periodicity Analysis

- Autocorrelation
  - Smoking is a rhythm activity



Outline

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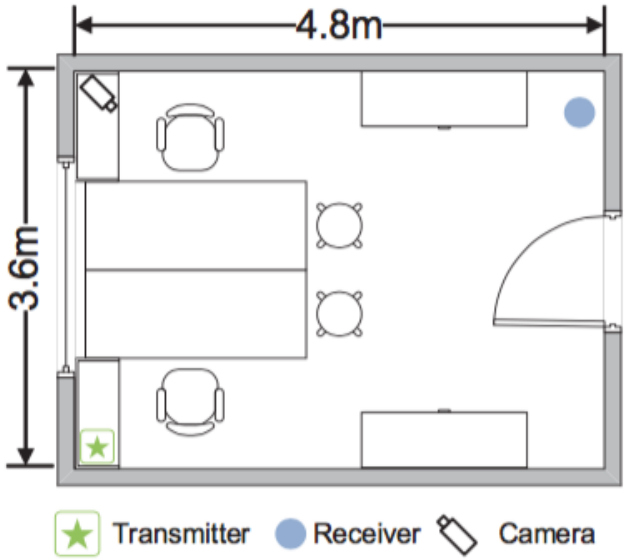
Evaluation Setting

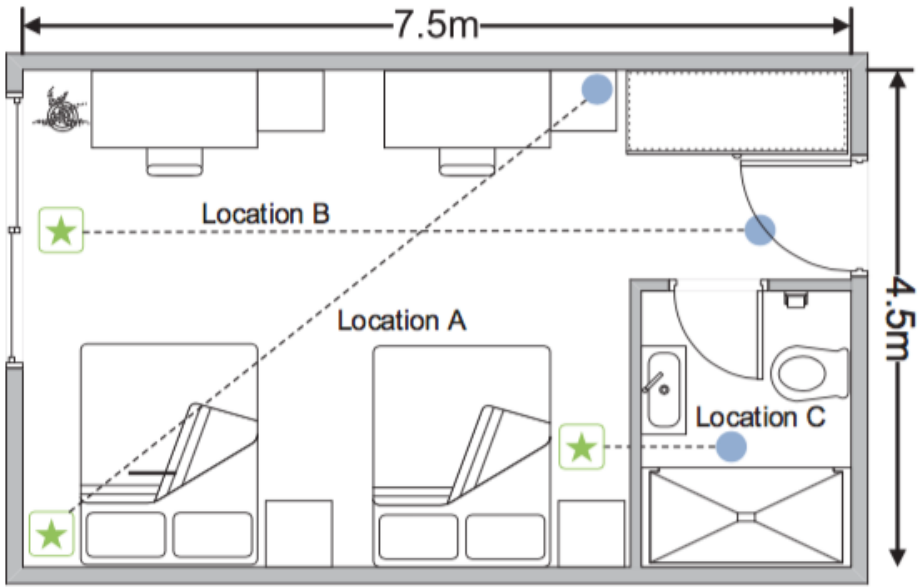
- Hardware:
  - TP-LINK TL-WR742N wireless router
  - Mini PC with Intel WiFi Link 5300 NIC with one antenna

- Software:
  - Operate in IEEE 802.11n mode on Channel 11 at 2.4GHz
  - The receiver pings the transmitter every 30ms
  - CSI measurements obtained by the Linux CSI tool

Evaluation Setting

- Environments:
  - Office room where smoking is allowed
  - Apartment





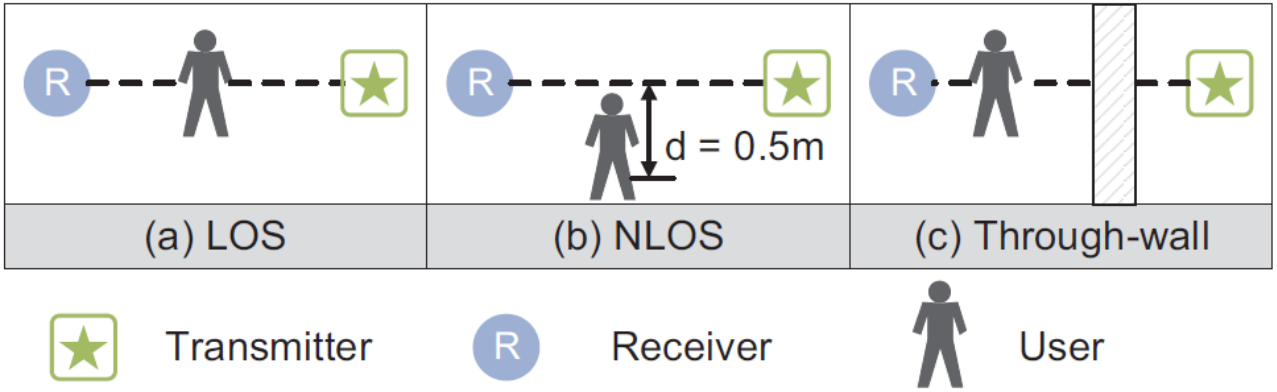
Evaluation Results

- Smokey accurately detects ***92.8%*** of the smoking activities and misjudges ***2.3%*** of the normal activities.

	Apartment with a smoker living	Apartment with a non-smoker living	Smoking-allowed rest room
Ground truth	42	0	235
TP of Smokey	41	0	216
FP of Smokey	7	4	27
Total activities Smokey detects	693	712	513

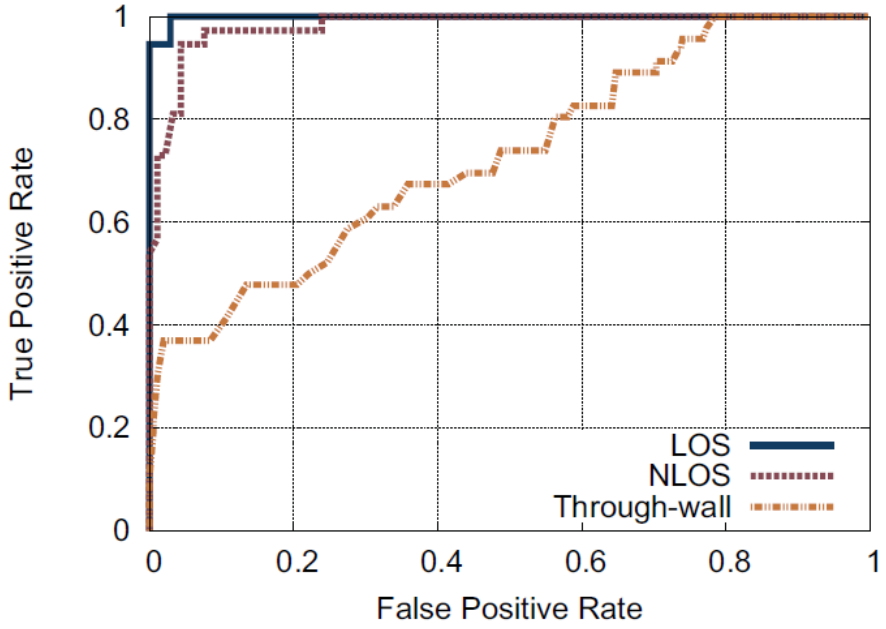
Evaluation Results

- Impact of NLOS propagation
  - Experiment scenarios:



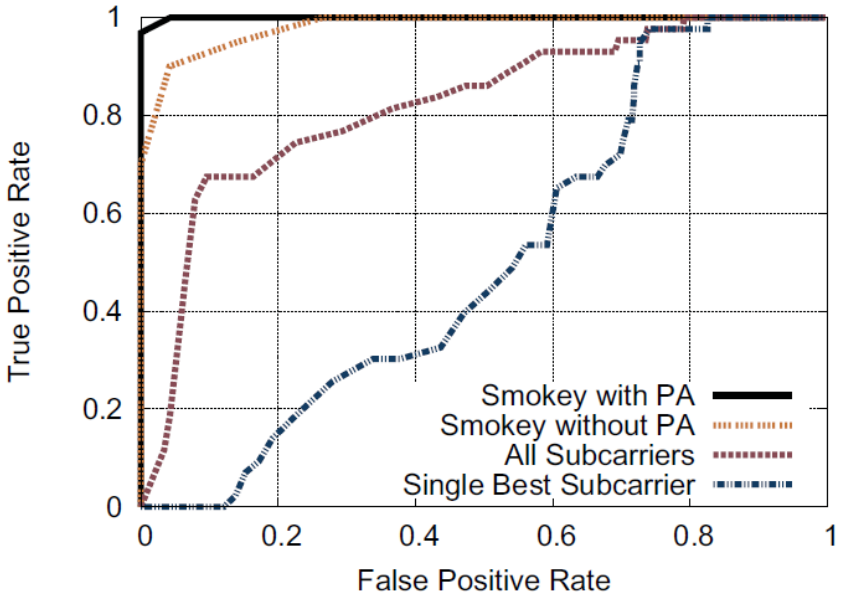
Evaluation Results

- Impact of NLOS propagation (FPR=0.01)
  - LOS: 0.946
  - NLOS: 0.567
  - Through-wall: 0.304



Evaluation Results

- Dynamic selection of subcarriers in Smokey improves accuracy
- Periodicity analysis improves accuracy



ROC curve

Conclusion

- Smokey: *Ubiquitous* Smoking Detection with Commercial *WiFi Infrastructures*
  - *Ubiquitous:* LOS, NLOS and through-wall scenarios
  - *No-intrusive:* without requirement of wearing devices

- *Accurate* with a low false alarm ratio
  - Accuracy: ***92.8%*** in real deployments

    66.7% at 3m (target-to-device distance)
  - False Positive Rate: ***2.3%*** in real deployments

Smokey:

Ubiquitous Smoking Detection with Commercial WiFi Infrastructures

Thank you!

Q&A