Qualcom



Deep Learning Frameworks for Unsupervised Indoor Wi-Fi Positioning

Qualcomm Al Research

Presenter: Farhad G. Zanjani (Al researcher, Qualcomm Technologies Netherlands B.V.)

NeurIPS Demo



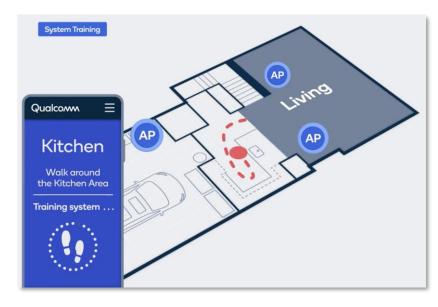


Indoor (Passive) Wi-Fi Localization

Problem: Localizing a person on a floor plan of building using Wi-Fi APs

We assume the following is available:

- Floor plan sketch or CAD
- Sequences of Channel State Information (CSI) while a person walking through the environment
- For each room, some labeled CSI samples









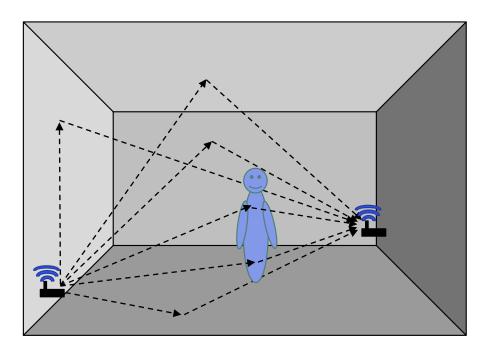
Multipath effect in passive Wi-Fi sensing:

- The measured Wi-Fi signal is the summation over the many different paths from Tx to Rx
- Channel State Information is defined as:

$$CSI_i = \sum_{k=0}^{K} r_k \cdot e^{-j2\pi f_i \tau_k}$$

- In equation form:
 - *K*: the number of paths
 - r_k : is attenuation
 - τ_k: is the propagation delay (length of path / speed of light)
 - f_i : frequency for sub-carrier i

In our experiments: 10 CSI packets 208 sub-carriers 8 antennas



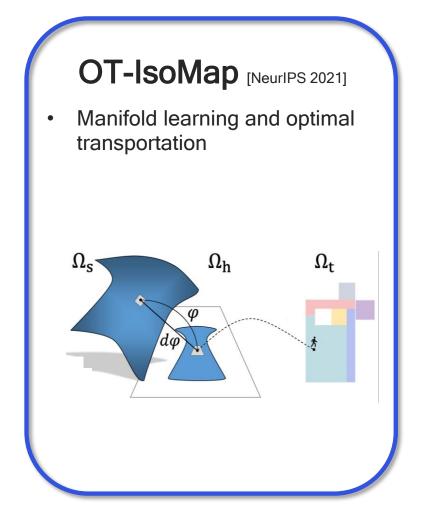
Multipath phenomenon in passive Wi-Fi sensing

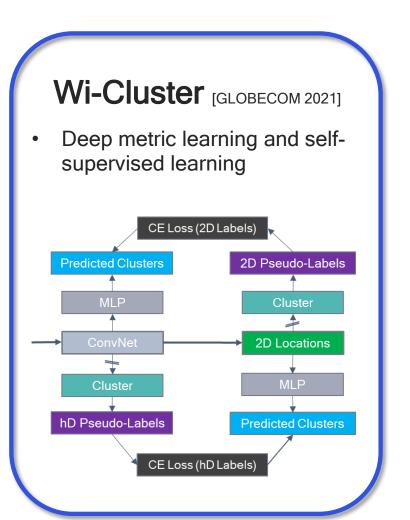




Our solutions:

Weakly-supervised deep learning frameworks:









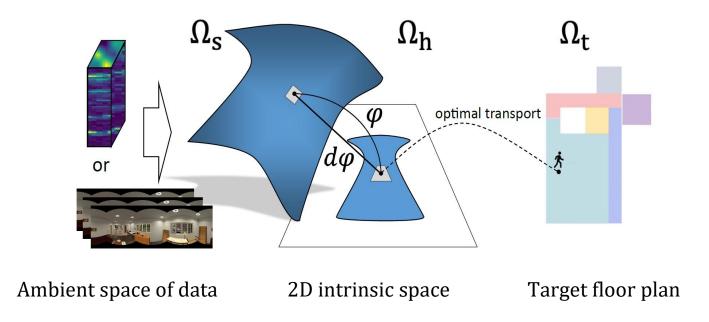
Modality-agnostic topology aware localization, F. G. Zanjani et al., NeurIPS 2021

- Weakly supervised passive Wi-Fi positioning
- Framework: manifold learning and optimal transportation





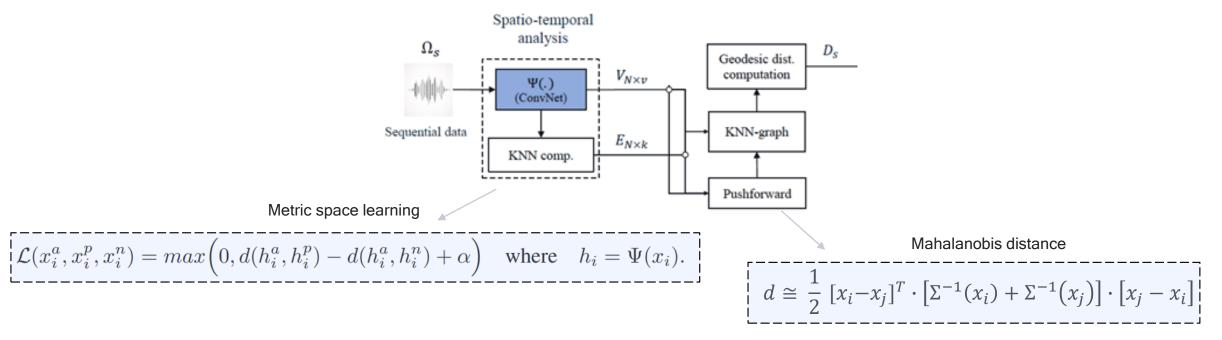
- Displacement of observer in the environment correspondence with 2D/3D intrinsic space of data
- Learning a parametric mapping (Φ) into an isometric 2D space is hard
- Learn a mapping that preserves the isometric while minimizing the transportation cost into a target map







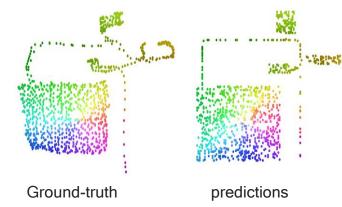
- 1. Estimating the distance matrix in 2D space
 - Construct a KNN graph after finding KNN samples
 - The distance between adjacent vertices is computed by Mahalanobis distance
 - The distance between non-adjacent vertices is computed by Dijkstra shortest path algorithm

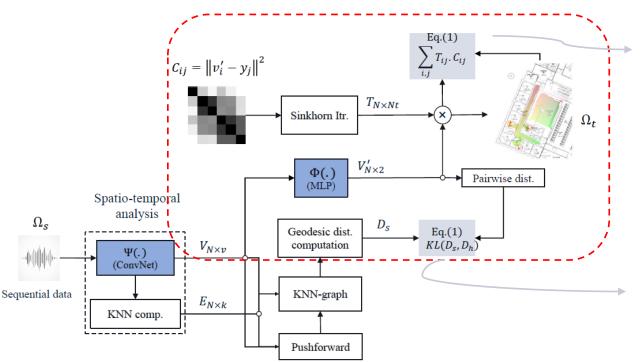






- 1. Estimating the distance matrix in 2D space
- 2. Learning a parametric map (Φ) into 2D space
 - Isometric embedding: distances should have similar distribution
 - Layout similarity: minimal cost under optimal transportation





Layout similarity

$$T(C, p, q) = argmin\langle T, C \rangle - \frac{1}{\lambda}H(T)$$
$$T \in \gamma(p, q)$$

Cost matrix:
$$C_{ij} = \alpha_{ij} \|\Phi(x_i) - y_i\|^2$$
 (Densely) sampled points from $\Omega_t \in \mathbb{R}^2$

Isometric embedding

 $\min D_{KL}(D_s||D_h)$, where $D_s, D_h \in \mathbb{R}^{N_s \times N_s}$

 D_s : Geodesic distance matrix of samples in \mathbb{R}^M D_h : Euclidean distance matrix of samples in \mathbb{R}^2





WiCluster

WiCluster: Passive Indoor 2D/3D Positioning using Wi-Fi without Precise Labels, I. Karmanov et al. GLOBECOM 2021

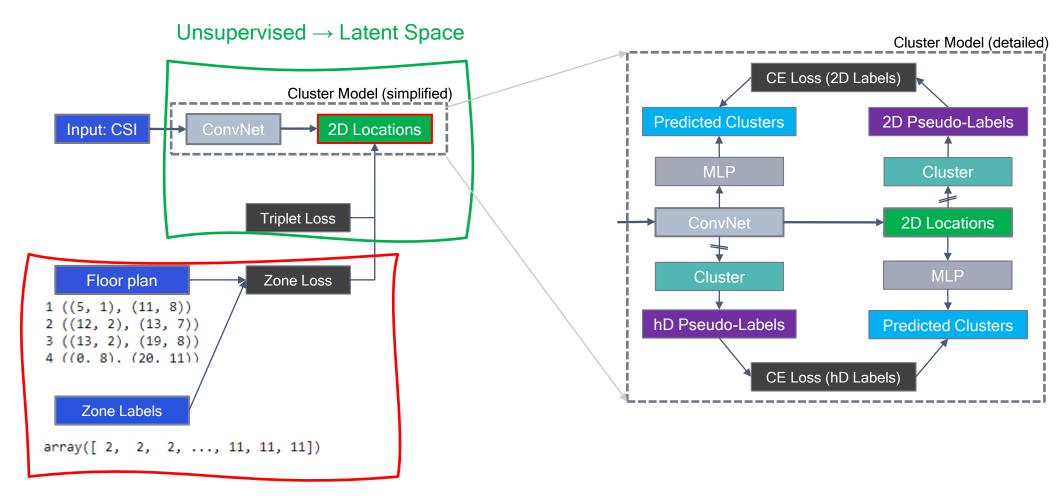
- Weakly supervised passive Wi-Fi positioning
- Framework: Deep metric and self-supervised learning





WiCluster

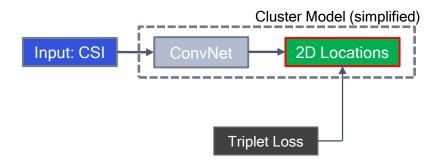
Full Architecture Diagram

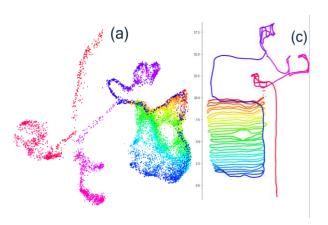


Weakly Supervised → Cartesian Map



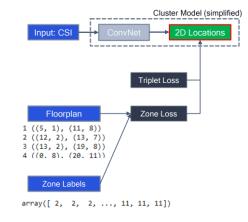
Unsupervised Component











Cluster Loss

$$\min_{C \in \mathbb{R}^{d \times k}} \frac{1}{N} \sum_{n=1}^{N} \min_{y_n \in \{0,1\}^k} ||f_{\theta}(x_n) - Cy_n||_2^2 \quad \text{s.t.} \quad y_n^{\top} 1_k = 1$$

$$L_C = -\frac{1}{N} \sum_{i=1}^{N} \log p(y_i | x_i)$$

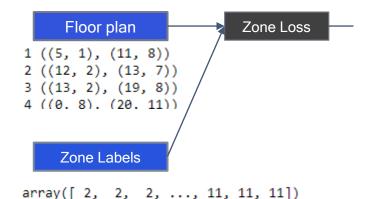
Triplet Loss

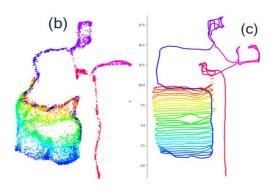
$$L_T = \frac{1}{N} \sum_{(i,j,k) \in \mathcal{T}} \max(0, (d(x_i, x_j) - d(x_i, x_k) + M_t))$$

$$d(x, x') = \|f_{\theta}(x) - f_{\theta}(x')\|$$

WiCluster Architecture

Weakly-supervised Component





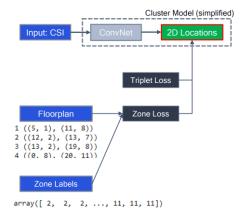
Zone Loss $L_Z = \frac{1}{N} \sum_{i=1}^{N} \max \left(0, d_m(x_i, B)\right)$

$$[B_{zone}] = ([x_0, y_0], [x_1, y_1])$$

$$d_m(x,x')$$











Experiments

Localization in Wi-Fi

 Four commercial IEEE 802.11 access points (AP), 5 GHz band

• Sensing area: **14×20** meters

Tx antenna: 1Rx antennas: 8

• Circular array with 4cm radius

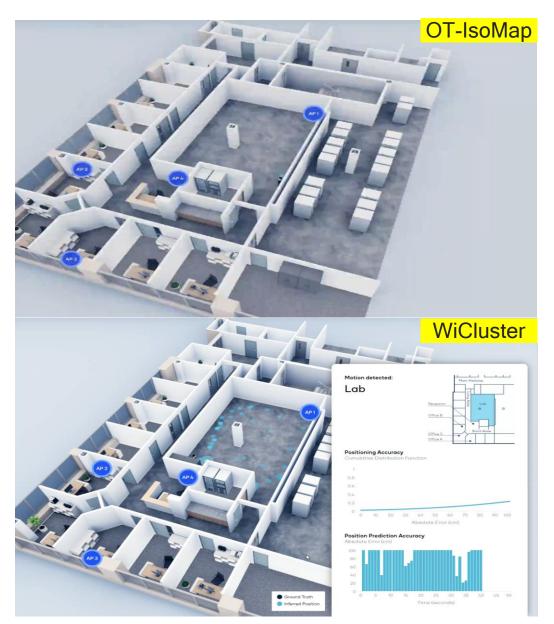
• BW: **80** MHz

• **208** frequency tones

Packet rate: 100 Hz

• Mean error: **1.2** m









Summary

- Weakly supervised learning shown meter level accuracy in Wi-Fi positioning
- The models only require the floor plan image and the zone-level labels
- Advances in Wi-Fi sensing can enable many applications such as surveillance, smart house, automation, etc.

References:

- Modality-agnostic topology aware localization, F. G. Zanjani et al., NeurlPS 2021
- WiCluster: Passive Indoor 2D/3D Positioning using Wi-Fi without Precise Labels, I. Karmanov et al., GLOBECOM 2021

Acknowledgement:

Contributors to the research project and publications: Farhad Zanjani, Ilia Karmanov, Hanno Ackermann, Daniel Dijkman,
 Simone Merlin, Ishaque Kadampot, Steve Shellhammer, Riu Liang, Brian Buesker, Harshit Joshi, Vamsi Vegunta, Raamkumar Balamurthi, Bibhu Monahty, Max Welling, Fatih Porikli

Qualcomm

Thank you

Follow us on: **f y** in **o**

For more information, visit us at:

www.qualcomm.com & www.qualcomm.com/blog

All data and information contained in or disclosed by this document is confidential and proprietary information of Qualcomm Technologies, Inc. and/or its affiliated companies and all rights therein are expressly reserved. By accepting this material the recipient agrees that this material and the information contained therein will not be used, copied, reproduced in whole or in part, nor its contents revealed in any manner to others without the express written permission of Qualcomm Technologies, Inc. Nothing in these materials is an offer to sell any of the components or devices referenced herein.

©2018-2021 Qualcomm Technologies, Inc. and/or its affiliated companies. All Rights Reserved.

Qualcomm is a trademark of Qualcomm Incorporated, registered in the United States and other countries. Other products and brand names may be trademarks or registered trademarks of their respective owners.

References in this presentation to "Qualcomm" may mean Qualcomm Incorporated, Qualcomm Technologies, Inc., and/or other subsidiaries or business units within the Qualcomm corporate structure, as applicable. Qualcomm Incorporated includes our licensing business, QTL, and the vast majority of our patent portfolio. Qualcomm Technologies, Inc., a subsidiary of Qualcomm Incorporated, operates, along with its subsidiaries, substantially all of our engineering, research and development functions, and substantially all of our products and services businesses, including our QCT semiconductor business.