ITU-ML-PS-002

WALDO: Wireless Artificial Intelligence based Location Detection

Team name: The Sixth Sense

Team Github Repo: ITU-AI-ML-in-5G-Challenge/ITU-ML-5G-PS-002-WALDO_TheSixthSense_SRIB_Final

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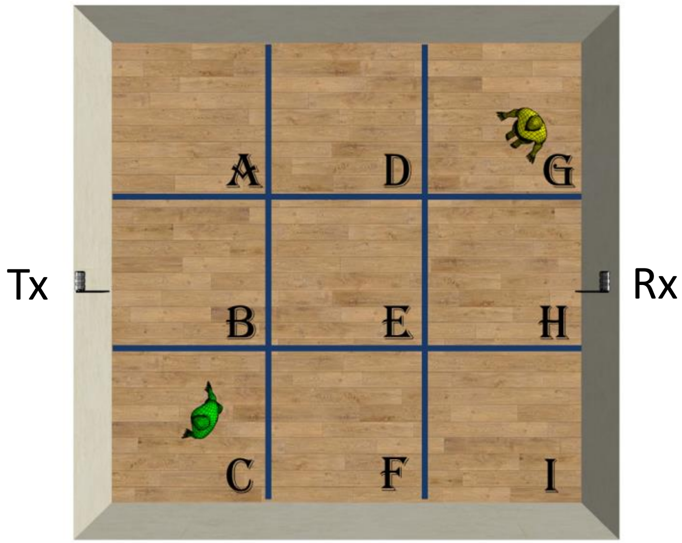
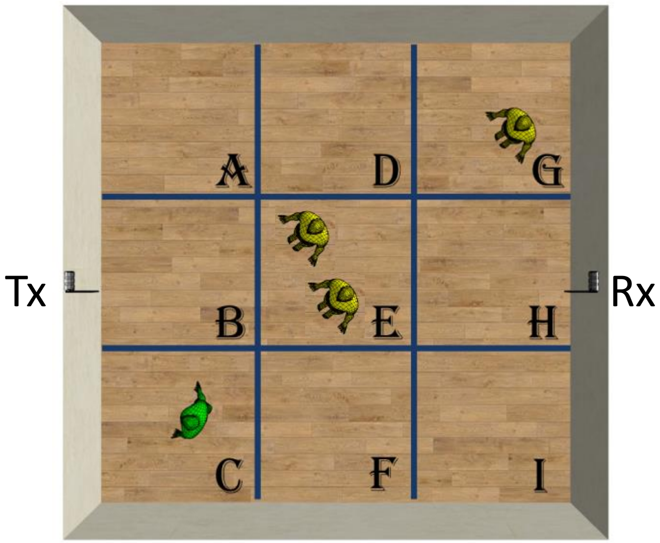
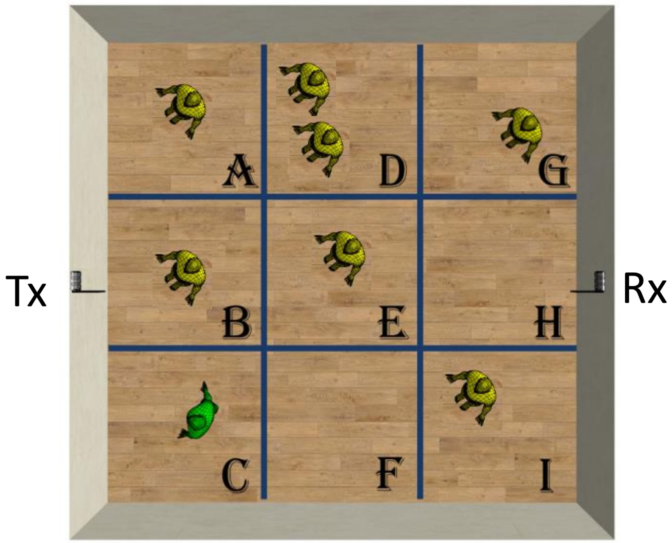
Problem statement







Given Received Signal : Channel estimation field of conventional IEEE 802.11ay packets

Sector	No of people
C	1
G	1
Rest of the sectors	0
Total	2

Sector	No of people
C	1
E	2
G	1
Rest of the sectors	0
Total	4

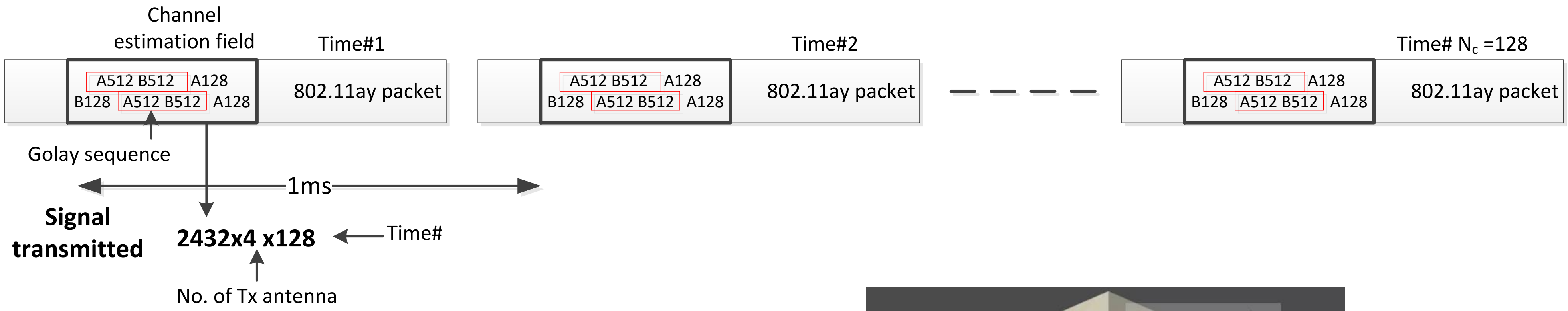
Sector	No of people
A	1
B	1
C	1
D	2
E	1
G	1
I	1
Rest of the sectors	0
Total	8

Problem:
1. Localization: Find number of persons in each sector
2. Counting: The total number of persons in the room.

Information provided

Signal transmitted :

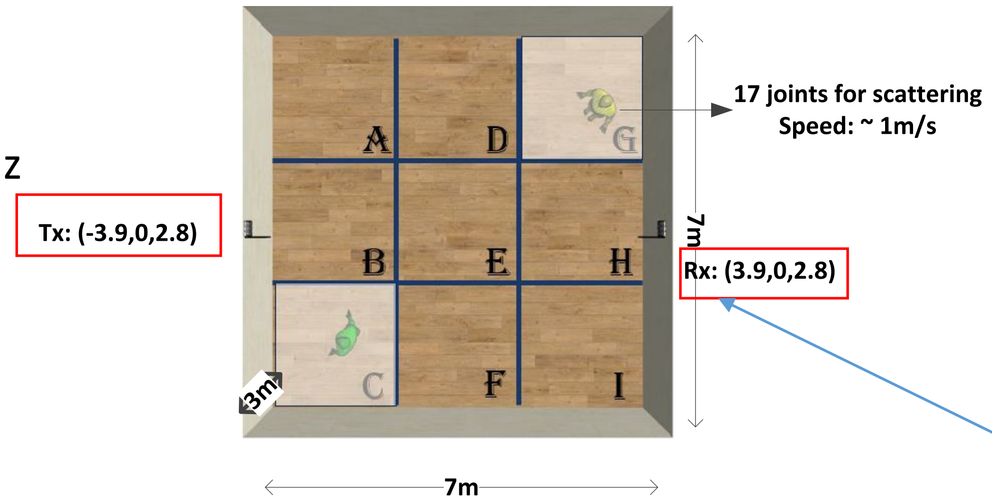
- Size : N_s x N_a x N_c

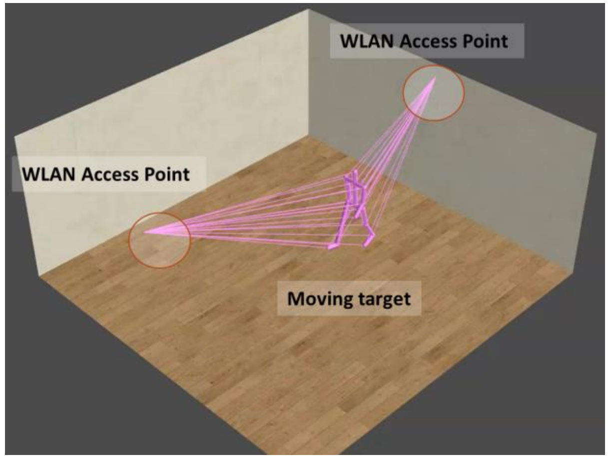


Channel :

Frequency: 60GHz

Bandwidth: 1.76GHz



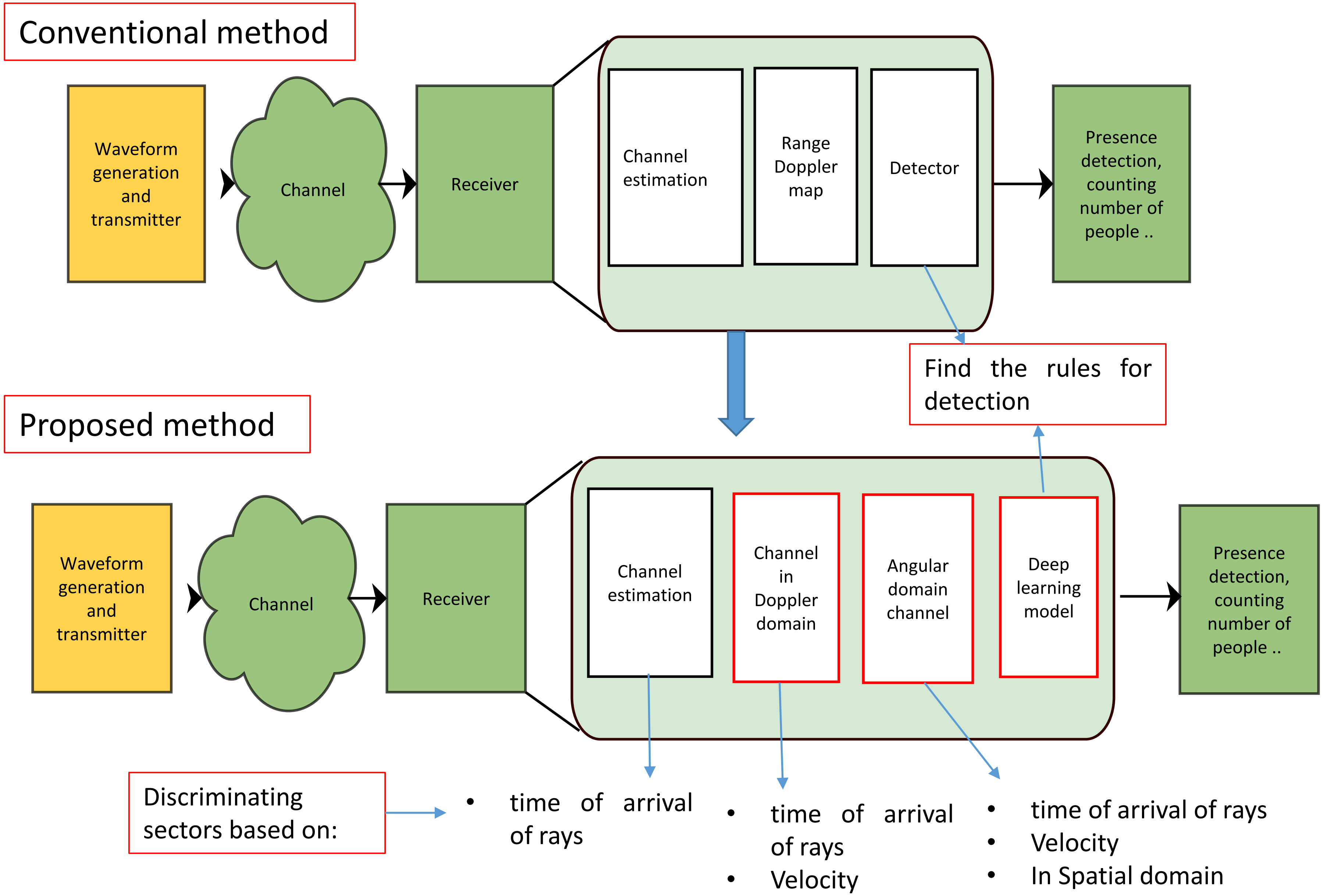


Use:
Received signal (raw)

Signal Received (Provided for the problem) :

- Size : $(N_s + \mathrm{L} - 1)$ x N_a x N_c where channel has 'L' taps (here L=45) and N_a is number of Rx antenna which is 4 here.
- Size : 2476x 4x 128

Solution outline



Solution Outline

Estimate channel
(discriminate sectors based on time of arrival of rays)

Conversion to Doppler domain
(further discriminate based on velocity)

Conversion to angular domain
(further discriminate based on angular position)

ML model
(Maps the channel to the number of people per sector)

Channel Estimation : L-Tap channel

Signal Model

- For each repetition (Total N_c) of CEF, we considered an 'L' tap channel impulse response (CIR) with
  - tap index $l \in [0, L-1]$,
  - transmit and receive antenna index $\mathrm{n_t}, \mathrm{n_r} \in [0, N_a]$,
  - training symbol index $\mathrm{n} \in [0, N_s]$ and
  - signal index at the receiver $k \in [0, N_s + L - 1]$
- Let $\mathrm{H} = [H_0, .., H_{L-1}]$ be the CIR matrix of the MIMO frequency selective channel, where
  - $$\mathrm{H_l} = \begin{bmatrix} H_{1,1}(l) \ldots & H_{1,N_a}(l) \\ \vdots & \vdots \\ H_{N_a,1}(l) \ldots & H_{N_a,N_a}(l) \end{bmatrix}$$
  - in which $H_{n_r,n_t}(l)$ … is the l-th tap of the CIR between the n_r-th receive antenna and the n_t-th transmit antenna.
- Y =HX+N where X is
  - $$\mathrm{X} = \begin{bmatrix} x(0).. & x(N_s-1)\ 0_{N_aX1}.. & & 0_{N_aX1} \\ 0_{N_aX1} & & & \vdots \\ \vdots & & \ddots & 0_{N_aX1} \\ 0_{N_aX1}.. & 0_{N_aX1} & x(0).. & x(N_s-1) \end{bmatrix}$$
  - $$Y = [y(0) \ldots y(N_s + L - 1)]$$
- Channel H can be estimated as LSE [1]:
  - $$H = (YX^T) * (XX^T)^{-1}$$
- With sampling rate =1.76 GHz, range resolution is 17cm

[1] S. Wang and A. Abdi, "Aperiodic Complementary Sets of Sequences-Based MIMO Frequency Selective Channel Estimation".

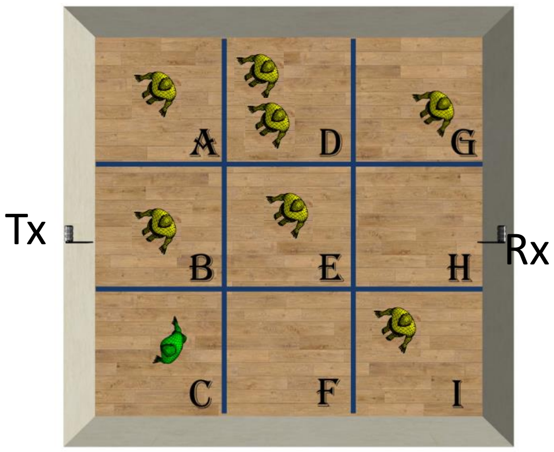
Use of L-tap channel :
To discriminate the sectors based on time of arrival of rays.
But is it sufficient ?

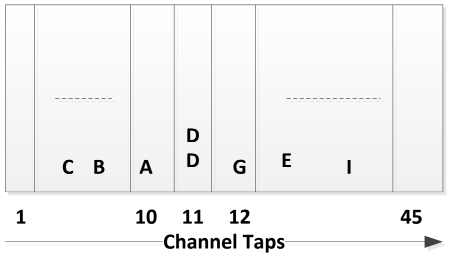
Size of channel estimated :
4x4x45x128

Rx, Tx antenna

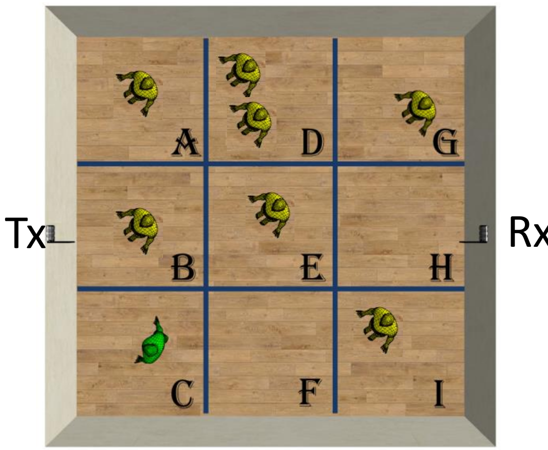
Taps

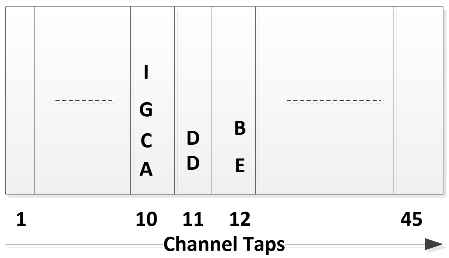
Repetition in time





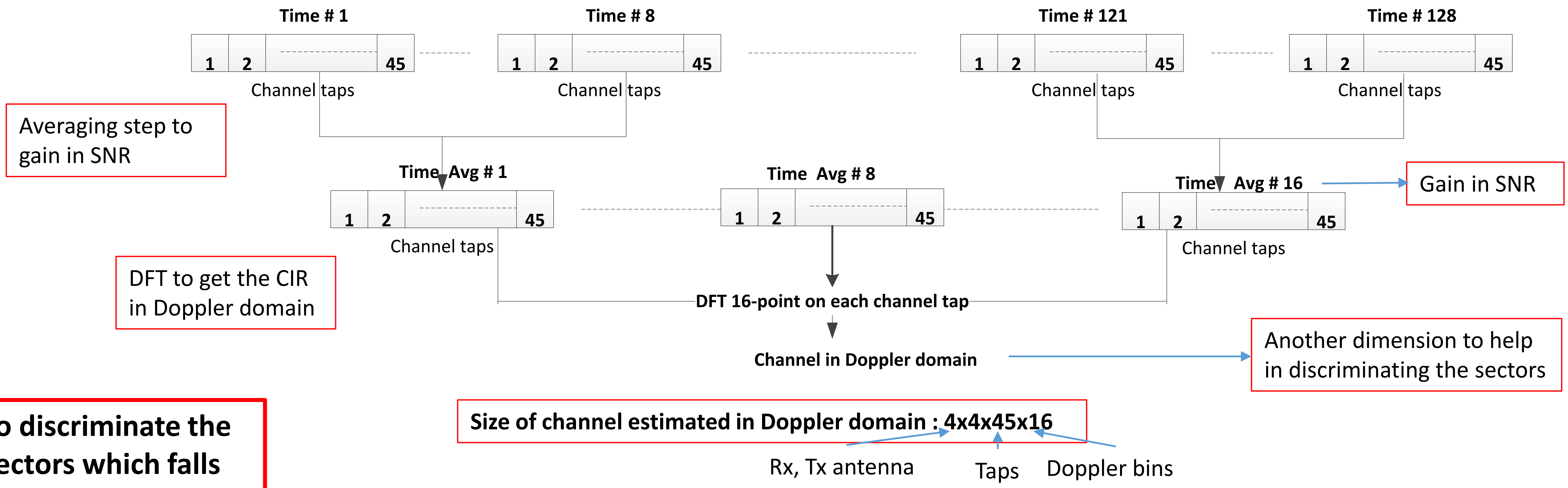
Easy to discriminate sectors





Need another dimension to discriminate

Channel Estimation : Doppler domain conversion



To discriminate the sectors which falls under same tap of channel :

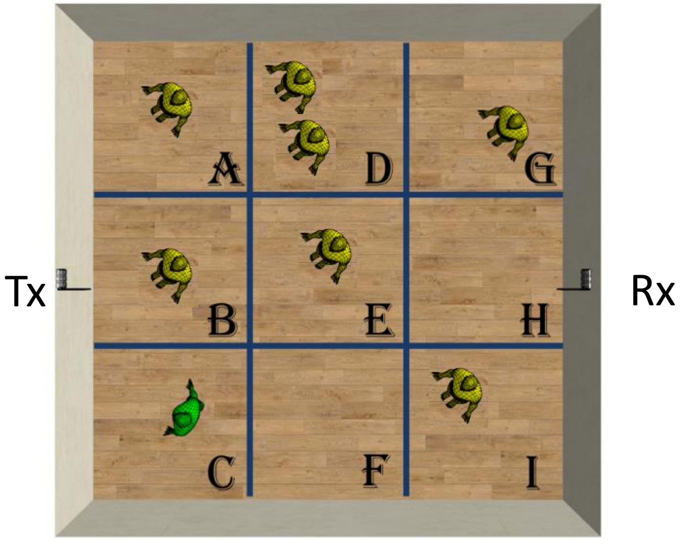
<u>Doppler domain processing</u> is helpful Which discriminate based on speed

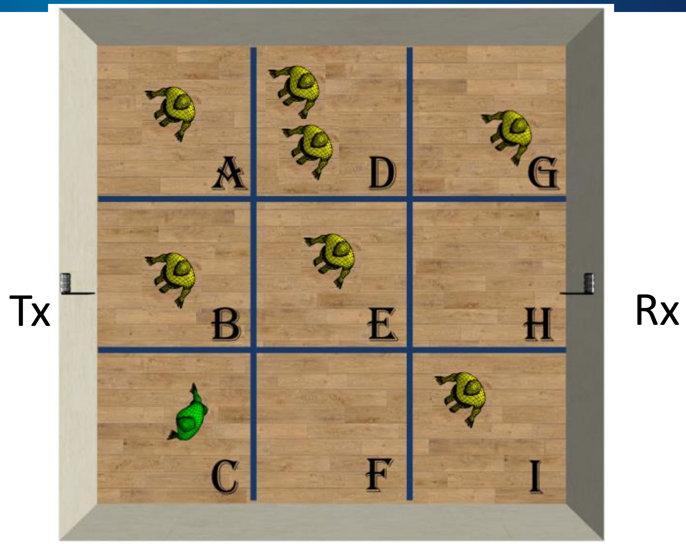
Objects which fall in same range bucket (same tap), can be differentiated with Doppler FFT which is as follows:

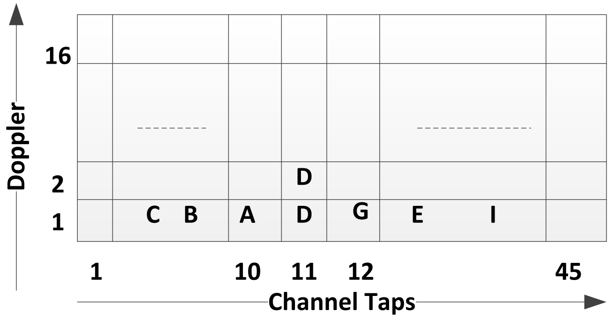
- First, H in time domain is averaged across multiple instances [2] (Here over K=8 instance where N_c=128):
  - $H_{time} = [H_{T_1}, \dots, H_{T_K}, \dots, H_{T_{N_c}}]$
  - $H_{time_{AV}} = \left[mean(H_{T_1} \dots H_{T_K}), mean(H_{T_{K+1}} \dots H_{T_{2K}}), \dots, mean(H_{T_{K(\frac{N_c}{K}-1)}} \dots H_{T_{N_c}})\right]$
  - Size of $H_{time_{AV}}$ = $(N_a, N_a, L, \frac{N_c}{K})$
- FFT is performed on $H_{time_{AV}}$:
  - $H_{Dopp} = FFT(H_{time_{AV}})$ in time dimension

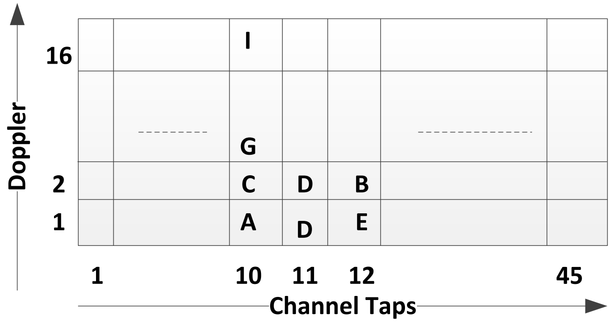
[2] https://training.ti.com/sites/default/files/docs/mmwaveSensing-FMCW-offlineviewing_1.pdf

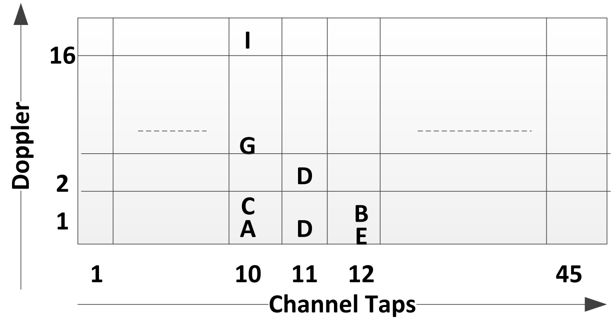
Channel Estimation : Doppler domain











Easy to discriminate sectors

Easy to discriminate sectors

Not sufficient to discriminate sectors

Now, two object with same tap and different velocity can easily detected.

What if, two object falls in the same tap and same Doppler bin … ?

- $V_{res} = \frac{\lambda}{2T_f}$ where : λ=5mm, $T_f = \frac{N_c}{K} * 1ms$ = 16ms. V_{res} =.15625 m/s

Channel Estimation : Angular domain

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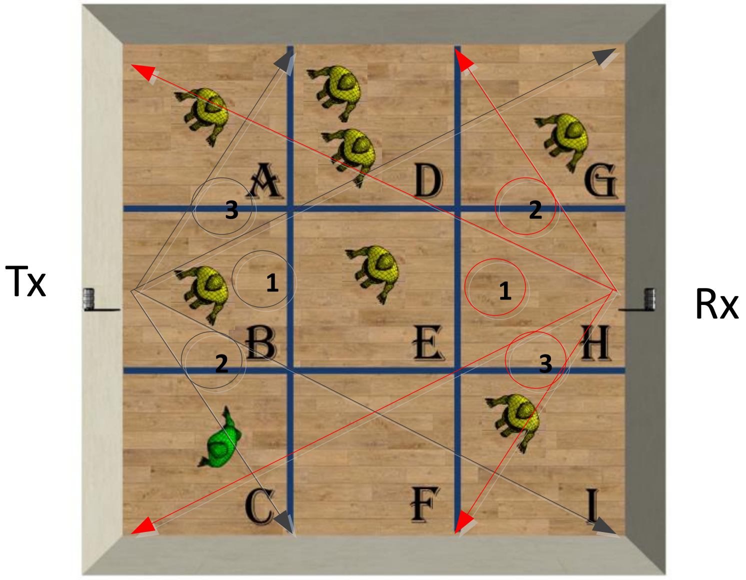
- Size of channel estimated in Doppler domain : $\boxed{4x4}$x45x16

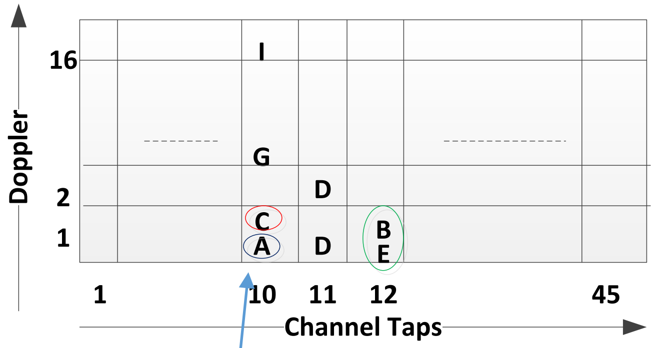
  ? Explored

- The resultant CIR (H_D) in Doppler domain is then converted to Angular domain using unitary matrices.
  - $H_{Ang} = U' * H_D * U$
  - where $U_{kl} = (1/sqrt(N_a))\exp(-j2\,\pi \frac{kl}{N_a})$
  - Here *k,l=1…4*

- The above transformation resolve the multiple rays in angular domain [2].

- Size of channel estimated in Angular domain : 4x4x45x16





4x4x45x16 → 4x4x45x16

Antenna pairs : Tx and Rx

Resolvable paths in angular domain from Tx and Rx

Another dimension to help in discriminating the sectors

Separable in angular domain : Same Tap and Doppler bin but different resolvable paths

[2]. Tse and Vishwanath , "Fundamentals of Wireless Communication", *Chapter: 7.3.4 Angular Domain Representation of MIMO Channels.*

ML based detection model

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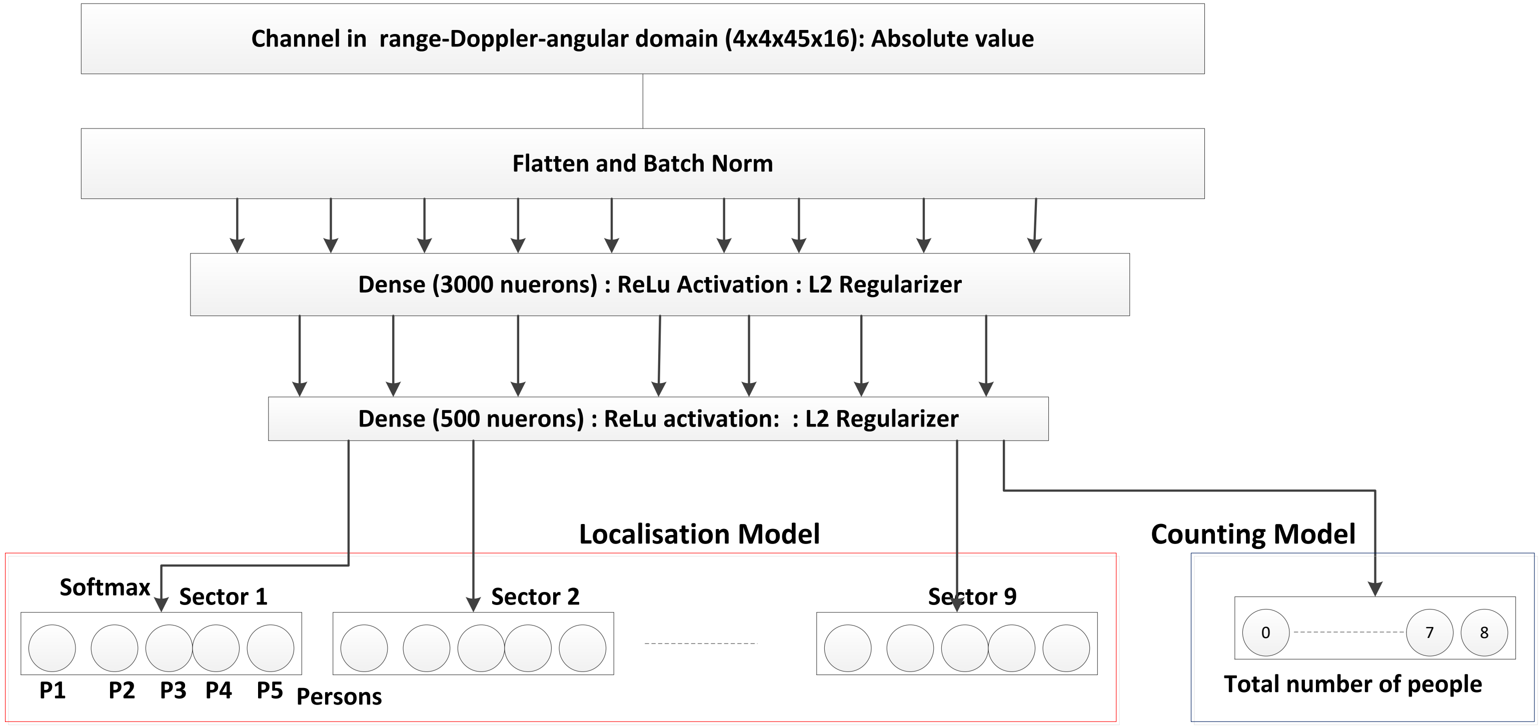
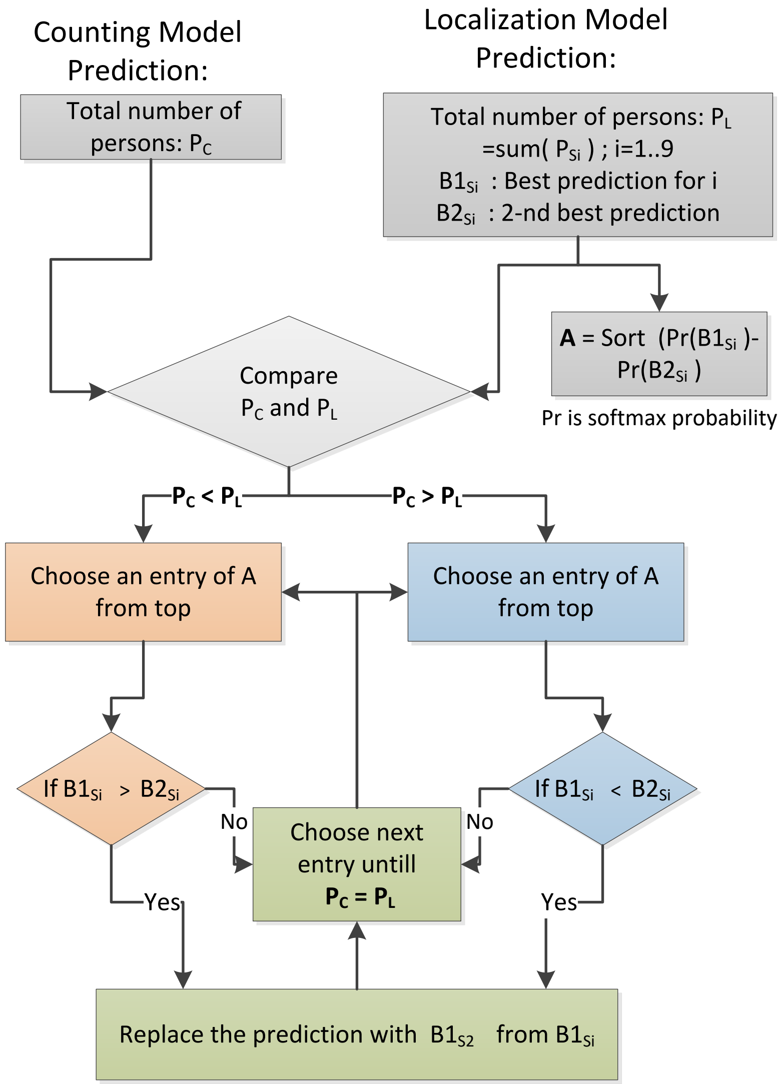
Machine learning based detector



- For back propagation : imbalanced dataset -> different weights for different labels.
- Learning rate decay and L2 regularizer to avoid overfitting.

Post Processing on ML model prediction



Performance evaluation

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Dataset and Training:

- Dataset provided for SNR 18, 0 and -18.
- Total of 15578 samples for each snr point and each sample is unique in terms of arrangement of people in the sectors.

Result:

Counting model accuracy: Number of times the total number of persons in the room are predicted correctly.

Localisation model accuracy: Number of times the number of persons in each sectors are predicted correctly.

Counting Model accuracy	
SNR	% Number of samples in which Correctly counting total number of persons in room
18	99%
0	99%
-18	39%

Parameter List for ML model	
Input size	4x4x45x16 (flatten)
Size of Hidden layer 1	3000 neurons with ReLu activation
Size of Hidden layer 2	500 nuerons with ReLu activation
Size of output layer	45 (localization model) and 9 for counting model
Epochs	200
Learning	ADAM optimizer and learning rate 0.0005 with exponential decay
Regularizer	L2

Localisation model accuracy	
SNR	% Number of samples in which Correctly identify number of persons in each sector
18	99%
0	85%
-18	2%

Thank you.

Questions ?