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Beamsteering for Training-free Counting of Multiple Humans Performing Distinct Activities

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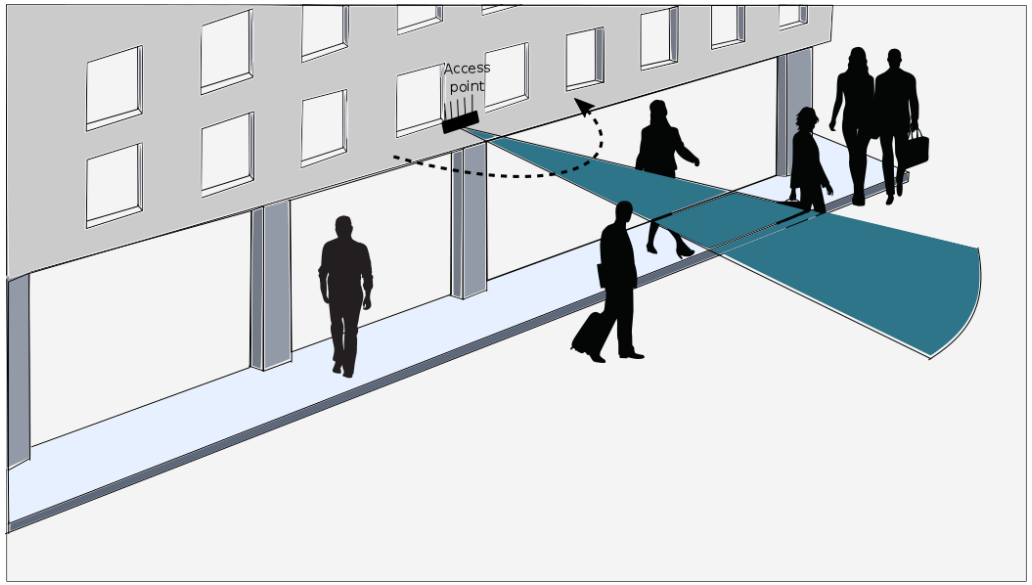
Crowd Counting

- **Retail shops and outlets**
  - Measure the success of promotional activities
    - Street count: How many shoppers passed by the store?
      - Effectiveness of window displays
    - Visitor count: How many customers are buyers?
- **Exhibitions and festivals**
  - Crowd control to prevent injuries
- **Public facilities**
  - Identify attractive public areas



A crowd counting scenario at a retail shop

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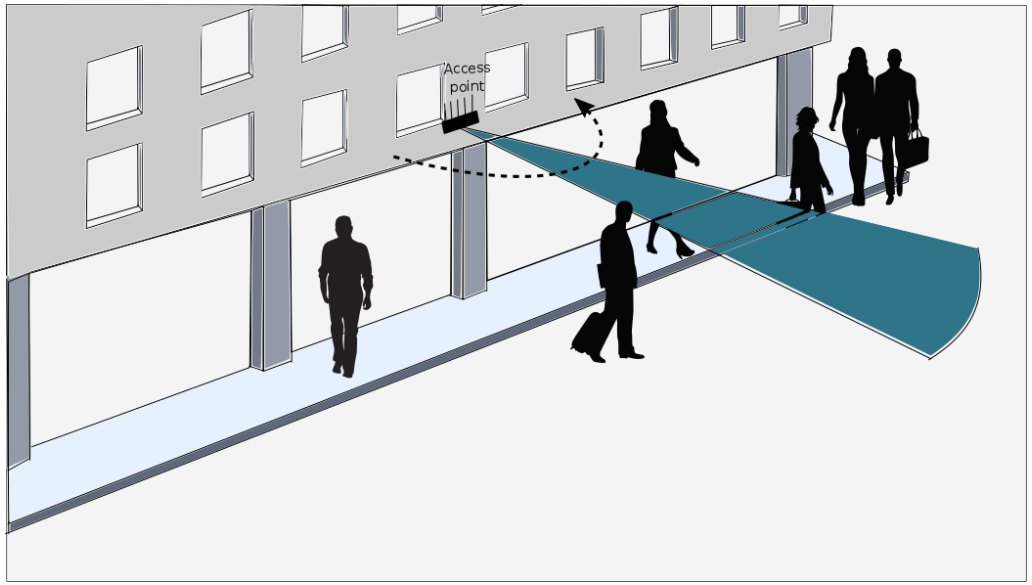

A street counting scenario at a retail shop

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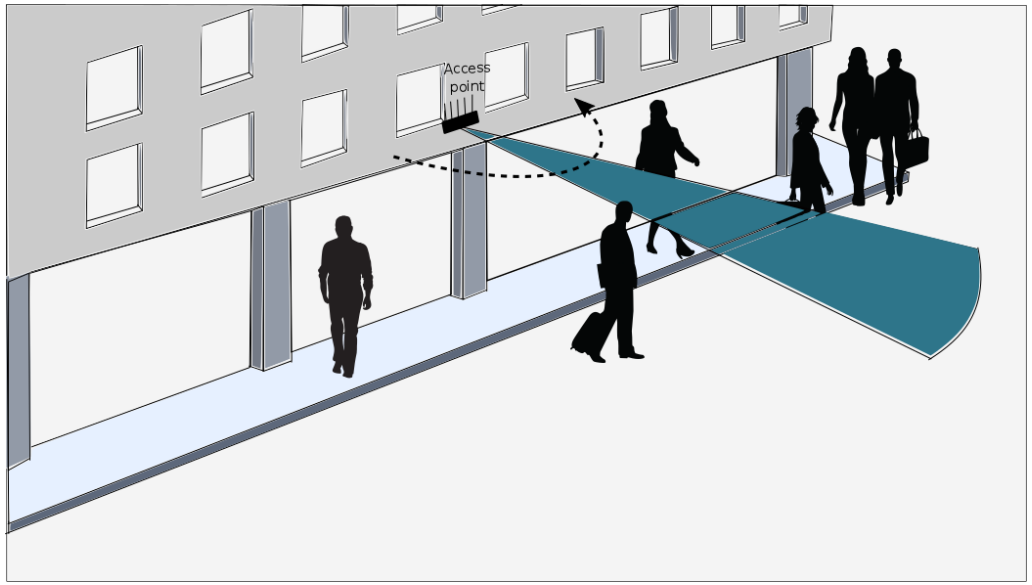
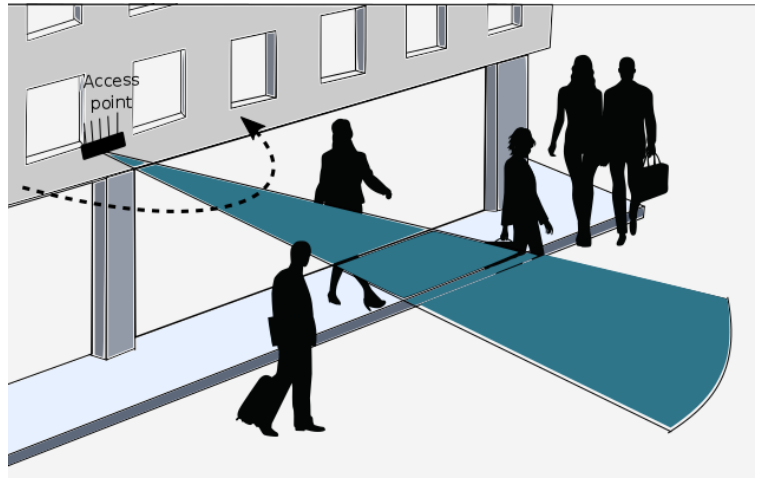


A crowd counting scenario at a retail shop

Existing Technologies

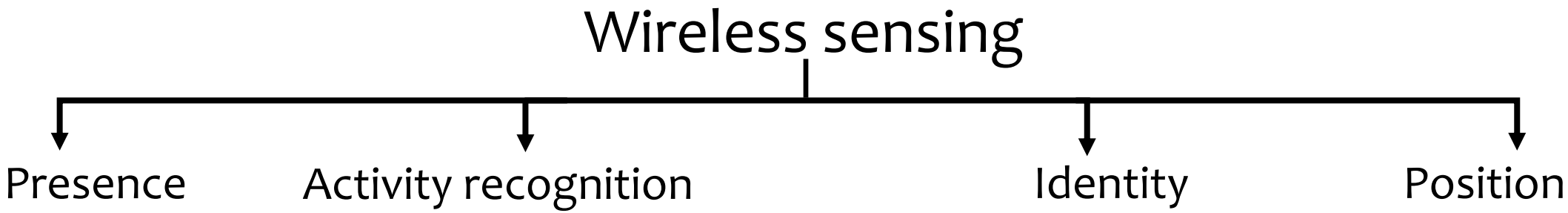
Cameras

WiFi beacons



Wireless sensing

State of the Art



People counting

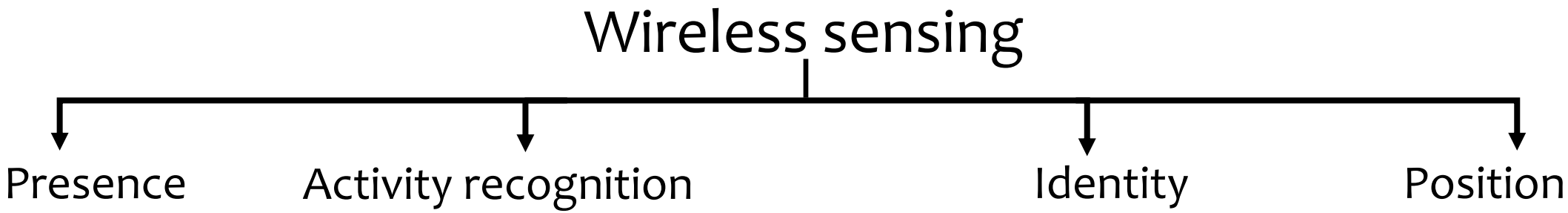
- Measure dispersion in RSS or CSI

[W. Xi et al. 2014], [S. Depatla et al. 2015]

- Spatially distributed transceivers *[C. Xu et al 2013]*
- Doppler features *[S. Di Domenico et al. 2016]*
- Transfer kernel learning *[H. Zou et al., 2017]*

- Count and extract activities of spatially distributed humans
- Beamsteering using antennas at the receiver
- Requires no prior training

State of the Art



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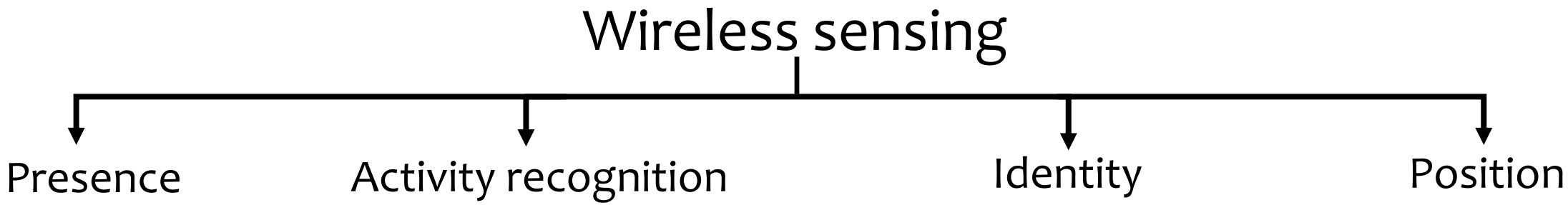

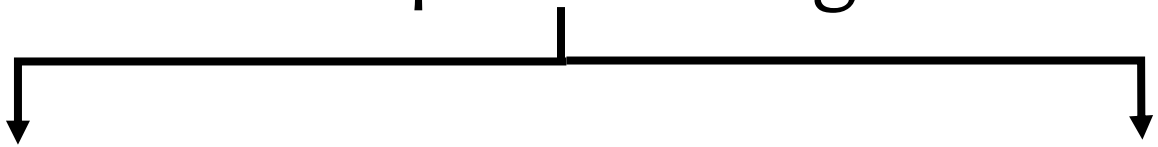

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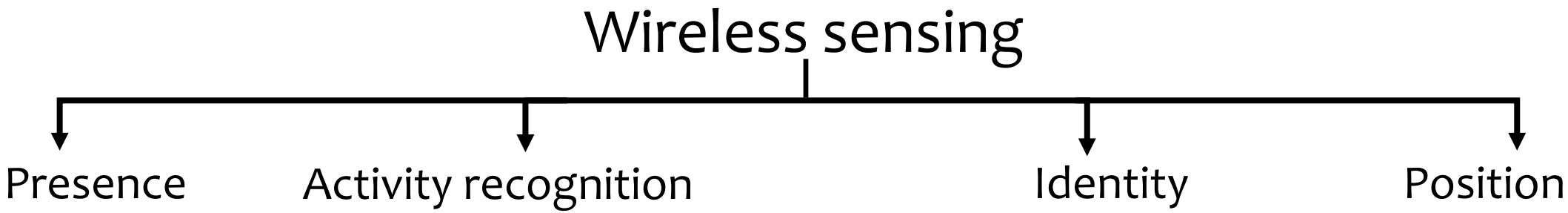

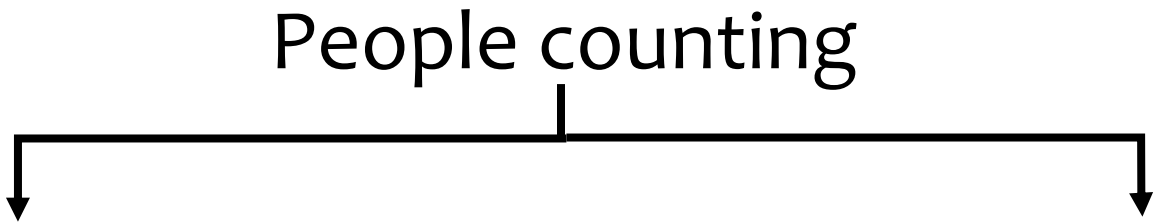

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Our WORK

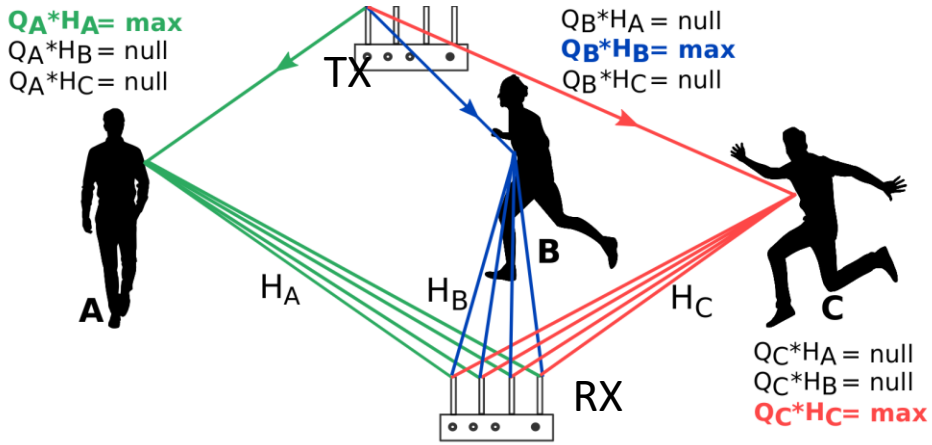
Exploiting Spatial Diversity

- Modelling scattered wireless signals of a human at a receiver
  - $\boldsymbol{x(t) = s(t) + i(t) + n(t)}$

  $\boldsymbol{x(t)}$ - received signal, $\boldsymbol{s(t)}$ - LOS signal, $\boldsymbol{i(t)}$ - signal scattered from human, $\boldsymbol{n(t)}$ - noise

- Beamforming and steering the beam
  - We use a delay-and-sum beamformer at the RX
  - Shift the phase of RX antennas to improve the gain in required direction

- Calibration for phase offsets
  - Use anchor points to transmit and measure the phases at the receiver



Spatially distributed humans

Delay and sum Beamformer

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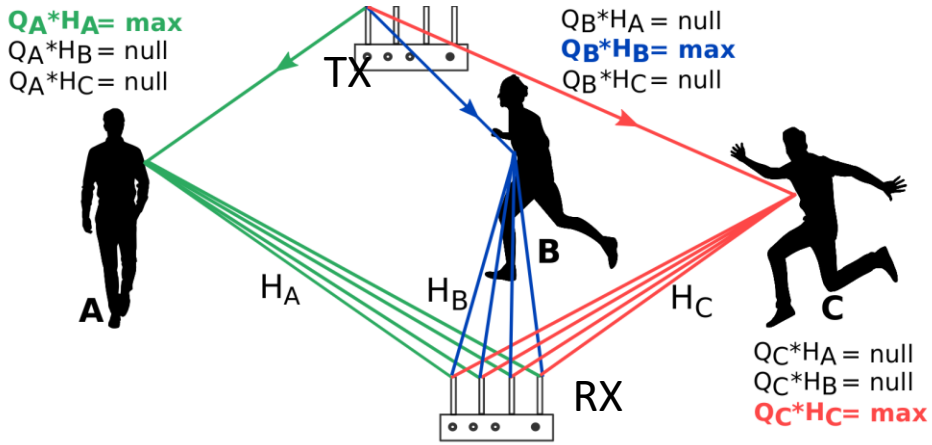

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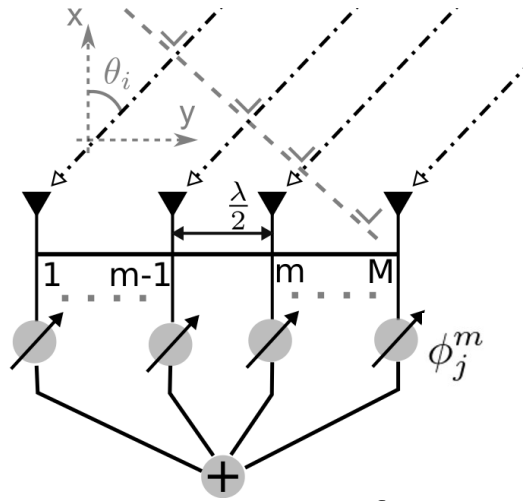

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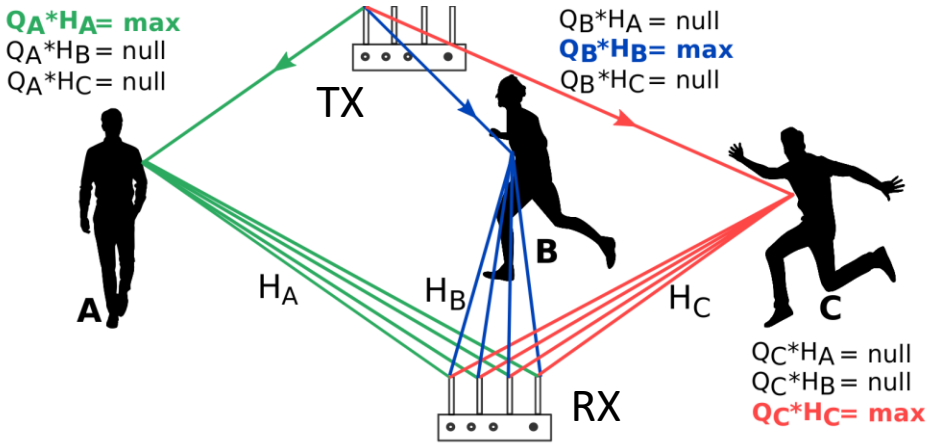

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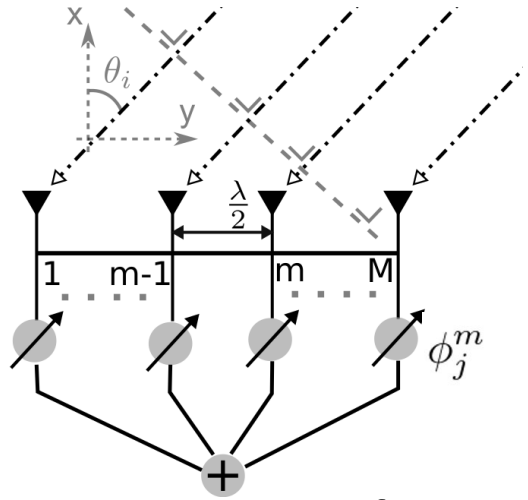
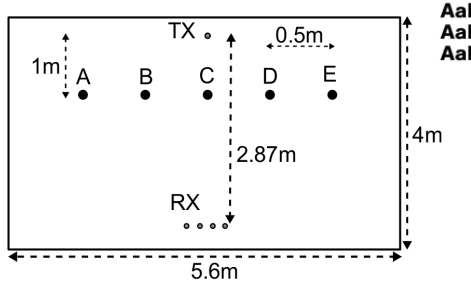
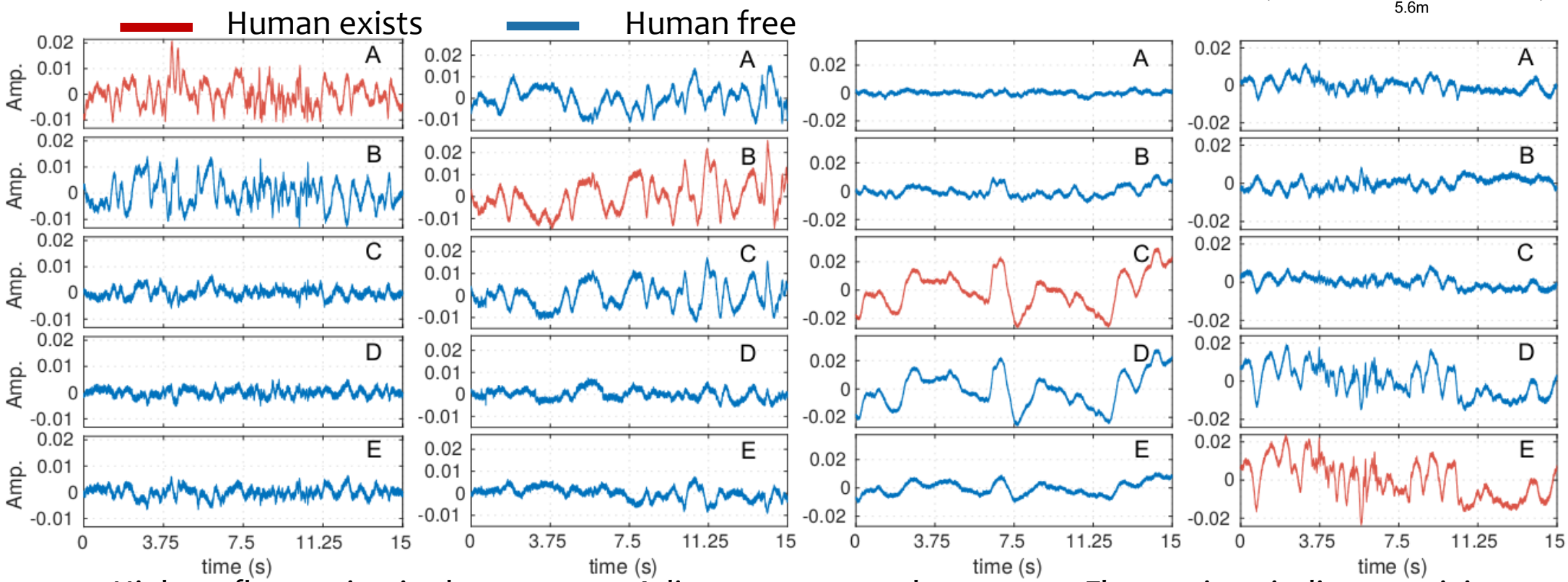


Delay and sum Beamformer

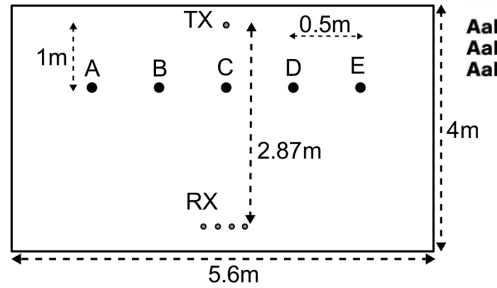
A Single Human Subject

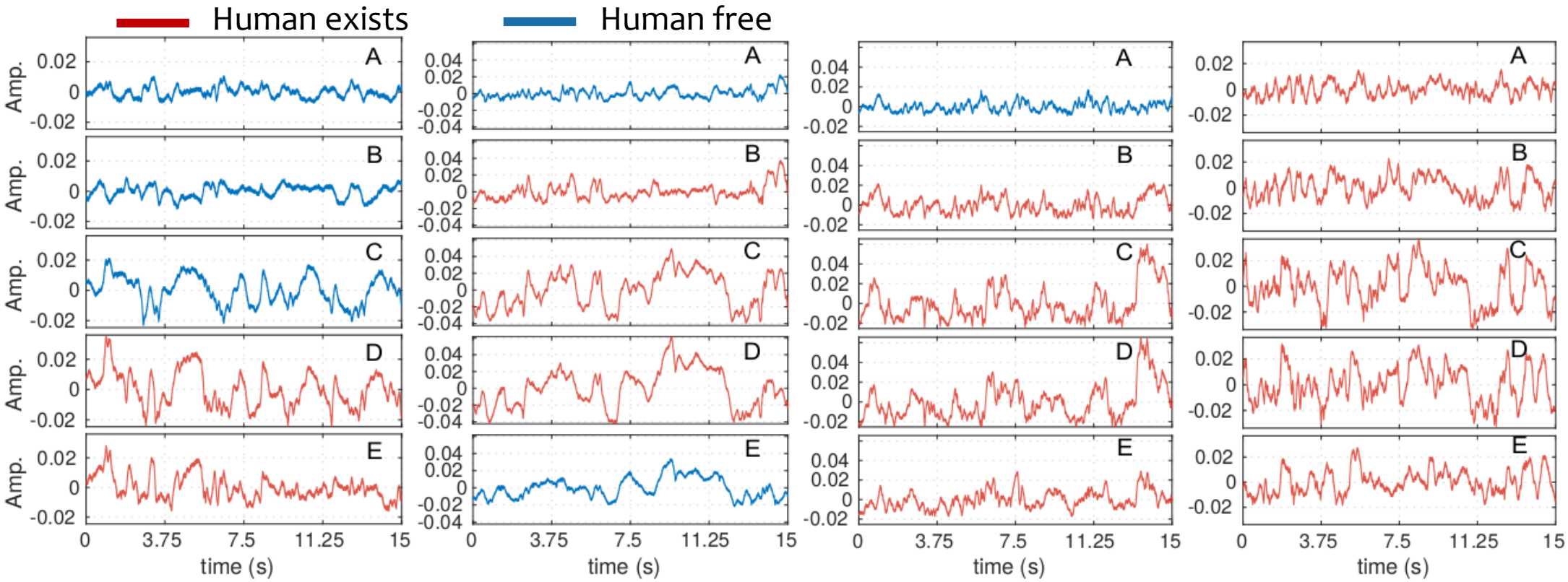




- Highest fluctuation in the direction of the person
- Adjacent streams also fluctuate
- Fluctuations indicate activity and direction

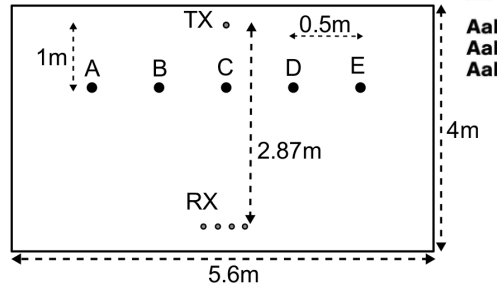
Multi-Subject Recognition

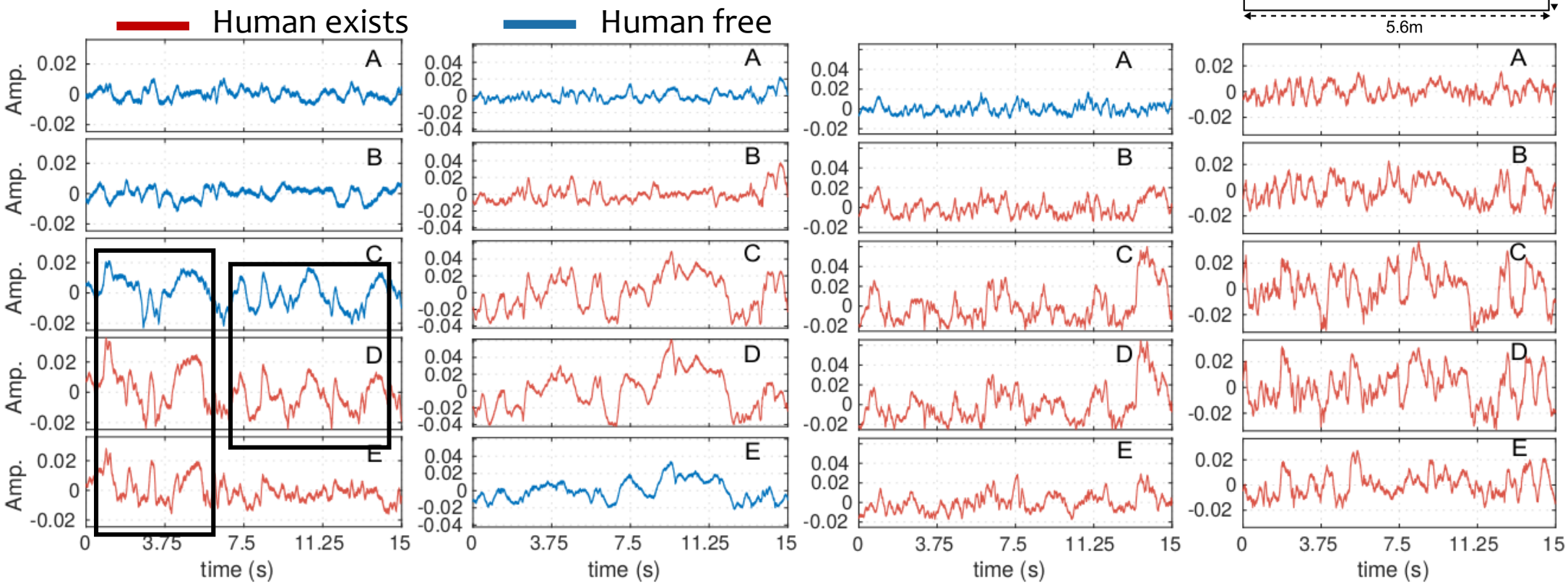




2 persons 3 persons 4 persons 5 persons

Multi-Subject Recognition





2 persons

- Highest fluctuation in the direction of the person

3 persons

- Adjacent beams also fluctuate

4 persons

- Fluctuations of beams are superpositions for adjacent humans

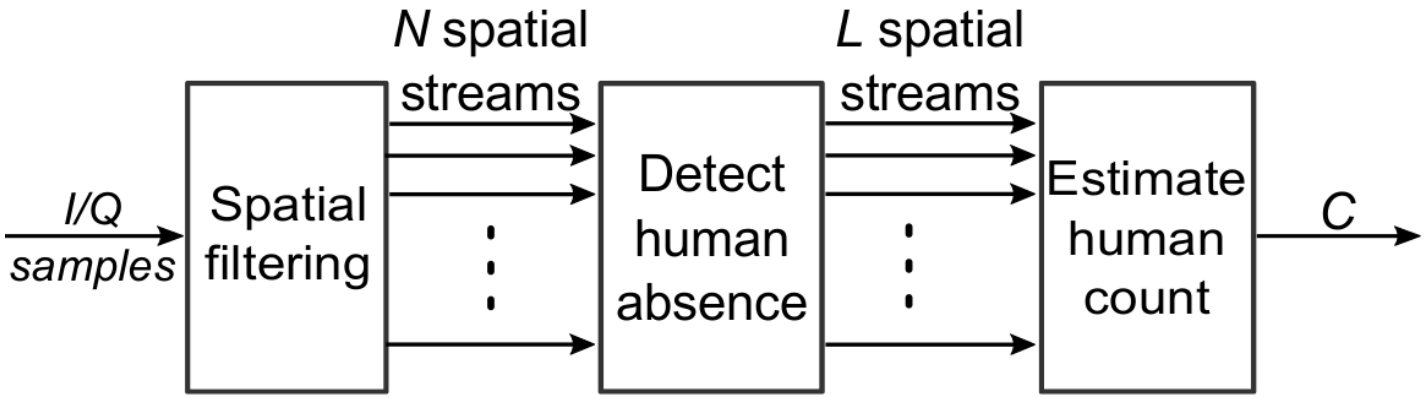
5 persons

Human Count Estimation Steps

i) Obtain spatial streams
   - Beamsteering using the IQ samples.

ii) Detect the absence of a person in a spatial stream
   - Discard those streams

iii) Estimate the human count
   - Use the remaining streams



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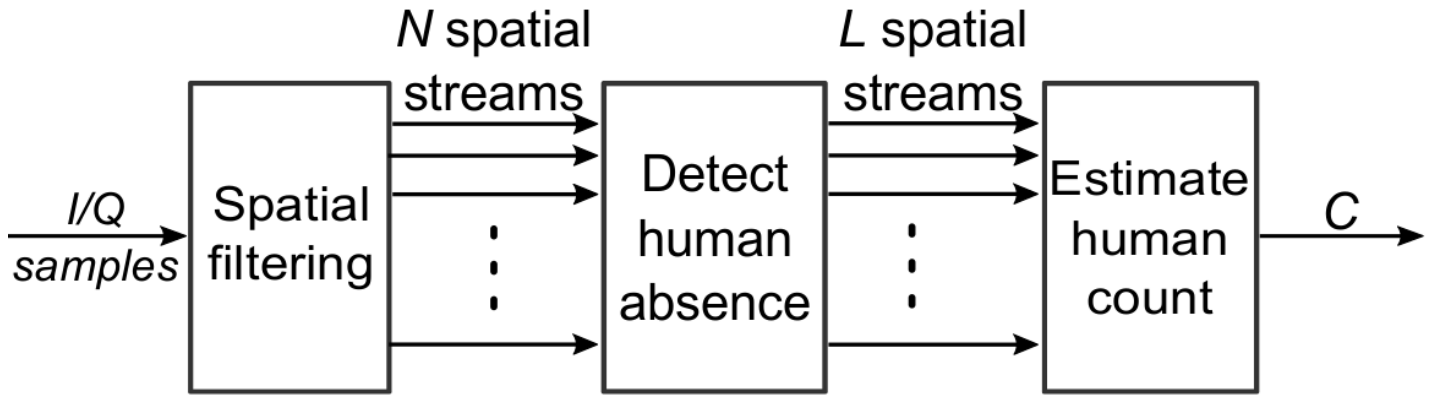
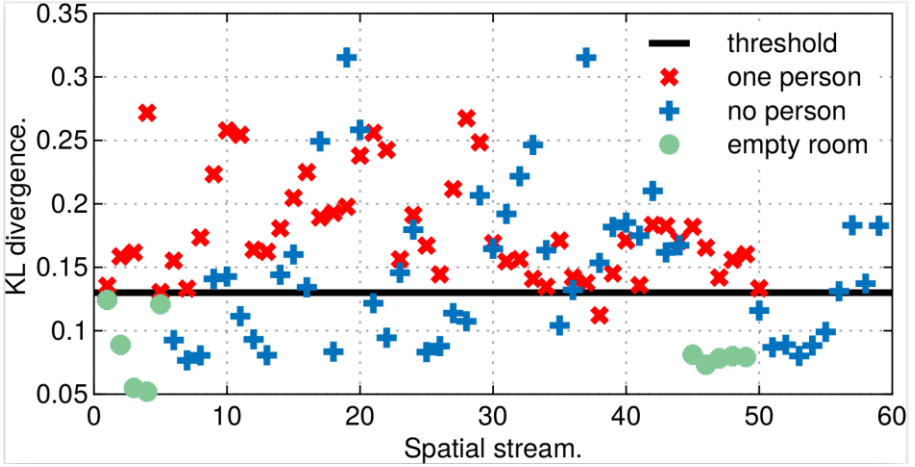


Detect the absence of a person

- Kullback-Leibler divergence
  - PMF of a Gaussian distribution modeling human-free traces
  - PMF of each stream
- Threshold to distinguish Empty room and streams with persons
  - Streams with no persons is difficult to detect
    - Reason: Interference from nearby streams
- Discard streams below the threshold



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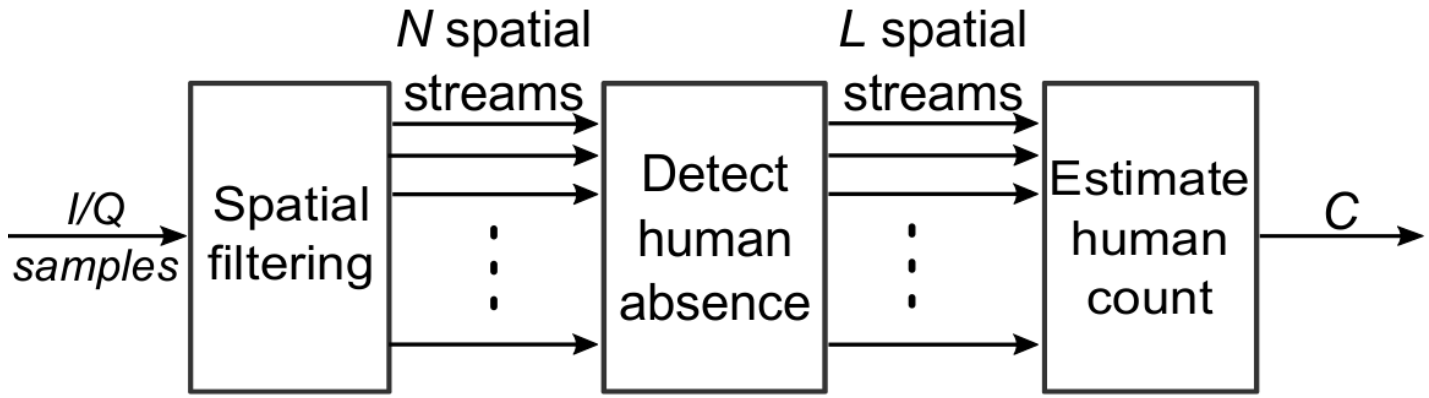
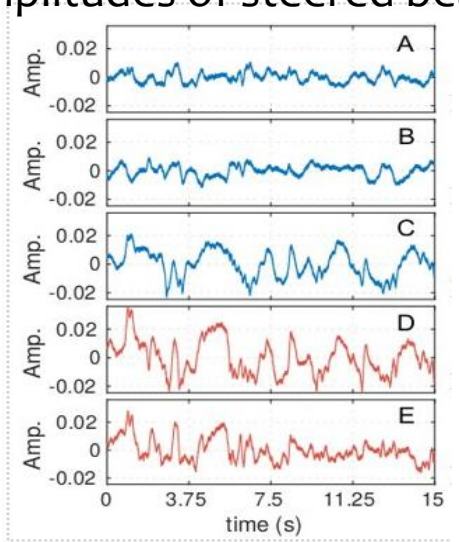


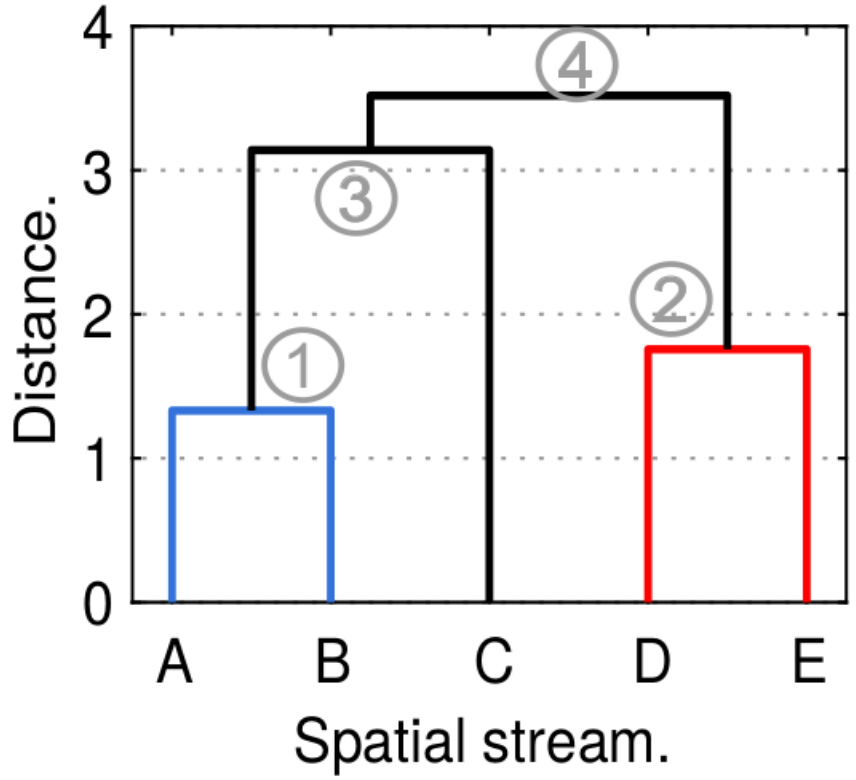
Estimate the human count

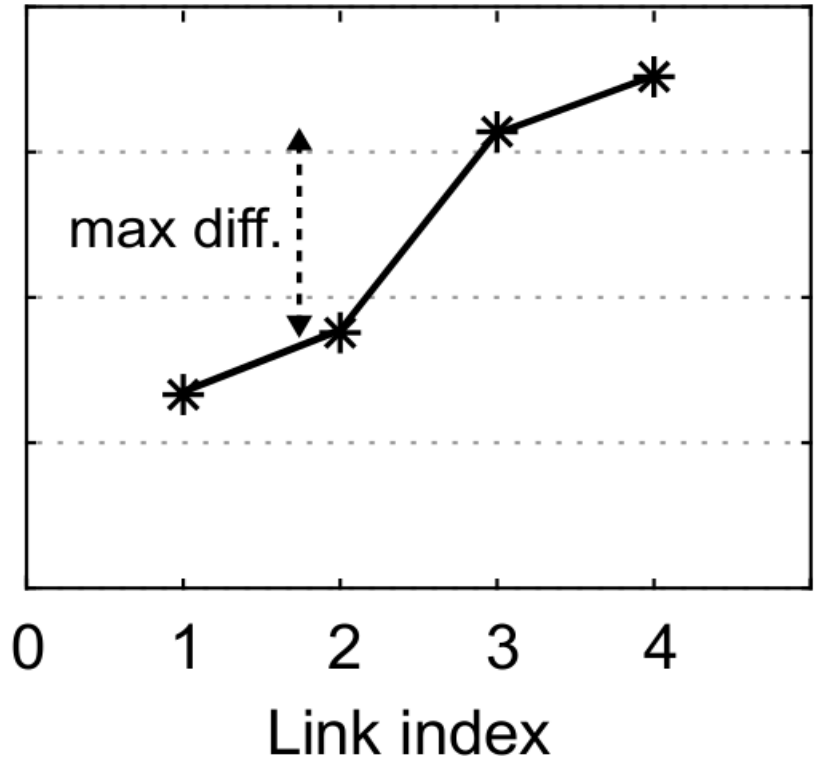
Amplitudes of steered beams



Divide time slots → Butterworth filter → Differential DTW → Agglomerative Hierarchical Clustering → Natural clusters → Moving median filter → Estimation of people count

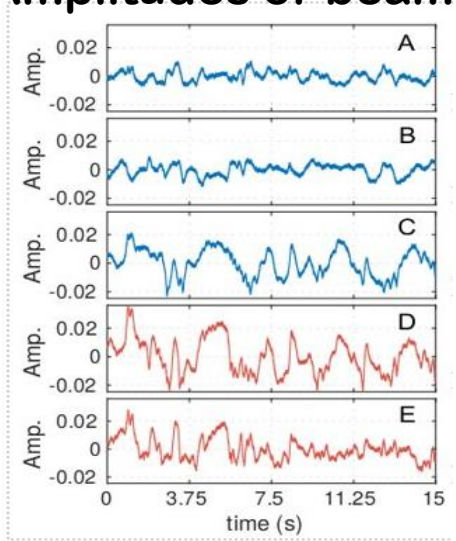
Finding natural clusters





Estimate the human count

Amplitudes of beams



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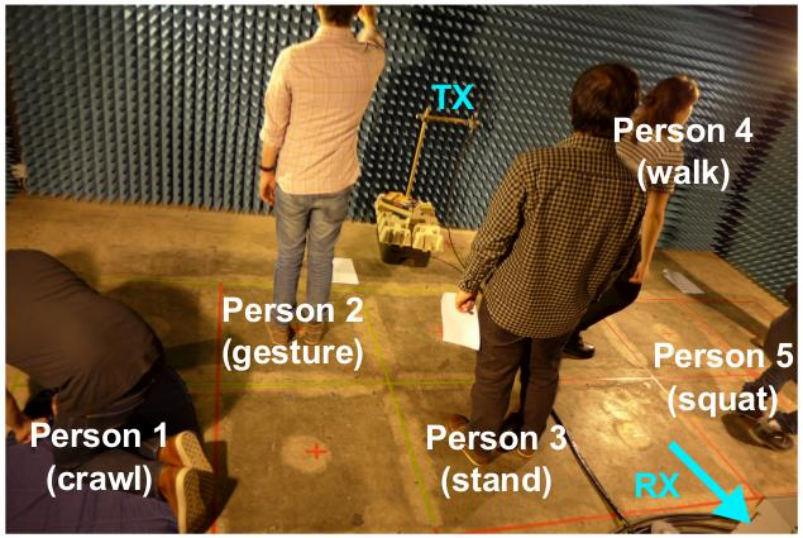
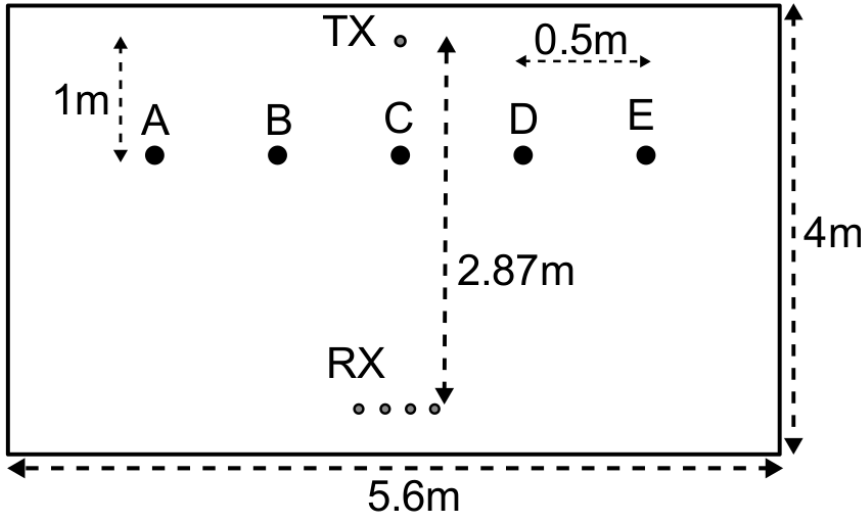
Experiments

- 5G testbed with software defined radios

Center frequency	BW	Useful subcarriers	Samples/s
3.42 GHz	15.36 MHz	52	5408

- USRP X300 series with UBX 130 and SBX RF daughterboards
- 1 SDR as TX, # of TX antennas: 1
- 3 SDRs as the RX, # of RX antennas: 4
  - 1SDR for synchronization
- Room size: 5.6 m ×4 m × 2.184 m
- Experiments upto 6 people
  - squatting, walking inside the assigned square, standing, jumping, crawling and hand gestures





Multi-subject Counting Results

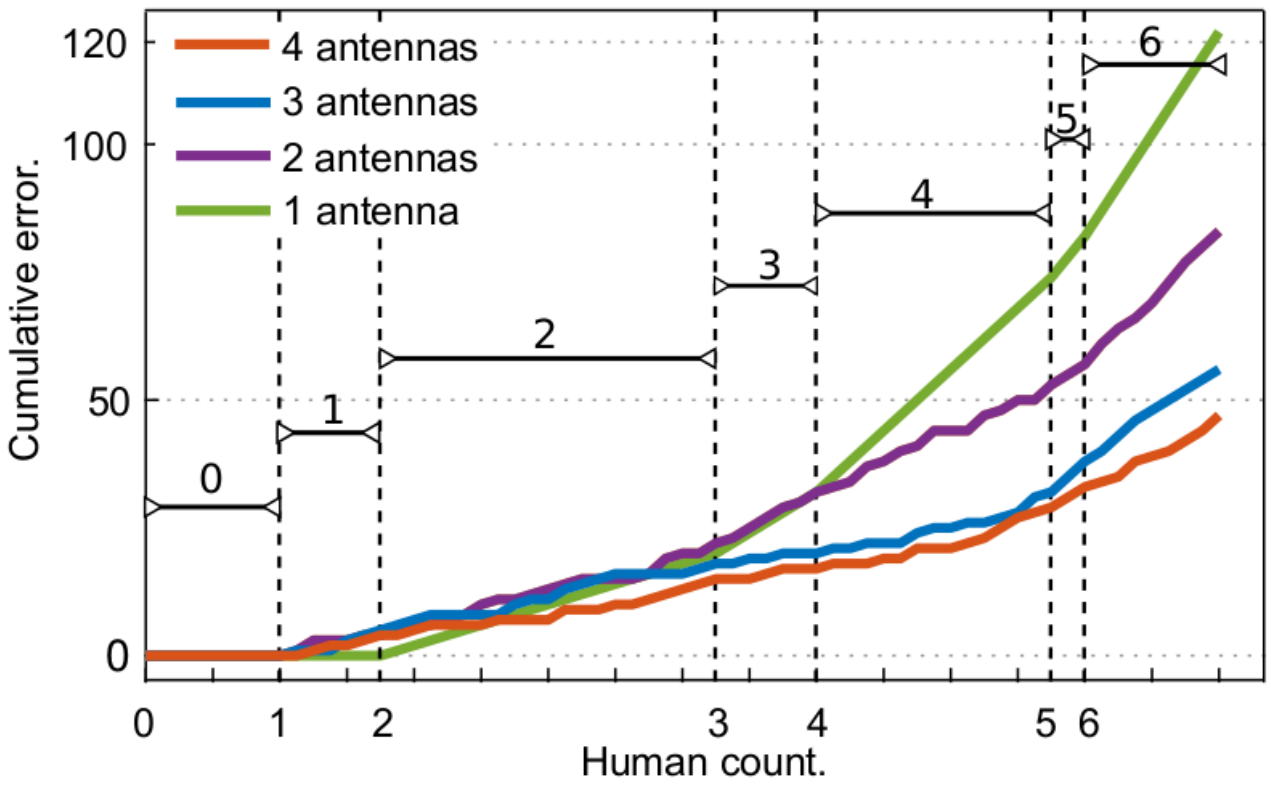
- 116 experiments with up to 6 human subjects

Actual (H_c) \ Estimated ($\tilde{H}_c$)	0	1	2	3	4	5	6
0	12	0	0	0	0	0	0
1	0	16	2	0	0	0	0
2	0	1	14	14	1	0	0
3	0	0	1	16	1	0	0
4	0	0	3	9	4	3	0
5	0	0	6	2	6	0	0
6	0	0	0	2	2	3	1

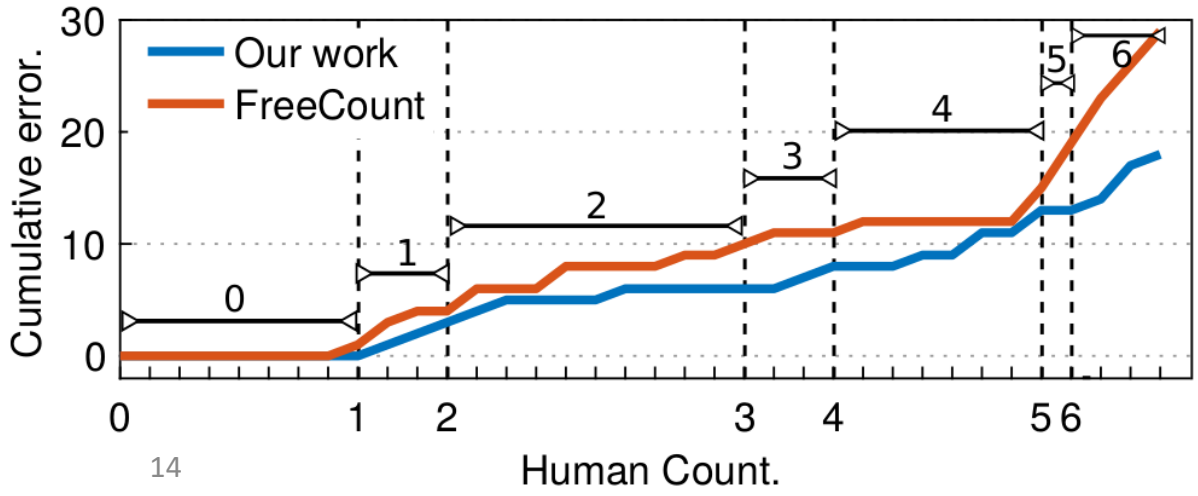
Actual (H_c) \ Estimated (%)	0	1	2	3	4	5	6
0	100	0	0	0	0	0	0
1	0	89	11	0	0	0	0
2	0	3	47	47	3	0	0
3	0	0	5.5	89	5.5	0	0
4	0	0	16	47	21	16	0
5	0	0	43	14	43	0	0
6	0	0	0	25	25	37.5	12.5

Multi-subject Counting Results

- Effect of the # of antennas

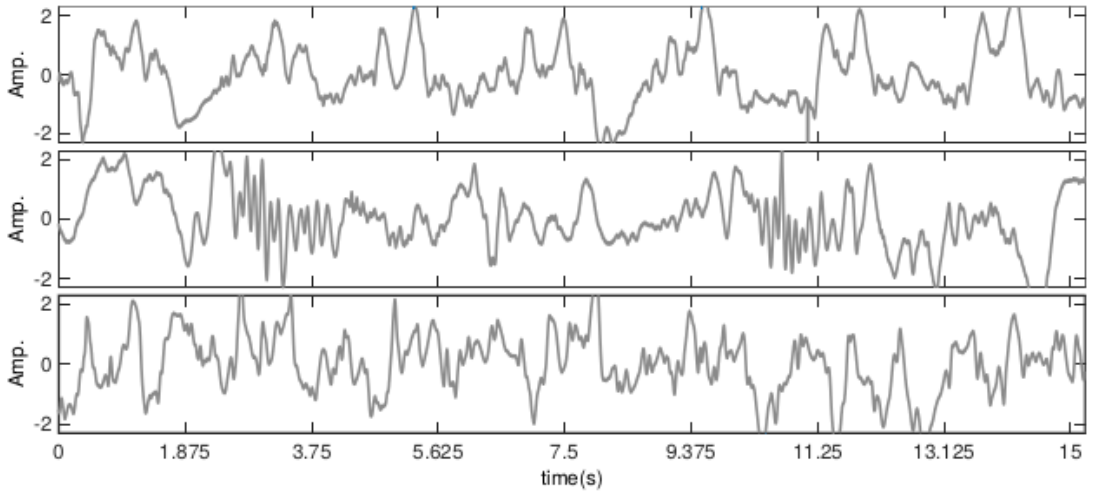


- State of the art comparison
  [H. Zou et al., 2017]

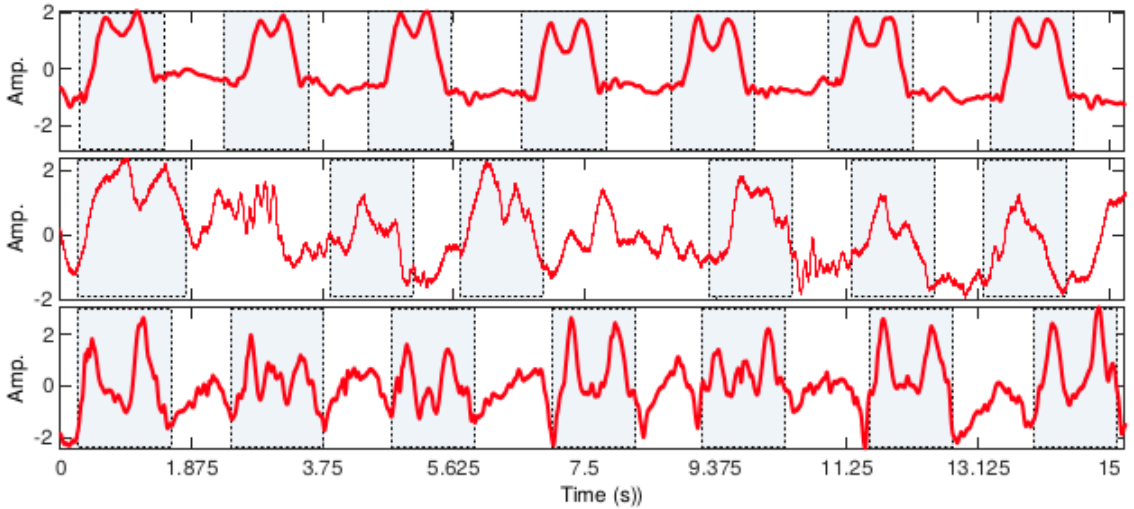


Extraction of Gestures

- Blind source separation for extraction of gestures
  - JADE algorithm: exploits the non-Gaussian nature of the source signals
- Extracted 20/21 push-pull gestures
  - 2, 2, and 3 humans in three experiments



Mixed signals from a single antenna for a push-pull gesture



Extracted gestures

Conclusions

- Reported from studies on beamforming for multi-subject recognition
- Performed experiments with multiple persons using narrowband reception devices with limited antennas
- We develop algorithms to count the people and extract activities
- Counting up-to 4 persons within 1-person error
- Compared the results with a state of the art algorithm
- The data we recorded is openly available for further studies

References

[W. Xi et al., 2014] W. Xi et al., “Electronic frog eye: Counting crowd using wifi,” In Proc. of INFOCOM. IEEE, 2014.

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[C. Xu et al., 2013] C. Xu et al., “SCPL: Indoor device-free multi-subject counting and localization using radio signal strength,” in Proc. of IPSN. ACM, 2013.

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Thank you!