D3PicoNet: Enabling Fast And Accurate Indoor D-Band Millimeter-Wave Picocell Deployment

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Research Motivation
Emerging Applications Stress Wireless Networks

Virtual reality

Data Rate: 10s of Gbps
Latency: 1-10 ms

V2V connectivity

Smart manufacturing

Smart city planning
Millimeter-Wave and D-Band

Wi-Fi and LTE

Millimeter-wave

D-Band: 110 GHz to 170 GHz

Millimeter-wave (30 GHz to 300 GHz)

Wavelength: 10 mm to 1 mm
Challenges of Millimeter-Wave Networks

Path loss

MacCartney, et al., 2013
Challenges of Millimeter-Wave Networks

LTE coverage area
5G-NR coverage area
High frequency, small coverage

Moayyed, et al., 2021
Moayyed, et al., 2021
Picocell
Challenges of Millimeter-Wave Networks

Frequent outage due to blockages

Picocell

Pedestrian

Client

Frequent outage due to blockages

Need reflectors to keep client connected

Reflector
Challenges of Millimeter-Wave Networks

- High frequency, small coverage
- Frequent outage due to blockages

We must deploy more picocells carefully for reliable connectivity
Indoor Environment
Indoor Environment
Possible Ways for Link Connectivity

- Picocell
- Beam Pattern
- Blockage

- Client with Link
- Client without Link
- Strong Reflectors

Line-of-Sight (LoS) Path
Possible Ways for Link Connectivity

Non-Line-of-Sight (NLoS) Path
Possible Ways for Link Connectivity

- Picocell
- Beam Pattern
- Blockage
- Client with Link
- Client without Link
- Strong Reflectors

It highlights the need for correct picocell deployment locations
Possible Ways for Link Connectivity

How can we deploy picocells correctly based on surrounding reflectors?
Effect of Multiple Picocell Locations
Effect of Multiple Picocell Locations

- strong reflector 1
- strong reflector 2
- strong reflector 3
- strong reflector 4
Effect of Multiple Picocell Locations

picocell

strong reflector 1

strong reflector 2

LOS is blocked

strong reflector 4

strong reflector 3
Effect of Multiple Picocell Locations
Effect of Multiple Picocell Locations

LOS is blocked
Effect of Multiple Picocell Locations

LOS is blocked

client 1

client 2

client 3

client 4

picocell 1

picocell 2

strong reflector 1

strong reflector 2

strong reflector 3

strong reflector 4
Effect of Multiple Picocell Locations

picocell 1

los is blocked

client 1

client 2

client 3

client 4

picocell 2

strong reflector 1

strong reflector 2

strong reflector 3

strong reflector 4
Brute-Force Search?

Link: 7
No Link: 8
Brute-Force Search?

Link: 8
No Link: 7

strong reflector 1

strong reflector 2

strong reflector 3

strong reflector 4
Brute-Force Search?

Link: 11
No Link: 4

strong reflector 1

strong reflector 2

strong reflector 3

strong reflector 4
Understanding the Environment

How visual camera sees

How mmWave device sees

Can we use visual camera input to predict Signal Reflection Profile (SRP)?
Our Proposed Approach

Measured SRPs

Loc 1

Loc N
Our Proposed Approach

Measured SRPs

Predicted SRPs
Challenges in Predicting SRP from Visual Data

- Different Field-of-View of visual AR device and mmWave device
- Non-linearity between visual depth image and signal reflection profile
- Inaccuracy in transfer-learning to new environment
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System Overview

SRP Prediction
- Point Cloud Data, Pose, Reflected Signals
  - Data Synchronization & Preprocessing
  - Deep Convolutional Neural Networks

Picocells Deployment
- Predicted SRPs at Multiple Locations
  - Deployment Algorithm
  - Picocell Locations, Data Throughput, & Coverage
Different Field-of-View (FoV)

- Different Field-of-View of visual AR device and mmWave device
- Non-linearity between visual depth image and signal reflection profile
- Inaccuracy in transfer-learning to new environment

Data preprocessing is necessary to correct different field-of-view of devices
Data Preprocessing

- Global PCD
- Local PCD (FoV = θ)
- Inverse Depth Image
- 2D Projection
- Transceiver Pose
- Beam Pattern
- Fixed Field-of-View (FoV)
- DCNN Input
- Masking
- Transceiver Pose
- Masked Inverse Depth Image (MIDI)
Challenges in Predicting SRP from Visual Data

- Different Field-of-View of visual AR device and mmWave device
- Non-linearity between visual depth image and signal reflection profile
- Inaccuracy in transfer-learning to new environment

Complex non-linear models are necessary to predict SRPs from visual depth images
Base Model

Visual PCD

Field-Of-View (FOV)

mmWave Transceiver

Depthwise Convolution

Pointwise Convolution

4x4x1280

1x128

1x64

1x6

MobileNetV2 Convolution Layers

FC Layers

mmWave transceiver pose

Signal Strength (dB)

Distance of the Signal Reflectors (m)

SRP of Env A.1
Challenges in Predicting SRP from Visual Data

- Different Field-of-View of visual AR device and mmWave device
- Non-linearity between visual depth image and signal reflection profile
- Inaccuracy in transfer-learning to new environment

Semantic features are necessary to adopt the model for new environments
Picocells Deployment Algorithm

Ray-tracing Simulation

- Tx Pos. 1
- Tx Pos. 2
- Tx Pos. K
- Tx Pos. N

SRPs

SRP Prediction Model

SRPs + Noise

Noise

Picocell Location 1

Picocell Location 2

Picocell Location K

Picocell Location Q

K available picocells
Data Collection Platform

- Center frequency: 122 GHz
- Bandwidth: 1 GHz
- AR Google Tango

- 4.2M data samples
- 16 diverse environments
- 420K for training
- 3.8M for testing
Base Model Performance

SRP Prediction Error (dB)

Env A.1  Env A.2  Env A.3  Env A.4
Average median SRP prediction error is 3.0 dB across 4 diverse environments
Median SRP prediction error reaches 8 dB when tested with different floor of similar surroundings.
Improvement in SRP Prediction
Improvement in SRP Prediction

Semantic aware model reduces SRP error from 8 dB to 2.2 dB with limited fine-tuning
D3PicoNet consistently deploys picocells to cover more areas than Random placements.
Conclusion

- D3PicoNet accurately predicts SRP across diverse environments
- Semantic-aware model facilitates transfer-learning
- Accurate SRP prediction enables optimal picocell deployment

Thank you!

Check out our group website for more results

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