PoDC: WiFi spying

Seeing, keylogging and hearing through walls

papers: See Through Walls with WiFi!
Tracking Keystrokes Using Wireless Signals
We Can Hear You with Wi-Fi!

François Wirz | 23-05-2017

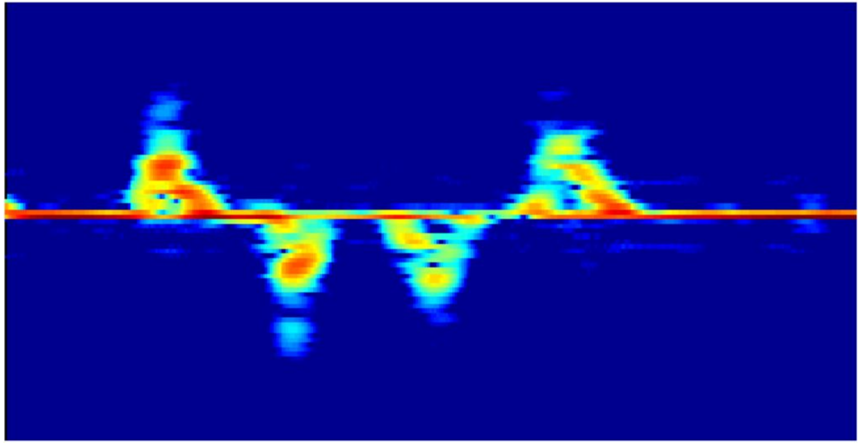
Motivation: Sensing with Wireless Signals

- Coarse granularity
  - tracking position in room

image sources: all images are adapted from the respective paper and poster, except where stated otherwise

Motivation: Sensing with Wireless Signals

- Coarse granularity
  - tracking position in room
- Fine granularity
  - tracking gesture through walls
  - binary H2M communication through walls

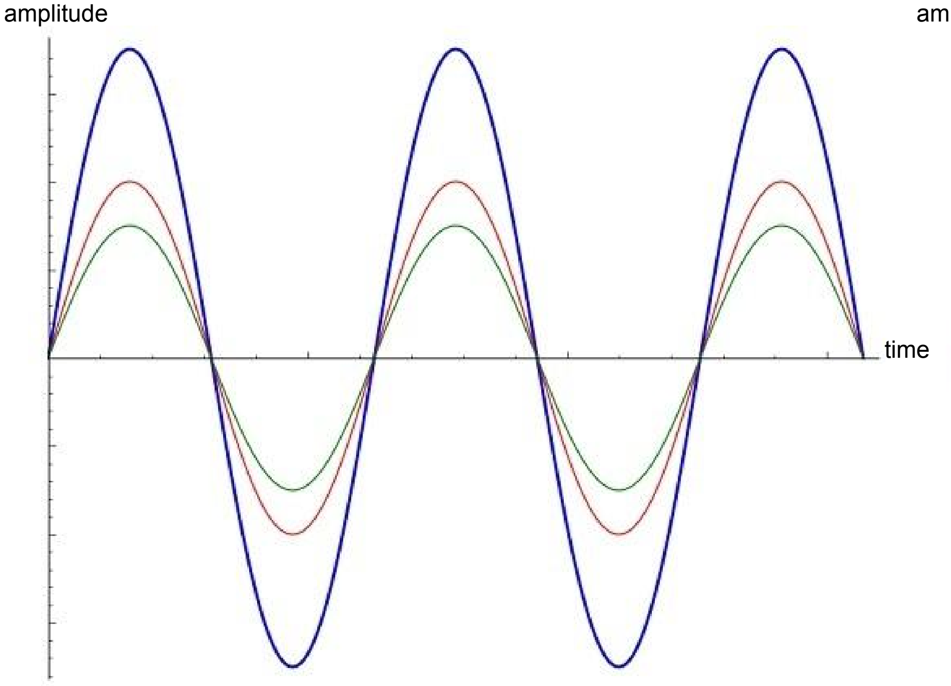


Motivation: Sensing with Wireless Signals

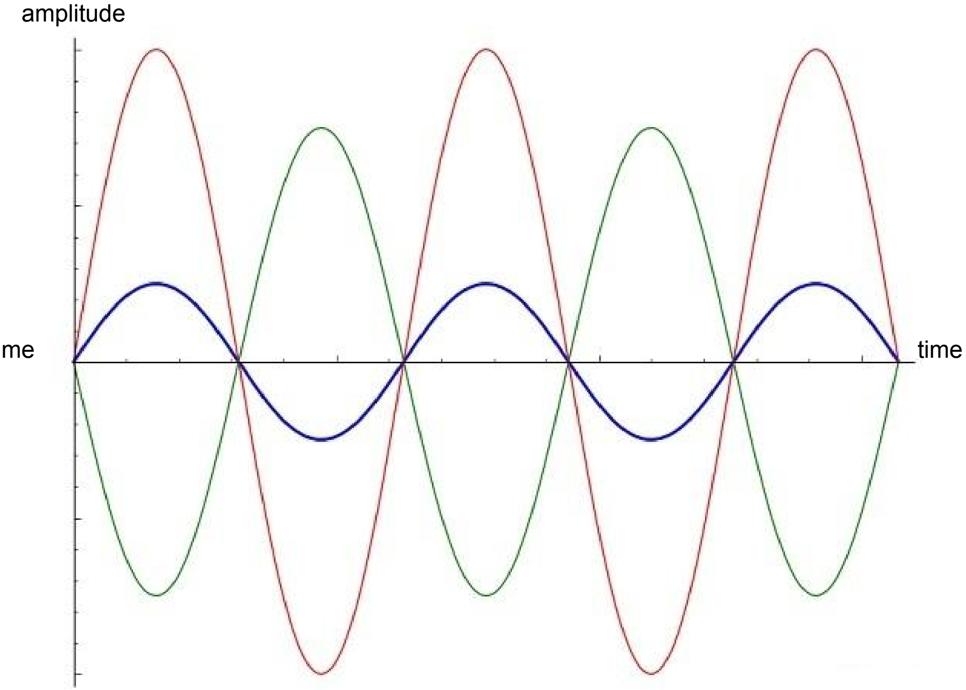
- Coarse granularity
  - tracking position in room
- Fine granularity
  - tracking gesture through walls
  - binary communication through walls
- Very fine granularity
  - tracking keystrokes
  - tracking lip movements

WiHear

Technical Primer



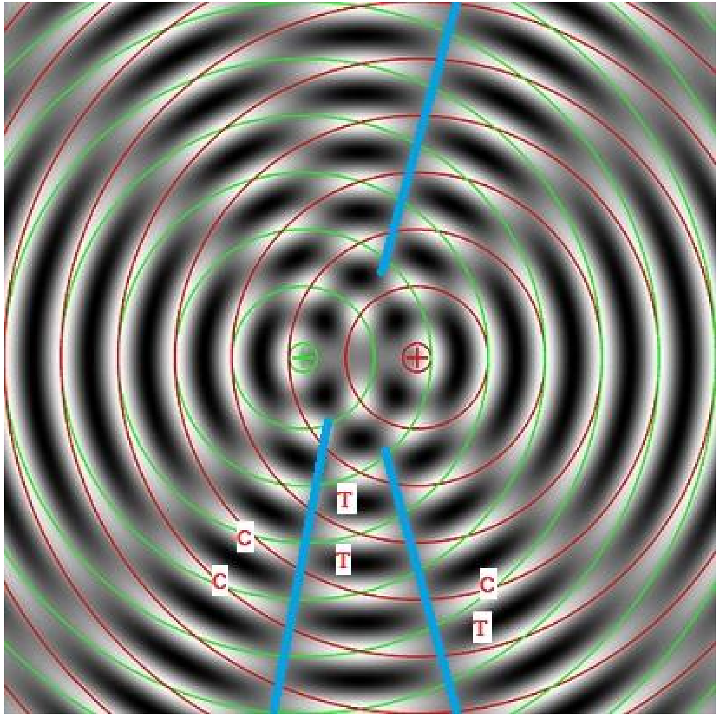
Constructive interference



Destructive interference

image sources: all images are adapted from the respective paper, except where stated otherwise
image src: http://pediaa.com/difference-between-constructive-and-destructive-interference/

Technical Primer: Interference Nulling



Interference nulling with two sources

image src: http://pediaa.com/difference-between-constructive-and-destructive-interference/

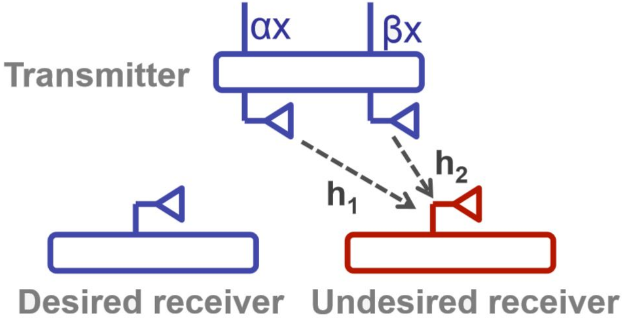
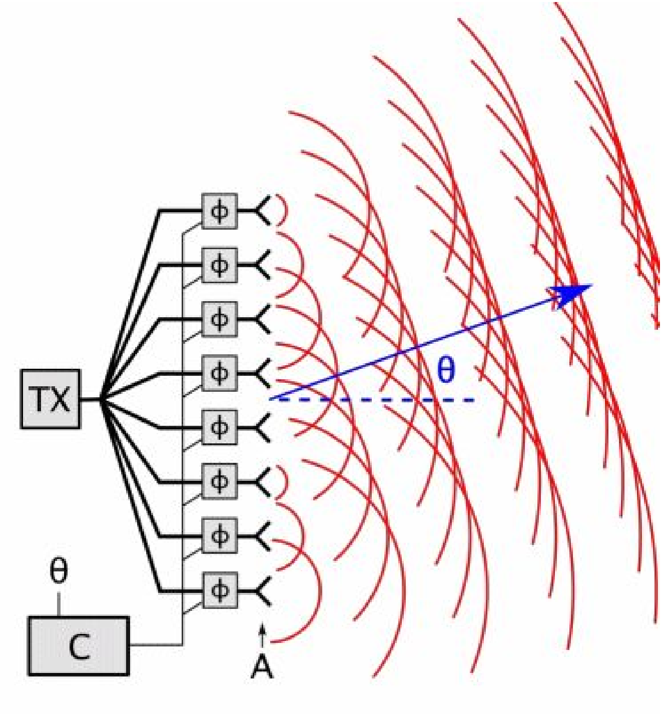


image src: https://people.csail.mit.edu/fadel/papers/wivi-poster.pdf

Technical Primer: Beamforming

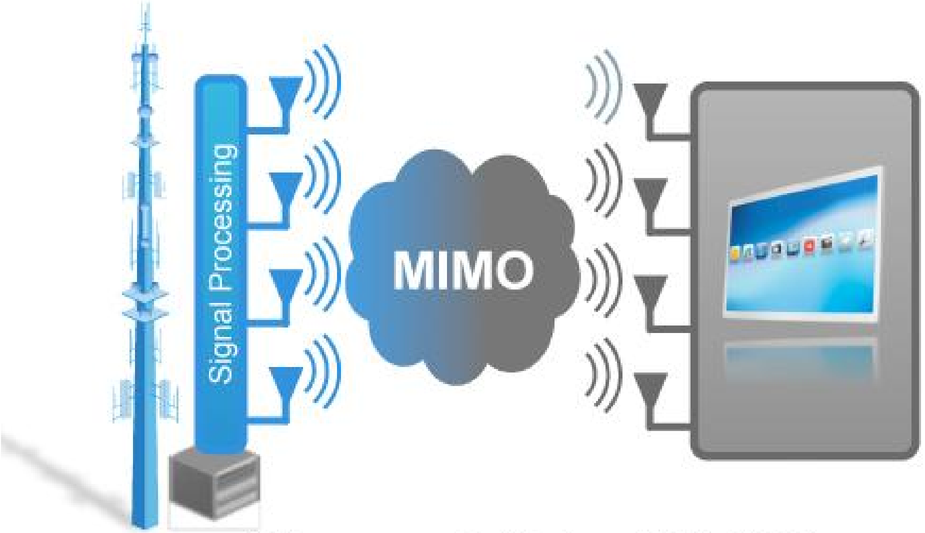


Beamforming through constructive interference

image src: https://en.wikipedia.org/wiki/Phased_array

Technical Primer: Multiple-Input Multiple-Output

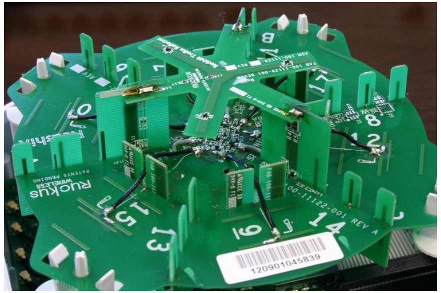
- MIMO is used in:
  - WiFi 802.11n standard
  - LTE standard
  - Power-line communication



MIMO leverages presence of multiple antennas at the BTS and the device

image src: http://www.fastweb.it/var/storage_feeds/CMS/articoli/f77/f77aa70d79b114d8f2c9ea49eb5719ba/mimio-graphic_0.jpg

Technical Primer: Multiple-Input Multiple-Output



- MIMO
  - allows to focus the signal emitted (beamforming)
  - allows signal to cancel out in a plane (interference nulling)
  - can use multiple senders or multiple receivers or both
  - more uniform signal that can be amplified (no receiver saturation)

image src: http://www.tomsitpro.com/articles/wi-fi-performance-problems,2-238.html

Technical Primer: Flash effect

- Flash effect
  - most of the signal gets reflected by the first obstacle
  - cancels out all weaker signal from behind
    - signal from bodies is drowned in noise
    - cannot amplify signal because receiver would saturate

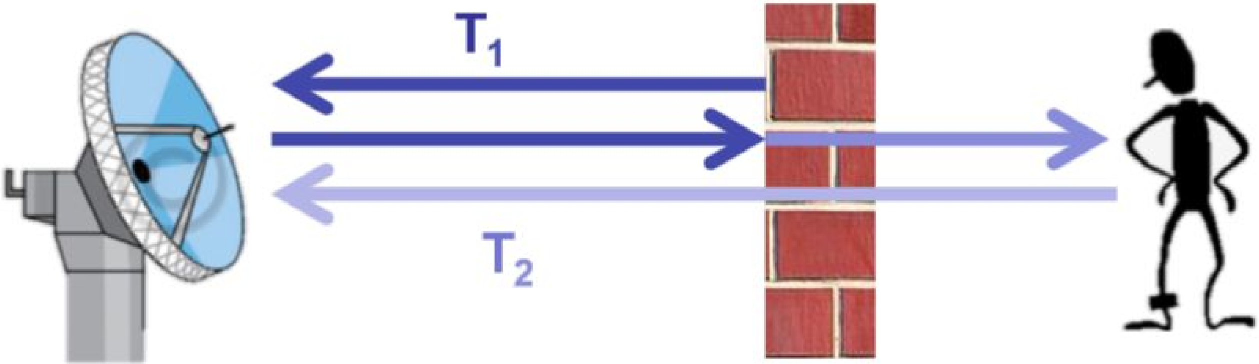


image src: https://people.csail.mit.edu/fadel/papers/wivi-poster.pdf

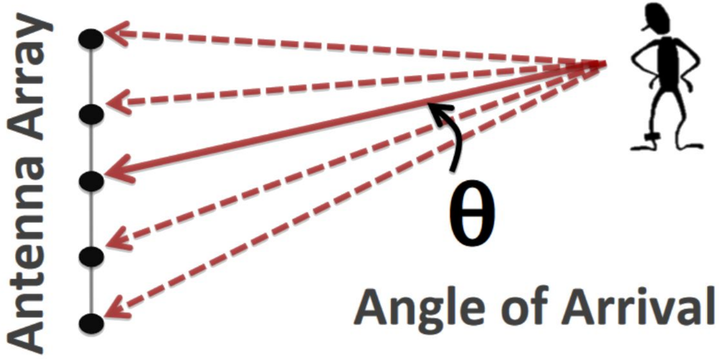
Technical Primer: Flash effect

- Other approaches use larger devices:
  - 2 GHz of bandwidth (UWB)
  - strong power source
  - large antenna array (2.5 m)

image src: https://www.researchgate.net/.../publication/292148851....pdf, bitly: http://bit.ly/2qnnwvD

Technical Primer: Inverse Synthetic Aperture

- Synthetic Aperture Sensing



- Inverse Synthetic Aperture Sensing
    - use temporal signal to extract spatial information
    - obtain angle of motion

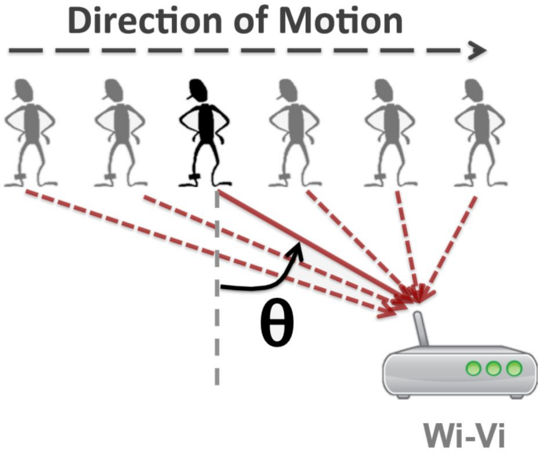
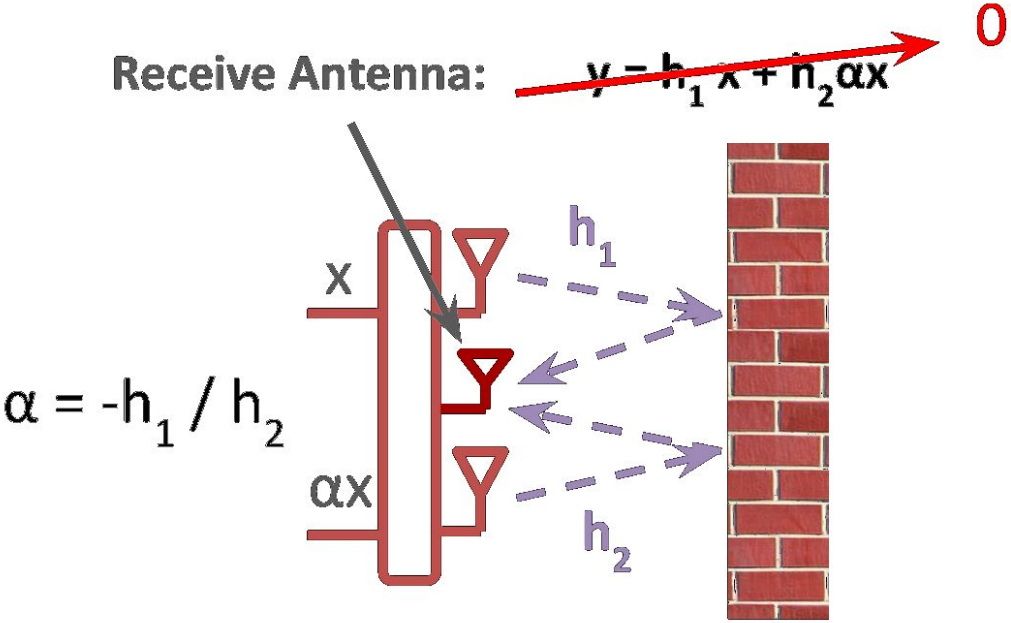


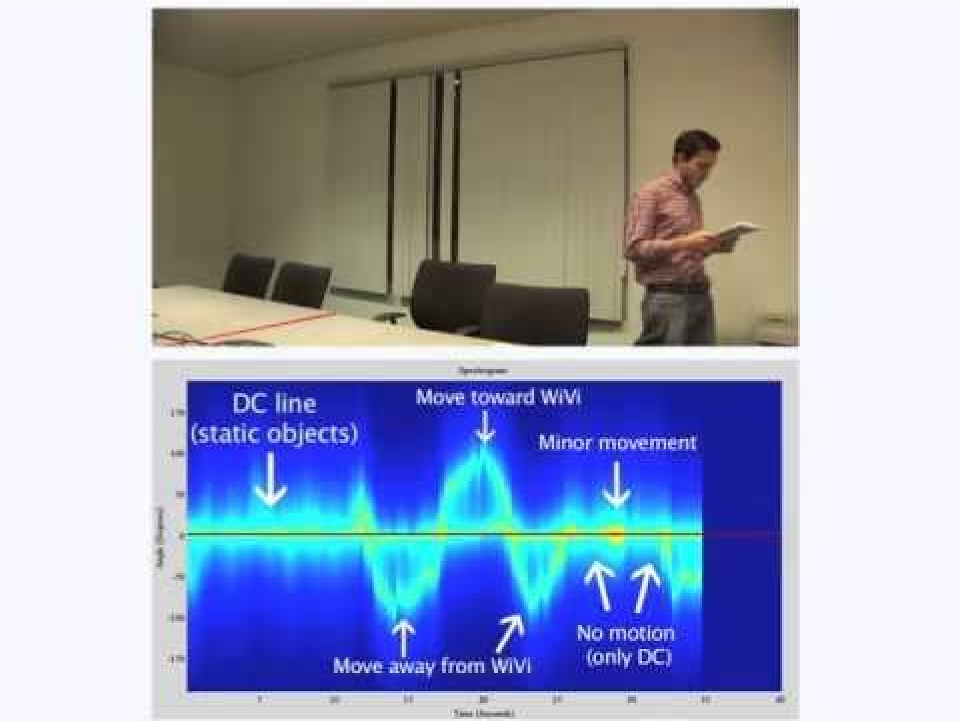
image src: https://people.csail.mit.edu/fadel/papers/wivi-poster.pdf

See Through Wall: WiVi

- Applying these techniques with WiVi:

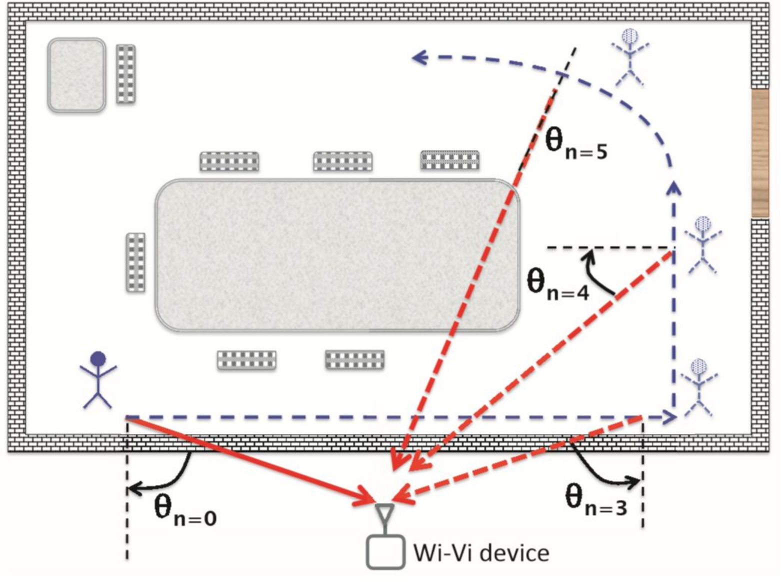


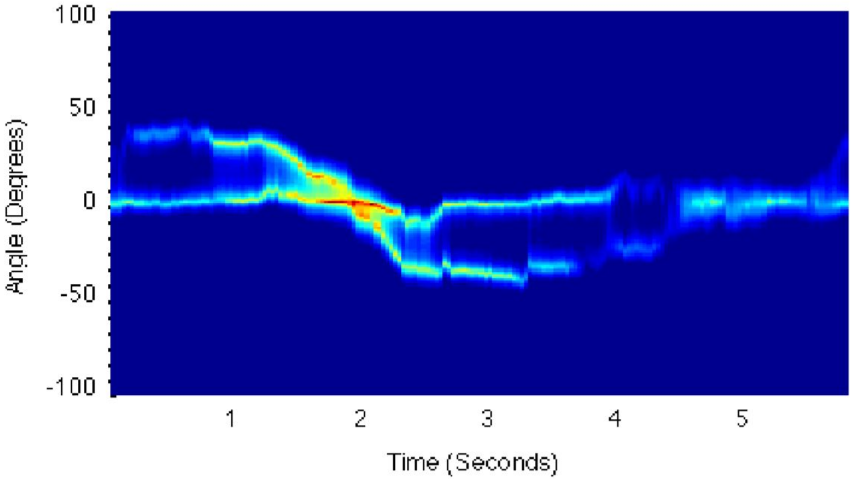
See Through Wall: WiVi



video src: https://youtu.be/uJkQzLjYBFI?t=6

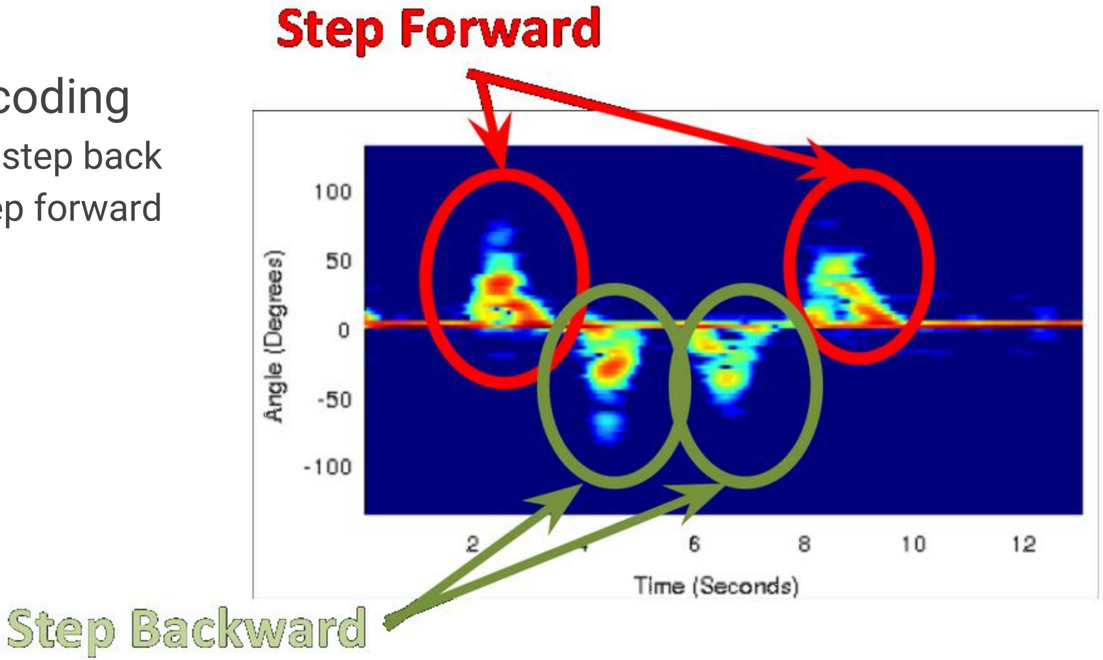
WiVi: angle and motion





WiVi: Gesture encoding

- Standard Return-to-zero encoding
  - Encode 0 bit as step forward, step back
  - Encode 1 bit as step back, step forward



Step Forward

Step Backward

See Through Wall: WiVi

- Property used
  - MIMO interference nulling at wall, first obstacle
  - Inverse Synthetic Aperture for emulated antenna array

image src: https://people.csail.mit.edu/fadel/papers/wivi-poster.pdf

See Through Wall: WiVi

- Property used
  - MIMO interference nulling at wall, first obstacle
  - Inverse Synthetic Aperture for emulated antenna array

- Objective achieved
  - Overcome flash effect
  - Have a portable solution

image src: https://people.csail.mit.edu/fadel/papers/wivi-poster.pdf

Tracking Keystrokes using Wireless Signals

WiKeylog

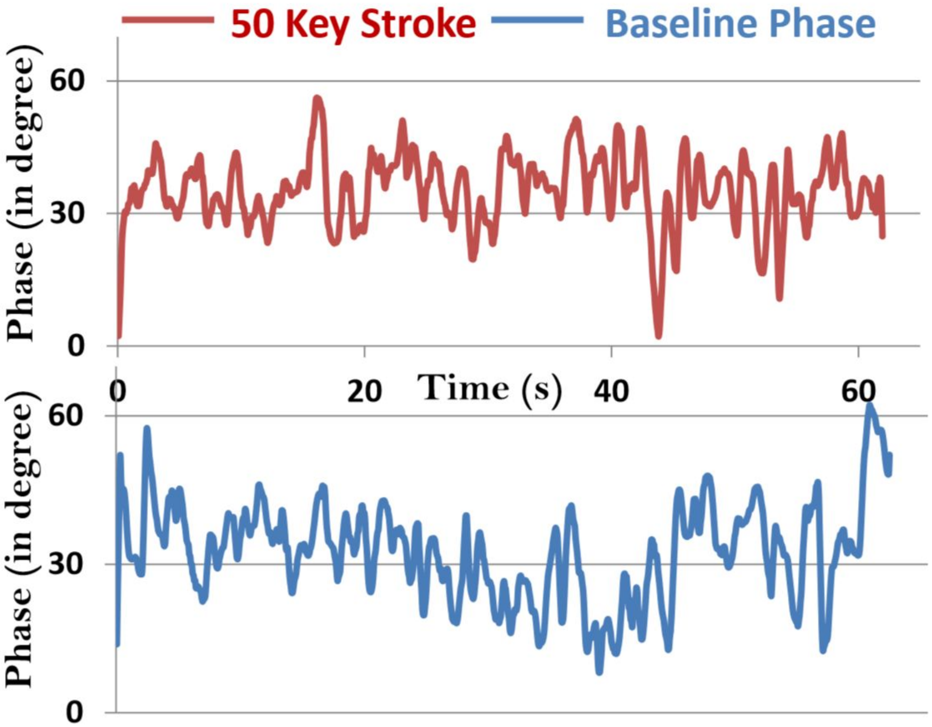
image src: https://c1.staticflickr.com/6/5053/5498834683_f579445346_b.jpg

Tracking Keystrokes using Wireless Signals

WiKeylog

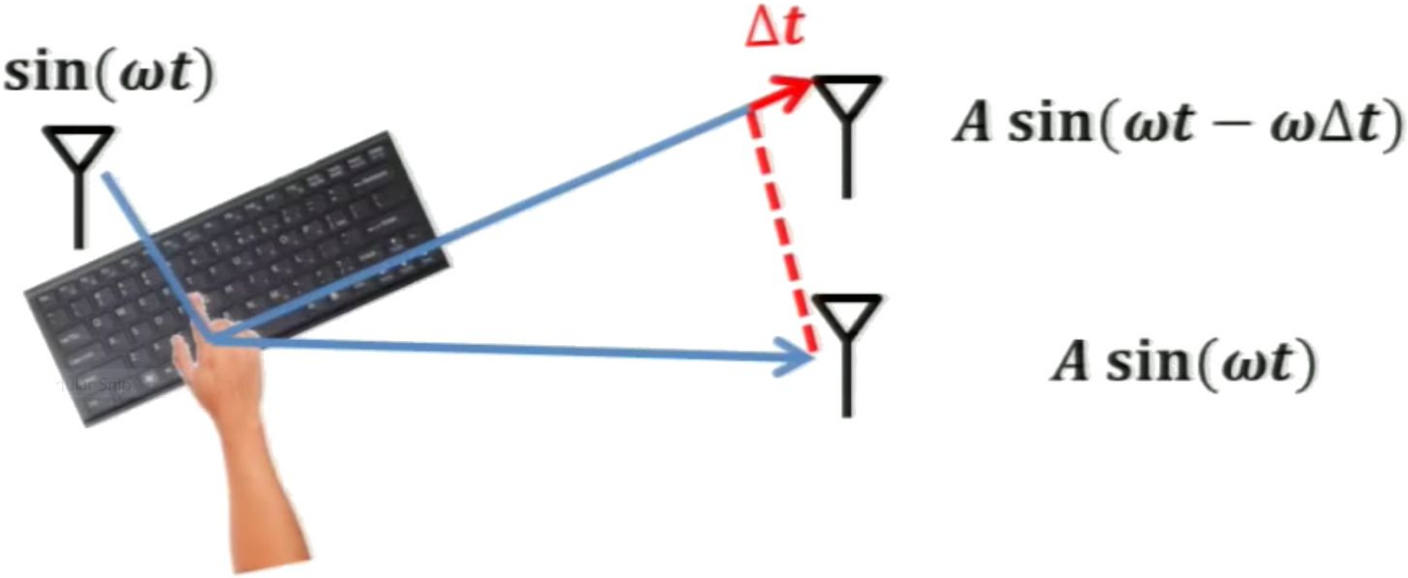
Tracking Keystrokes using Wireless Signals

WiKeylog



From phase to delay

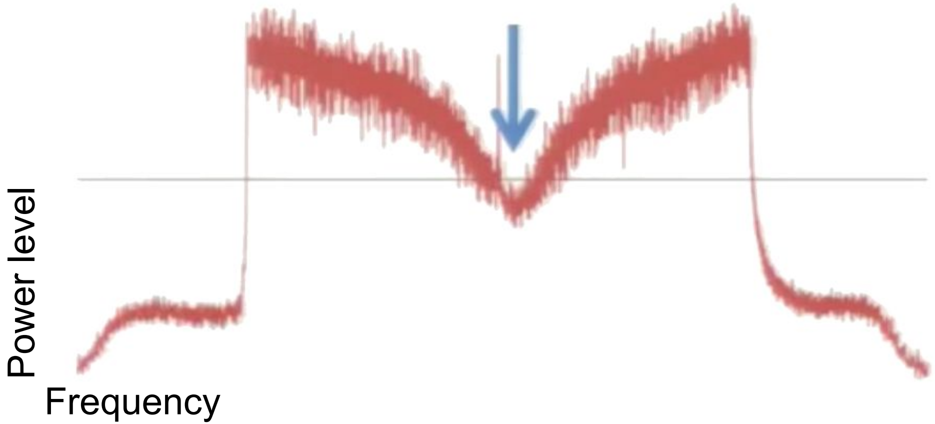
WiKeylog



- Get delay introduced by keystroke by converting phase shift into delay
- Capture delay effect by using cancellation at receiver

From delay to keystroke

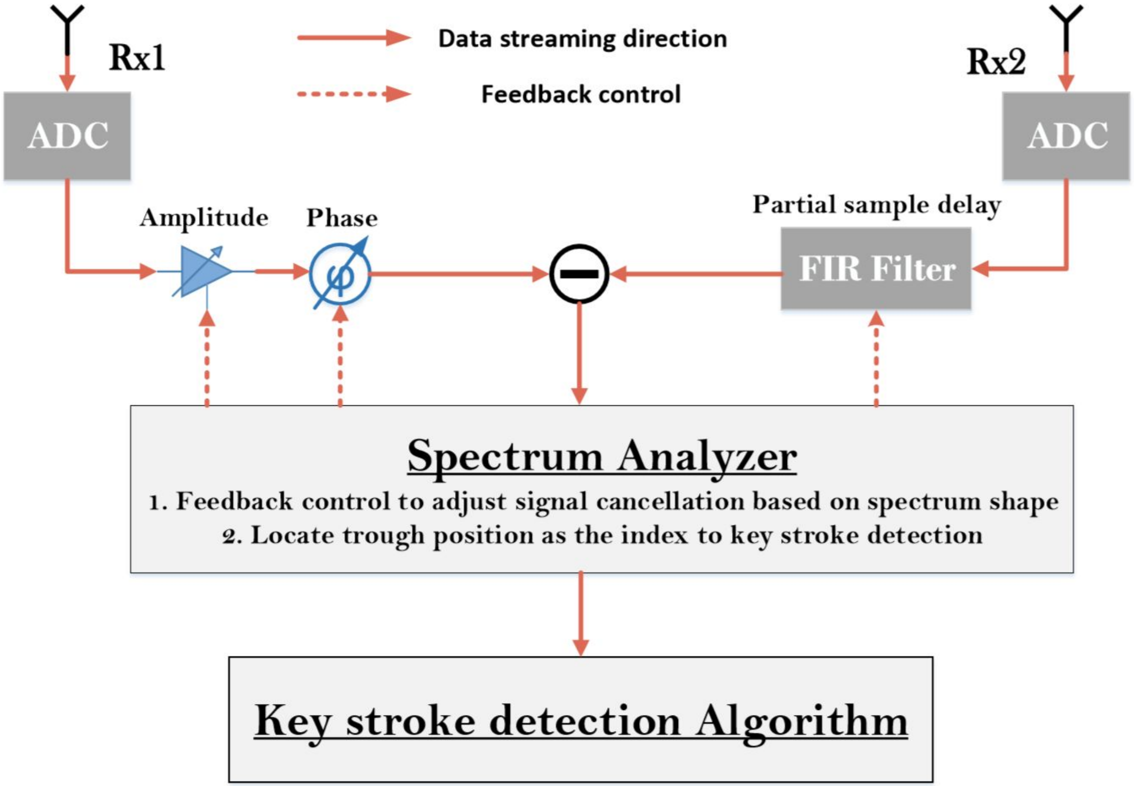
Trough location ↔ delay ↔ keystroke



- Measure trough location to infer change in channel
- Introduce artificial delay to make trough more significant

The keystroke tracking system

WiKeylog



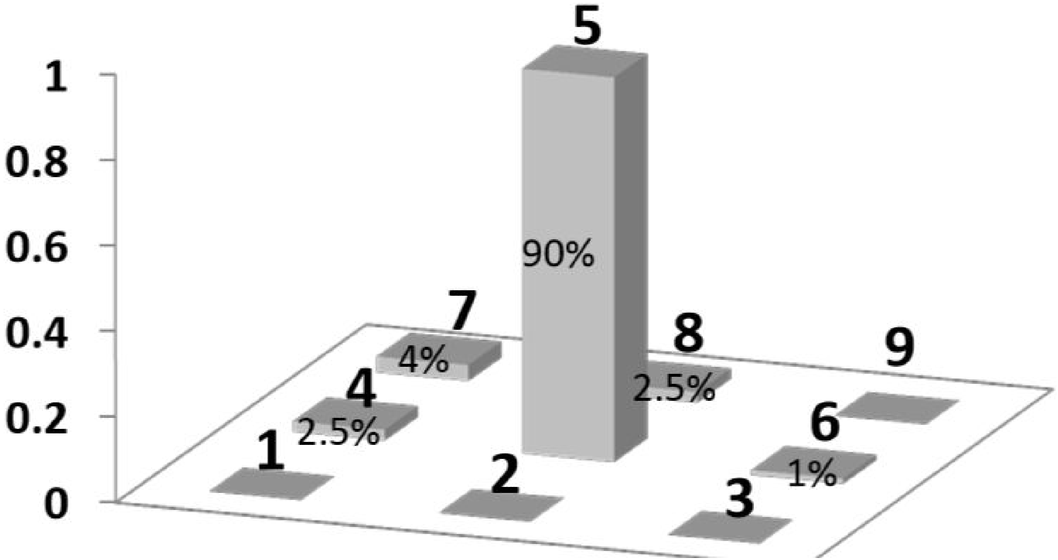
Spectrum Analyzer

1. Feedback control to adjust signal cancellation based on spectrum shape
2. Locate trough position as the index to key stroke detection

Key stroke detection Algorithm

Tracking Keystrokes: Performance

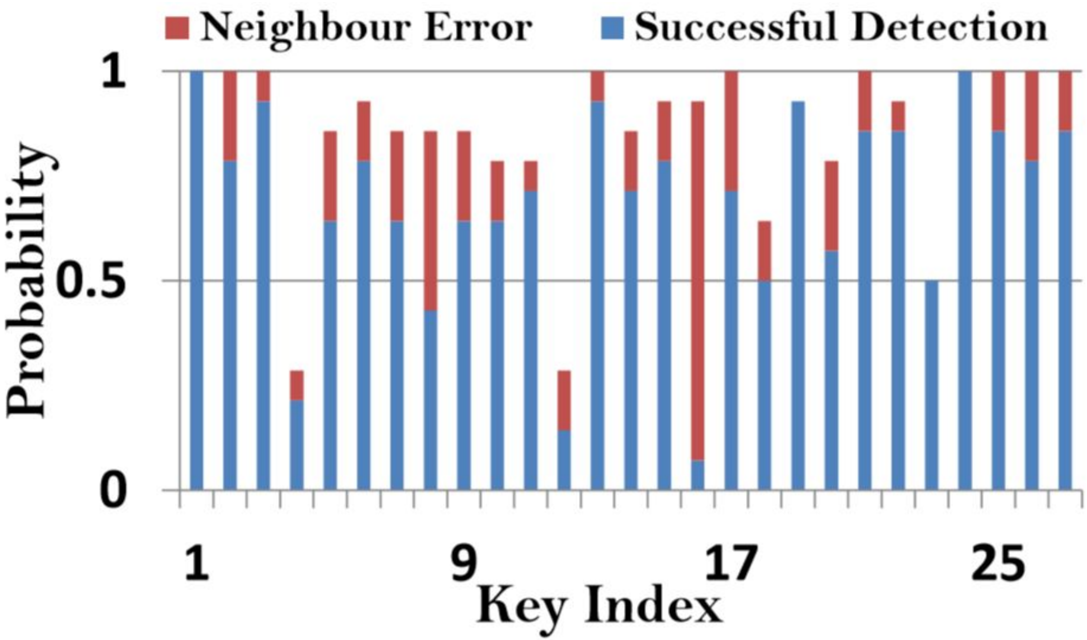
WiKeylog



Repeated key 5 on keypad: accuracy

Tracking Keystrokes: Performance

WiKeylog



Full key range, partially trained

Tracking Keystrokes using Wireless Signals

WiKeylog

- Property used
  - Shift in frequency of cancellation through caused by phase shift of channel
  - Finger modeled as source of multipath signal

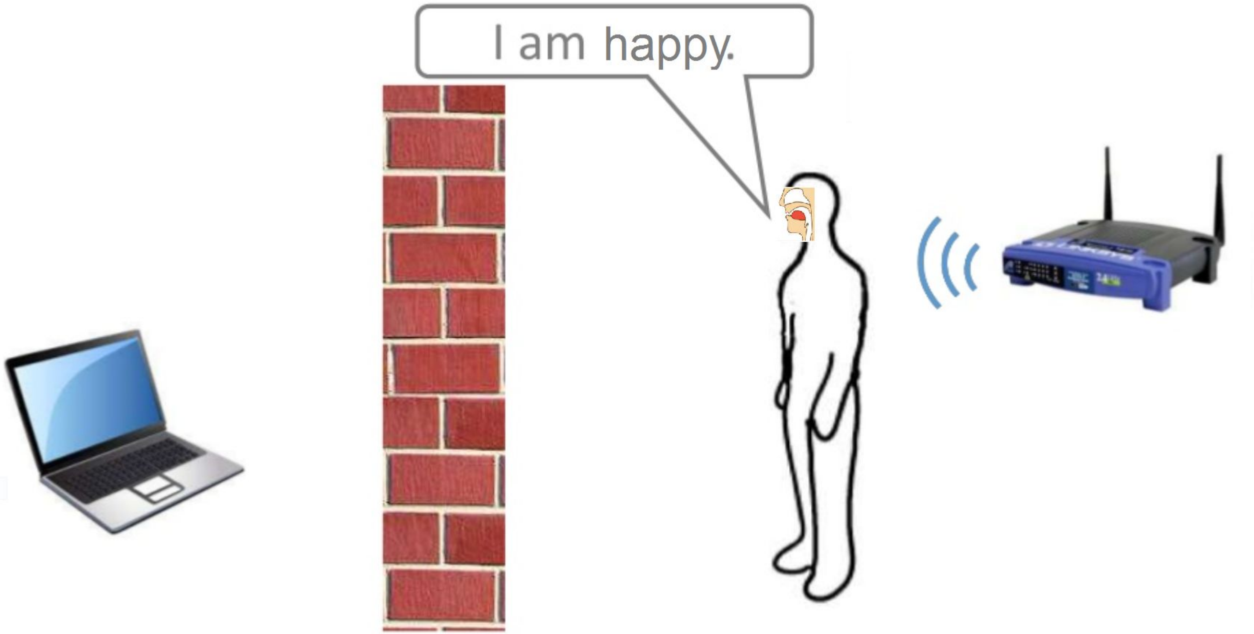
Tracking Keystrokes using Wireless Signals

WiKeylog

- Property used
  - Shift in frequency of cancellation through caused by phase shift of channel
  - Finger modeled as source of multipath signal

- Objective achieved
  - first passive, single receiver keystrokes tracking system
  - agnostic of physical layer and MAC protocols

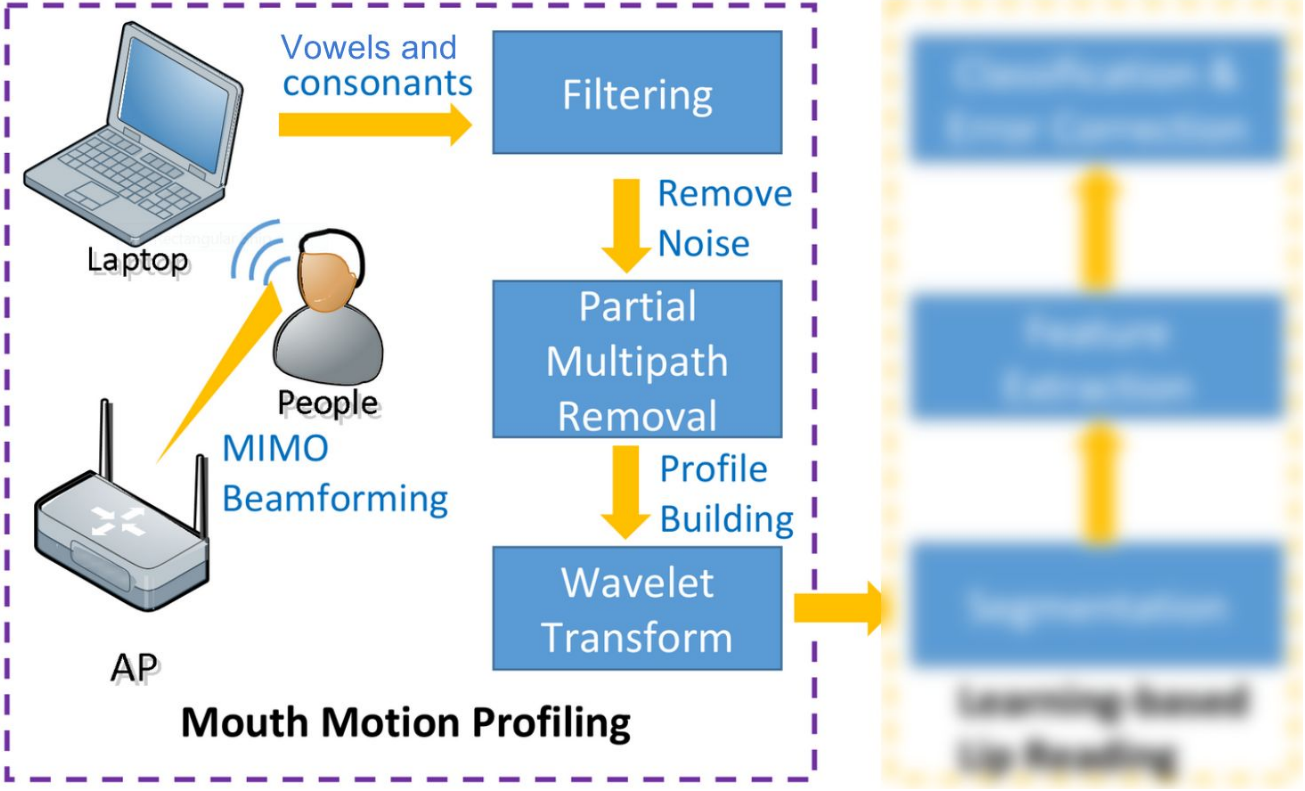
We Can Hear You with WiFi: WiHear



Device free, non-invasive remote ‘hearing’

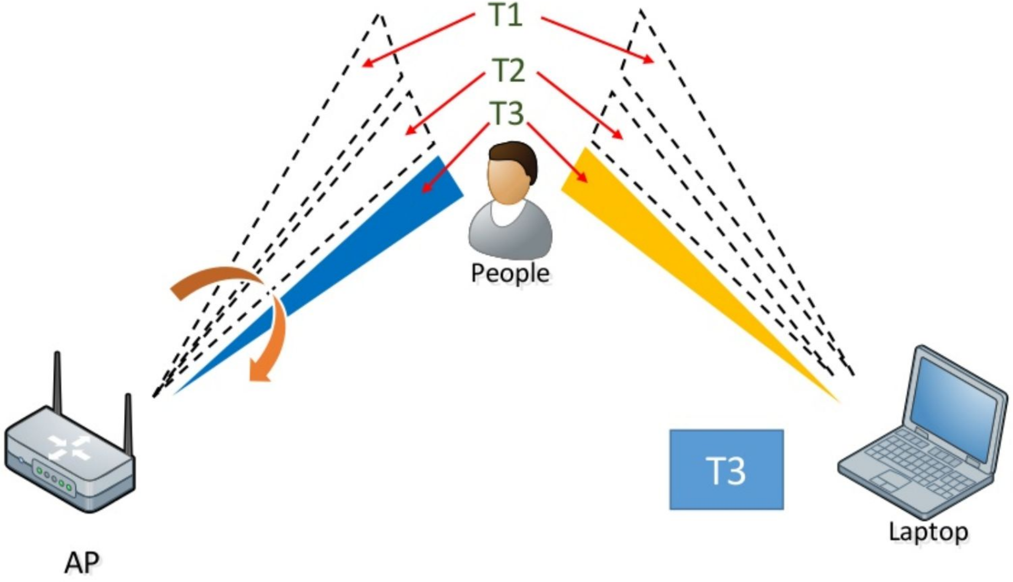
WiHear

We Can Hear You with WiFi



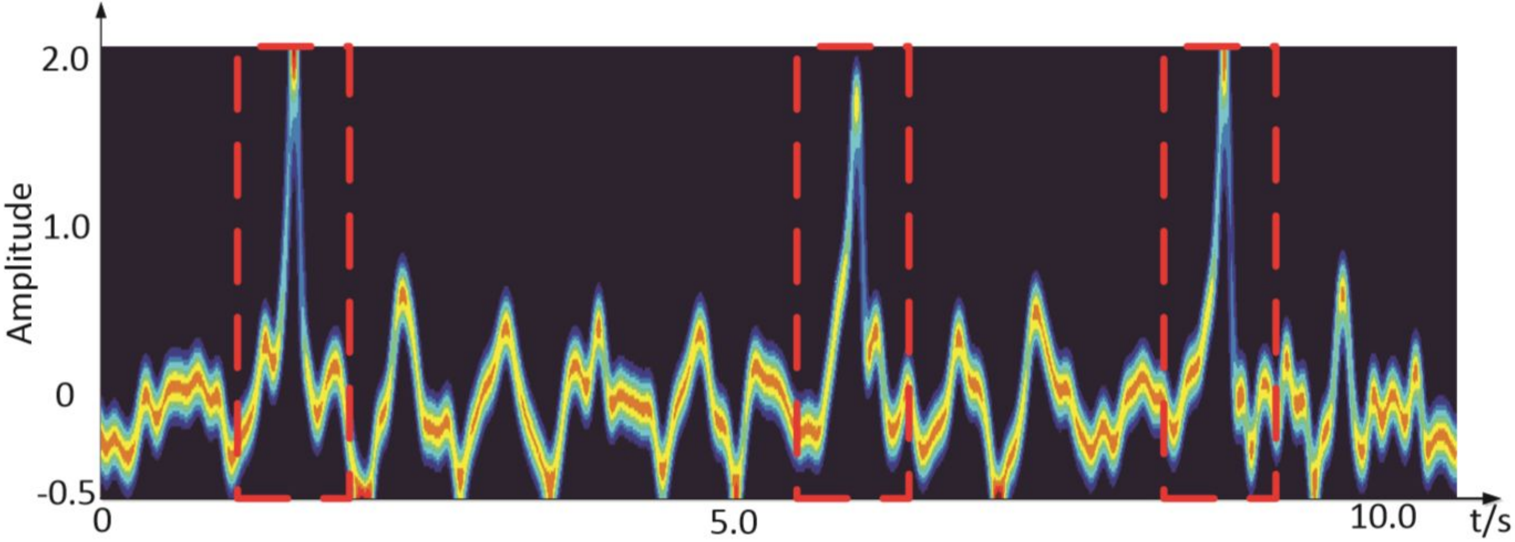
Mouth motion profiling

- Locating mouth



Mouth motion profiling

- Filtering out-band interferences
  - cancel high frequency interferences
  - remove both static interferences and winking using band-pass filter (red boxes)



Mouth motion profiling

- Partial multipath removal
  - Convert Channel State Information to time domain via IFFT

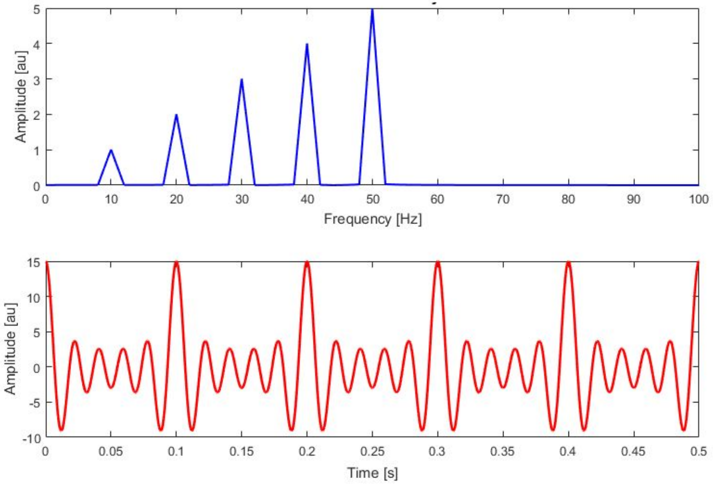


image src: https://upload.wikimedia.org/wikipedia/commons/6/64/FFT_of_Cosine_Summation_Function.png

Mouth motion profiling

- Partial multipath removal
    - Convert Channel State Information to time domain via IFFT
    - Remove multipath >500 ns

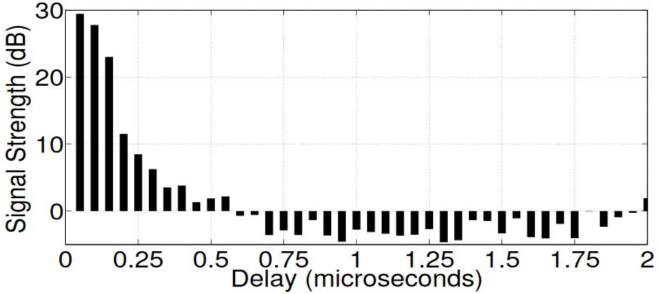
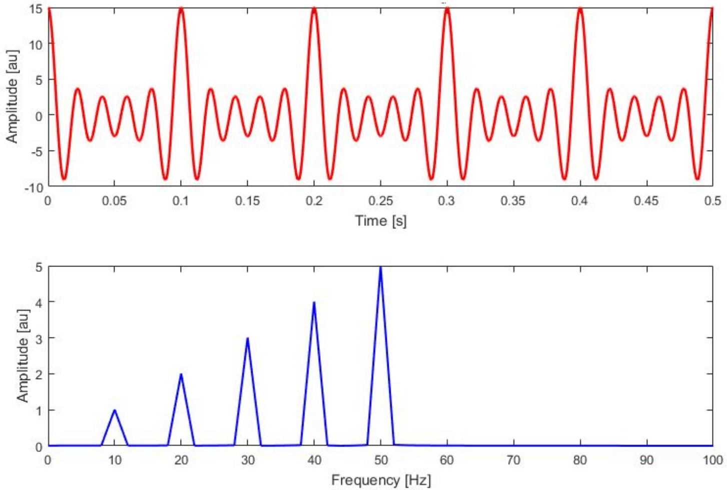


image src: https://dl.acm.org/citation.cfm?doid=2462456.2464463

Mouth motion profiling

- Partial multipath removal
  - Convert Channel State Information to time domain via IFFT
  - Remove multipath >500 ns
  - Convert CSI back to frequency domain via FFT



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Mouth motion profiling

- Partial multipath removal
  - Convert Channel State Information to time domain via IFFT
  - Remove multipath >500 ns
  - Convert CSI back to frequency domain via FFT
- Rational
  - mouth motion is non-rigid compared to other body movements
  - multipath reflections with similar delays do all contain information about the mouth motion

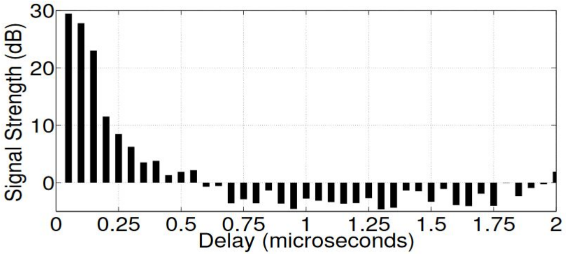
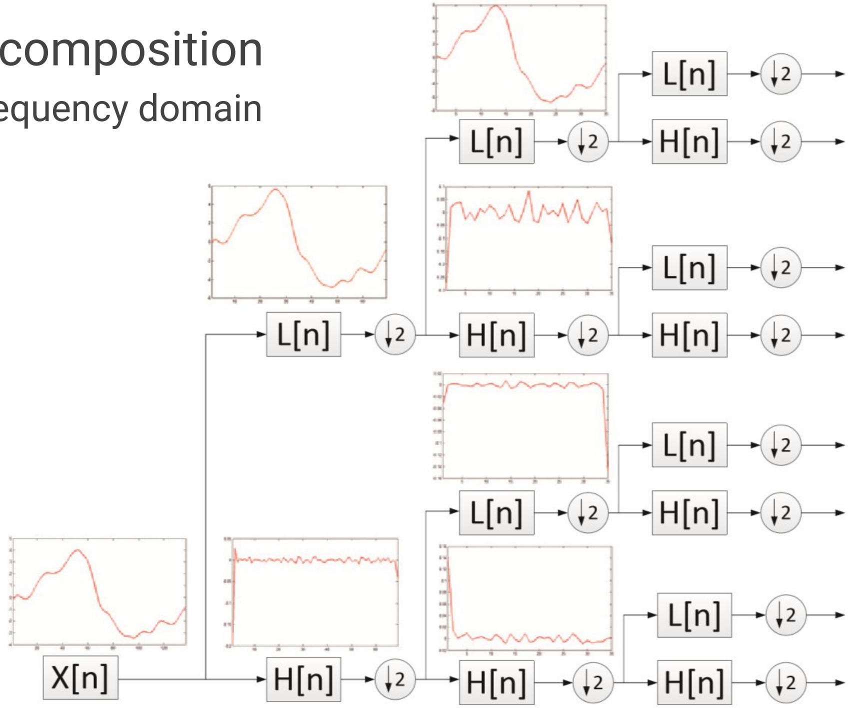
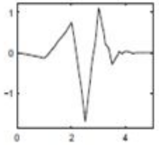


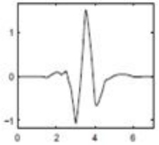
image src: https://dl.acm.org/citation.cfm?doid=2462456.2464463

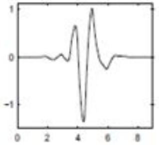
Mouth motion profiling

- Apply discrete wavelet packet decomposition
  - easier signal analysis on time and frequency domain
  - allows multi-scale analysis

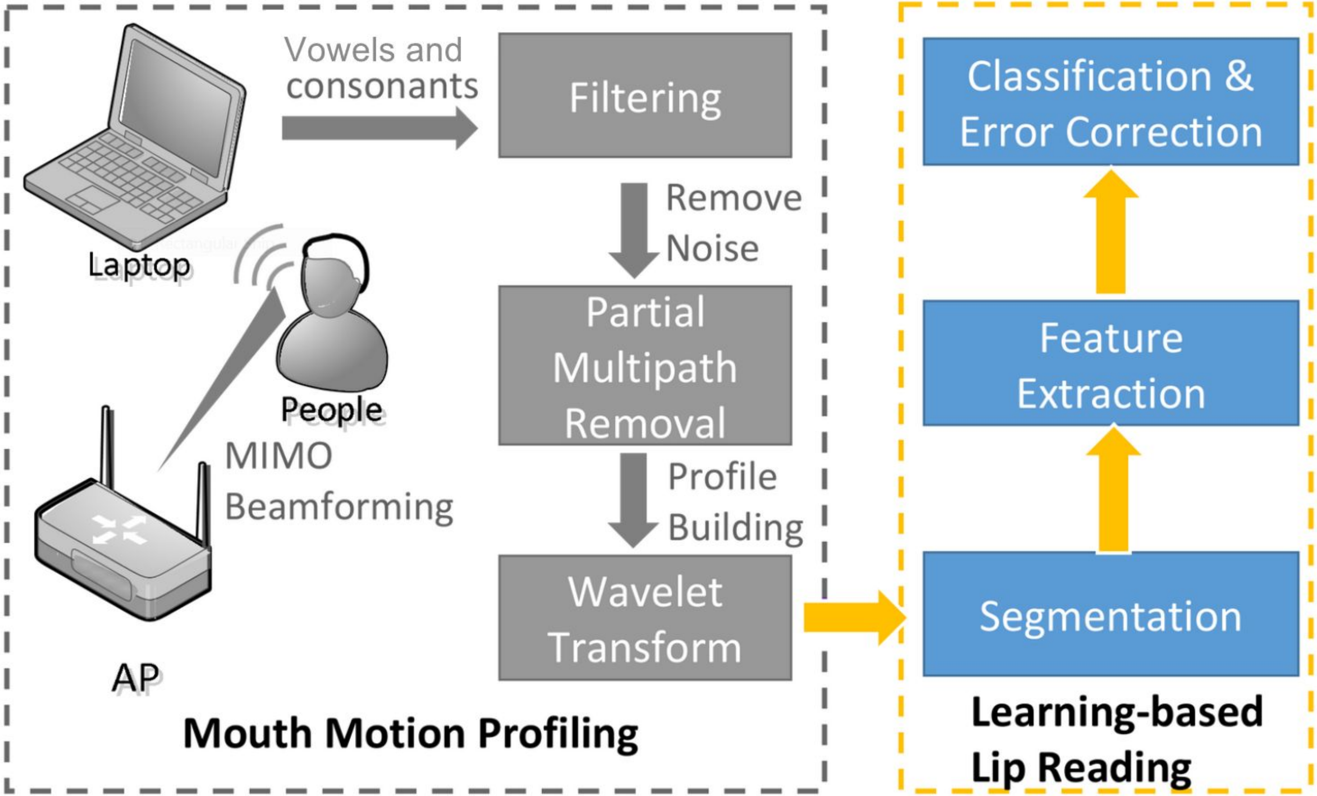



sym3


sym4

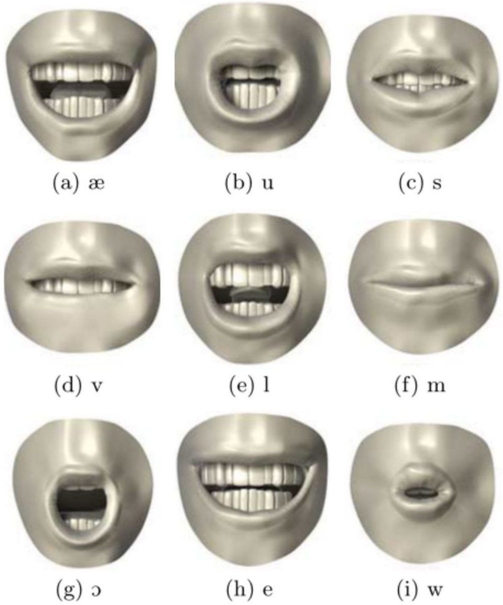

sym5

Learning based lip reading



Learning based lip reading

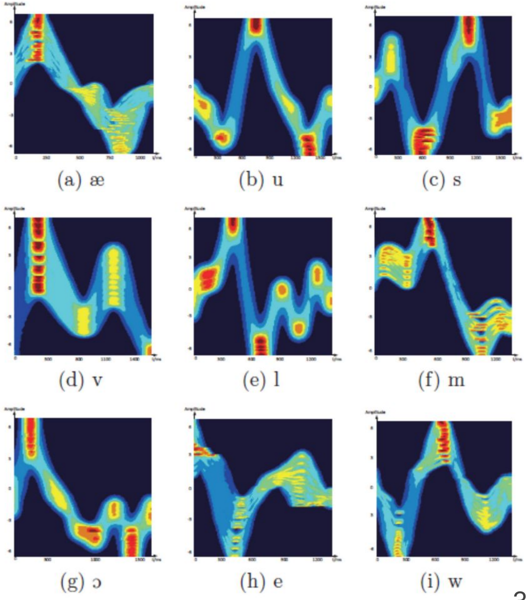
- Word segmentation
- Inner-word segmentation
- Feature extraction
- Classification



(a) æ (b) u (c) s

(d) v (e) l (f) m

(g) ɔ (h) e (i) w



(a) æ (b) u (c) s

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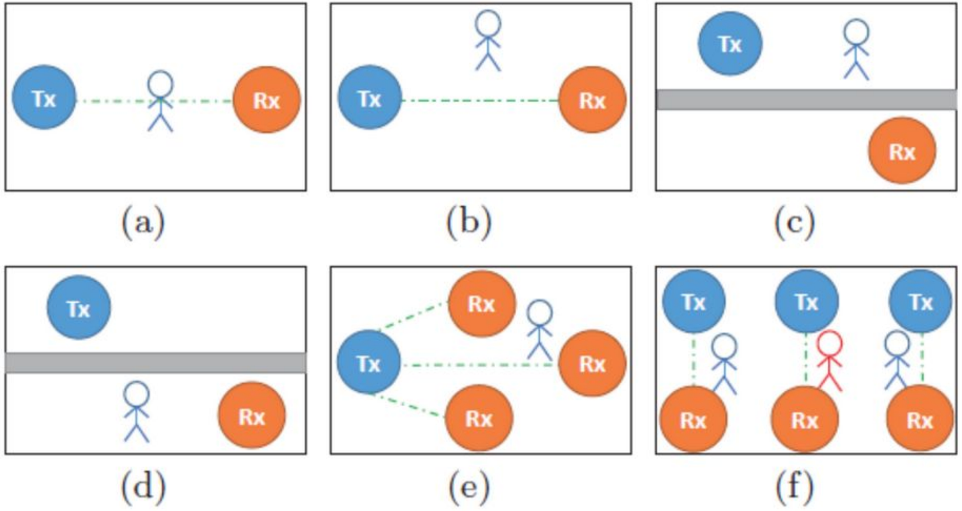
We Can Hear You with WiFi

WiHear



(a) (b) (c)

(d) (e) (f)

We Can Hear You with WiFi

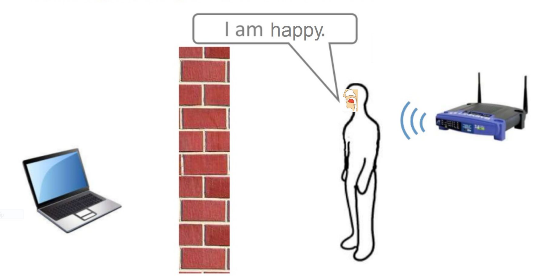
- Property used
    - MIMO beamforming, focused on mouth
    - Partial multipath effect, partially remove multipath after wavelet packet transformation

We Can Hear You with WiFi

WiHear

- Property used
  - MIMO beamforming, focused on mouth
  - Partial multipath effect, partially remove multipath after wavelet packet transformation

- Objective achieved
  - lip reading and speech recognition without line of sight
  - Context aware speech recognition enhancement



Conclusion

WiVi

WiKeylog

WiHear

- All three very innovative
- Early stage proofs of concept
- Novel use cases requiring NLOS sensing
- Far reaching privacy implications
- The ISM band can be used for more than machine to machine communication, e.g. indoor localization, sensing and control

Follow up results

video src: https://youtu.be/sbFZPPC7REc?t=122

Follow up results

video src: https://youtu.be/3Atky2Jt_-4?t=3