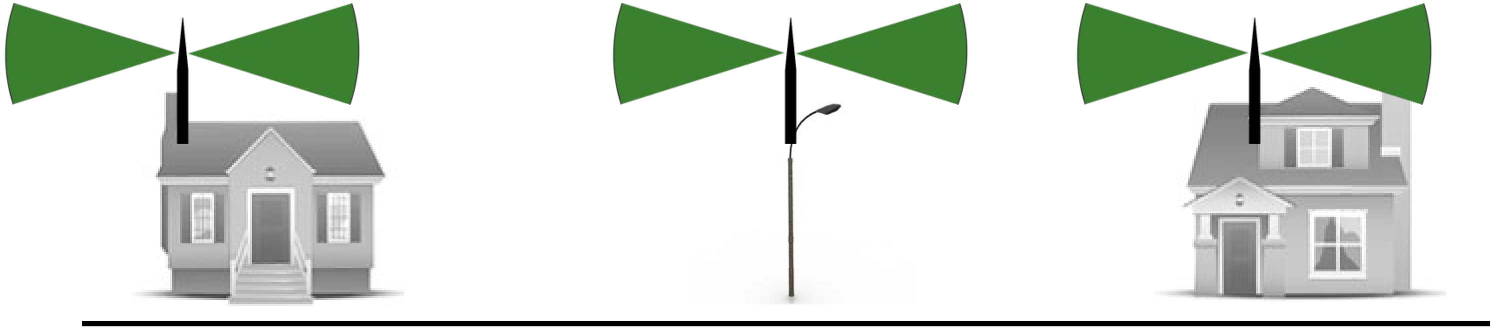
Adaptive Antenna Adjustment for 3D Urban Wireless Mesh Networks

Guoqing Yu, **Wei Wang**, James Yong,
Ben Leong, and Wei Tsang Ooi

School of Computing
National University of Singapore

Introduction

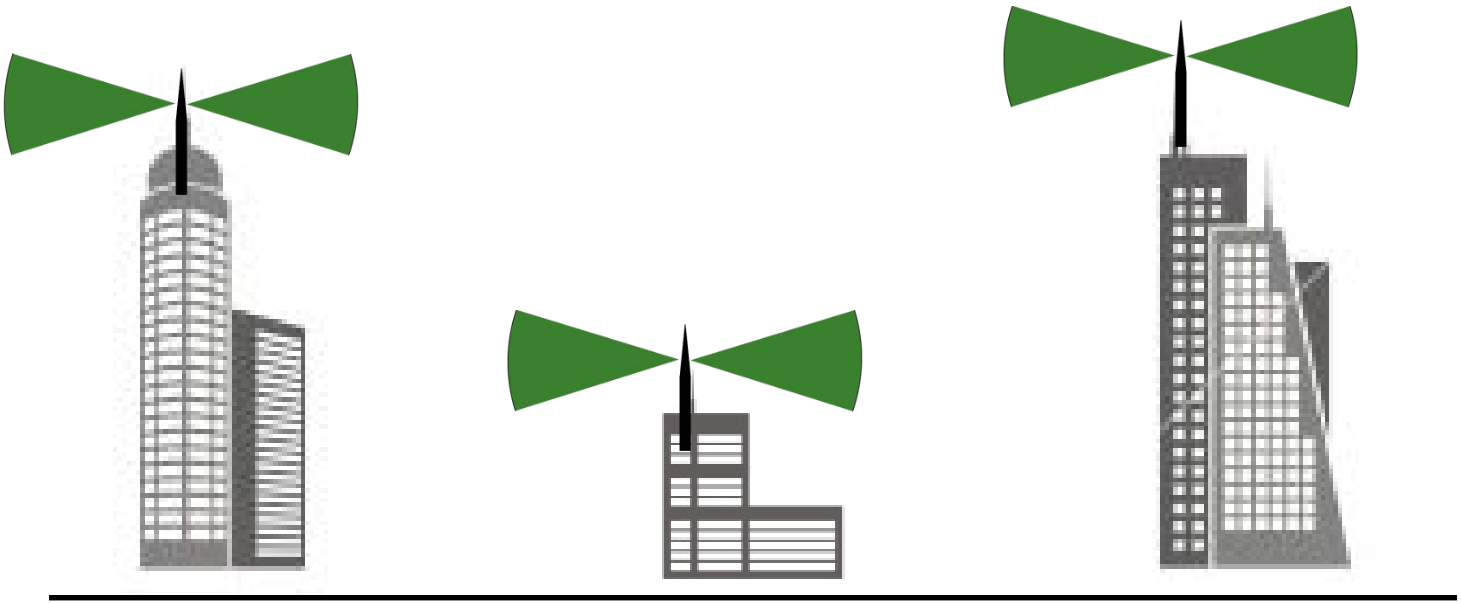
Most existing mesh networks are deployed in a **2D plane**.



The default **vertically-upright orientation** of antenna works well in 2D.

Introduction

3D urban mesh networks



Clearly, vertically-upright orientation no longer optimal.

How do we find **good antenna orientation**?

Challenges

The search space of orientations is **HUGE!**

- Antenna orientation has 2-degree of freedom
- Complexity increases exponentially with the number of antennas
- Take time to probe an orientation

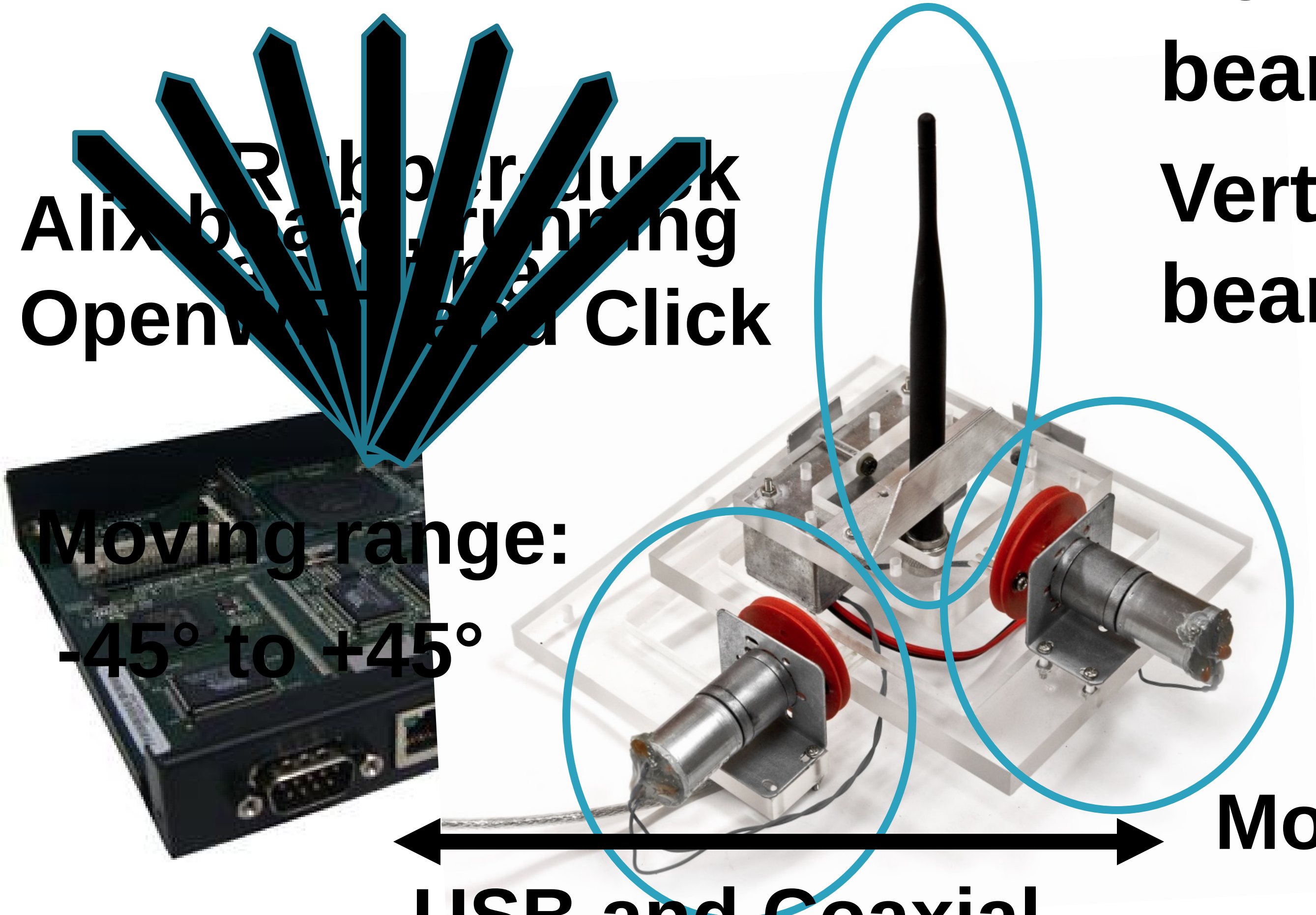
Impractical to probe all the orientations.

Need an efficient way to find a good orientation!

Our Contributions

- Design and implement low-cost mobile-antenna nodes (called **Dyntenna** node) for a 3D urban mesh testbed
- Measure the effect of antenna orientation in 3D urban mesh
- Develop a basic **antenna adjustment algorithm** to find a good orientation and improve throughput

Dyntenna Node



Rubber-duck antenna

Alix board, running OpenWRT and Click

Moving range:

-45° to +45°

Horizontal beamwidth: 360°

Vertical beamwidth: 90°

< $100

Motor, Y-axis

USB and Coaxial

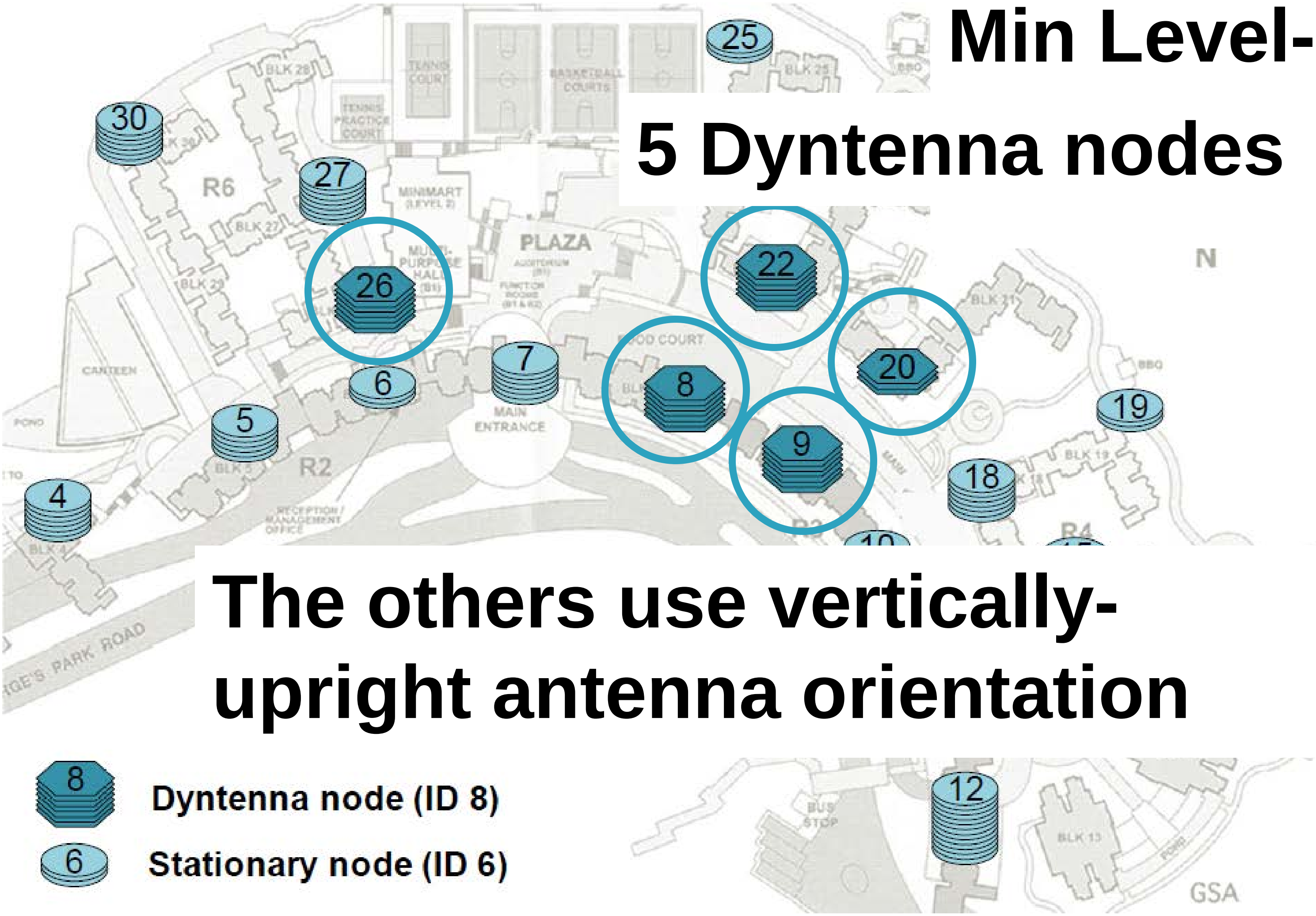
Motor, X-axis

3D Mesh Testbed

Min Level-3

5 Dyntenna nodes

The others use vertically-upright antenna orientation



RSSI Map

An intuitive way to describe the **effect of antenna orientation on RSSI** for a link

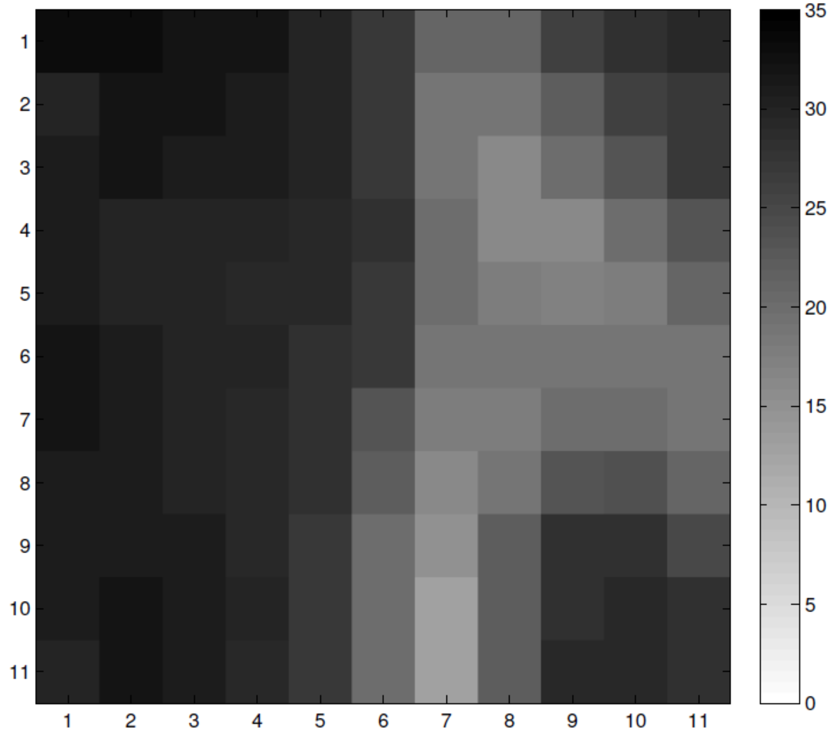
-45° to +45° range

↓

11 steps in each axis,
9° of each step

↓

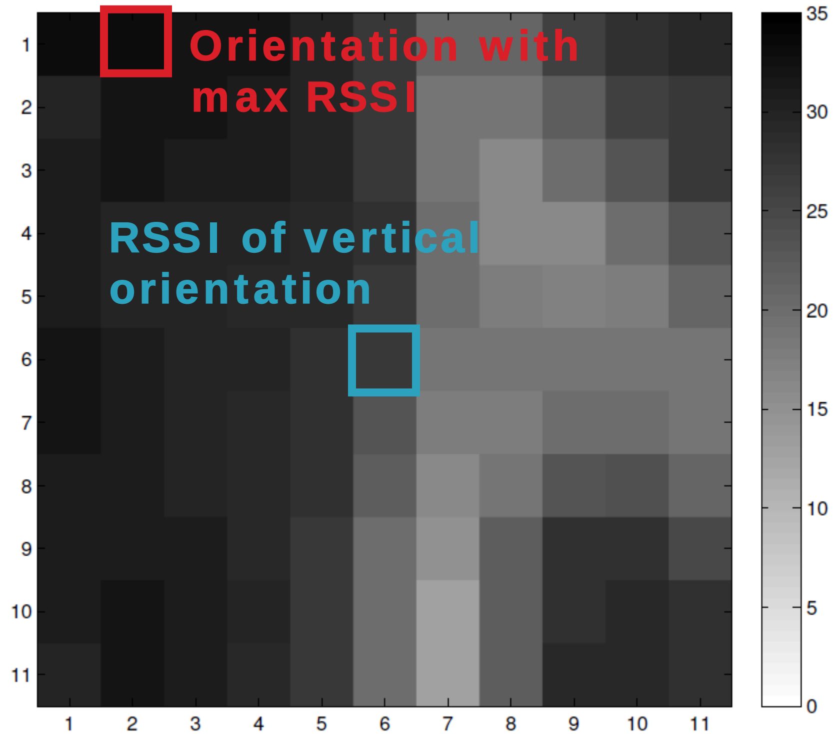
Total 11x11 = 121 antenna orientations



An 11x11 RSSI map

Key Observations

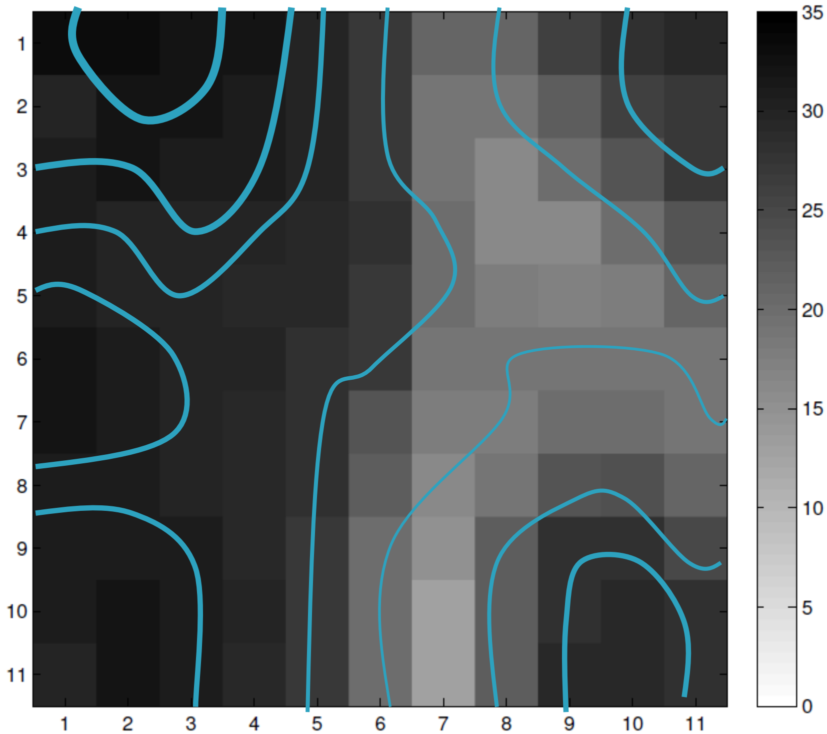
The default vertical orientation **may NOT have the optimal RSSI.**



Median RSSI difference between vertical and optimal orientations is about **5dB**.

Key Observations

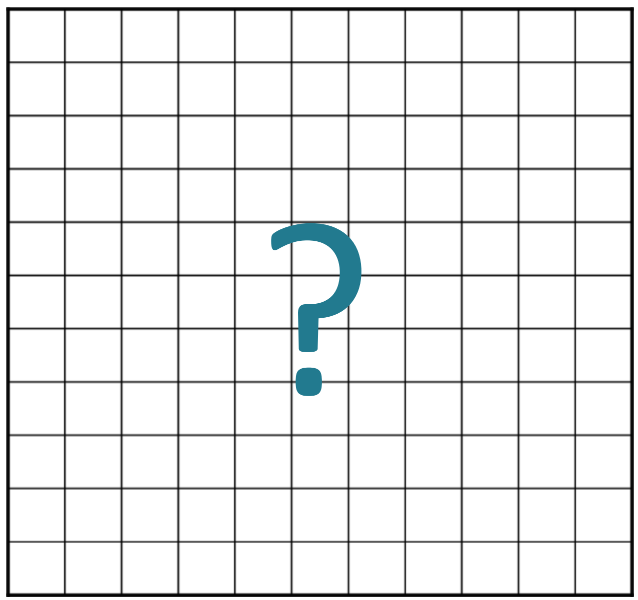
RSSI values vary **smoothly** with antenna orientation.



Idea: develop **efficient algorithm** to estimate the RSSI map with small number of probes.

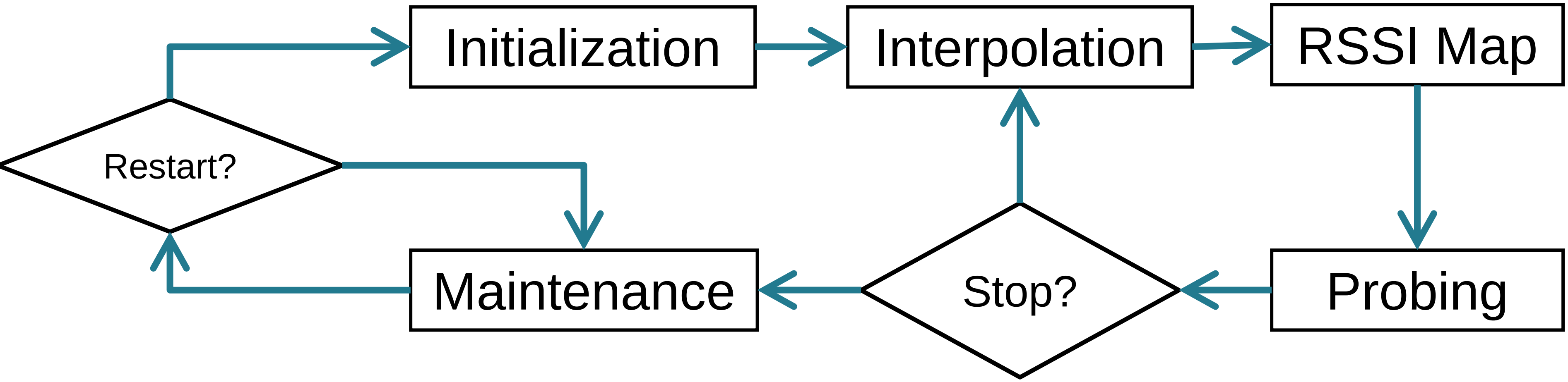
Antenna Adjustment Algorithm

Goal: find the orientation with **maximum RSSI**, using the least probing steps.

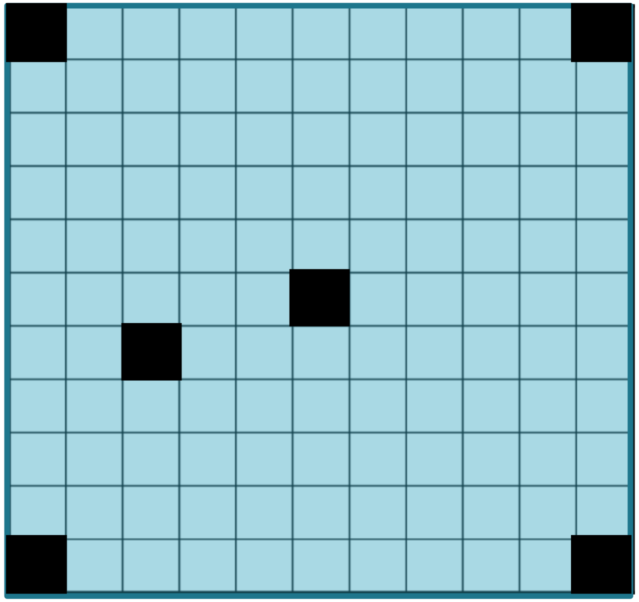


Only one Dyntenna moving at one time

Algorithm Overview



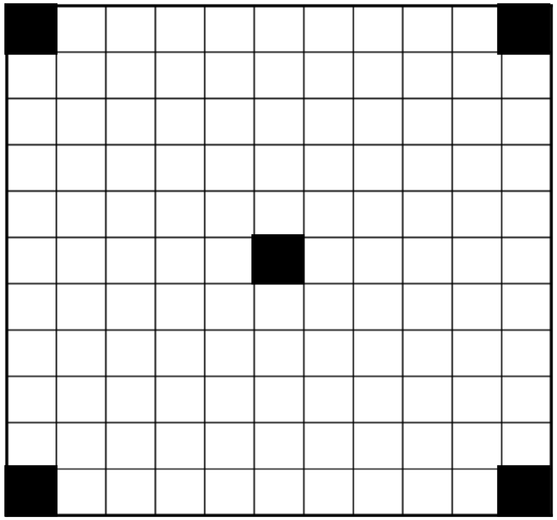
- [illegible] phase.



Anchor Orientations

A trade-off:

- Fewer anchor orientations
  - Larger error of subsequent interpolation
- More anchor orientations
  - May not be necessary

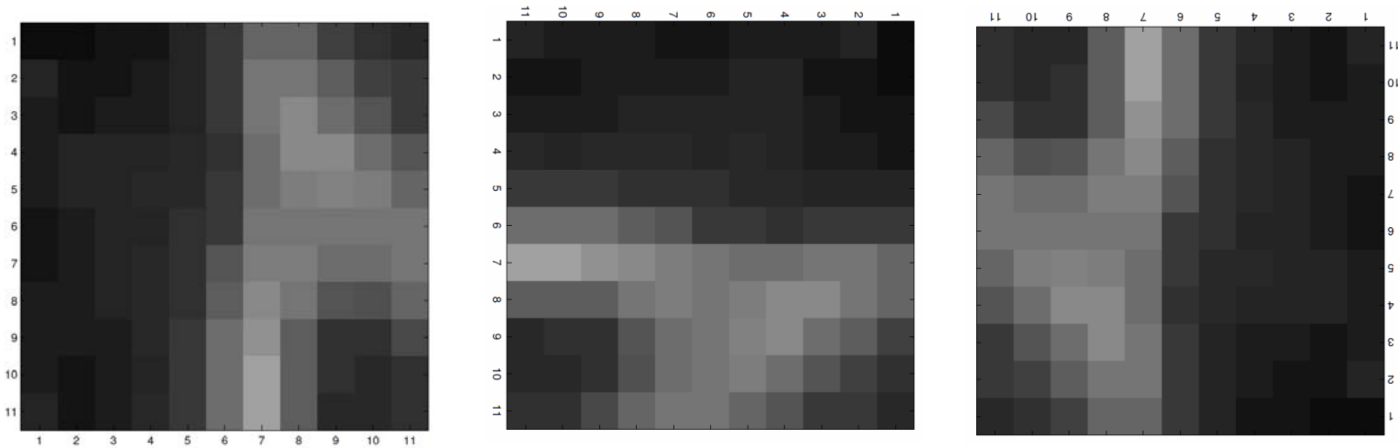


Best, according to offline simulation

Linear Interpolation

- Delaunay-triangulation based
  - Fast
  - Sufficiently accurate
- Also tried Cubic Interpolation
  - Computationally more expensive
  - No big improvement in accuracy

Multiple Links and RSSI Maps



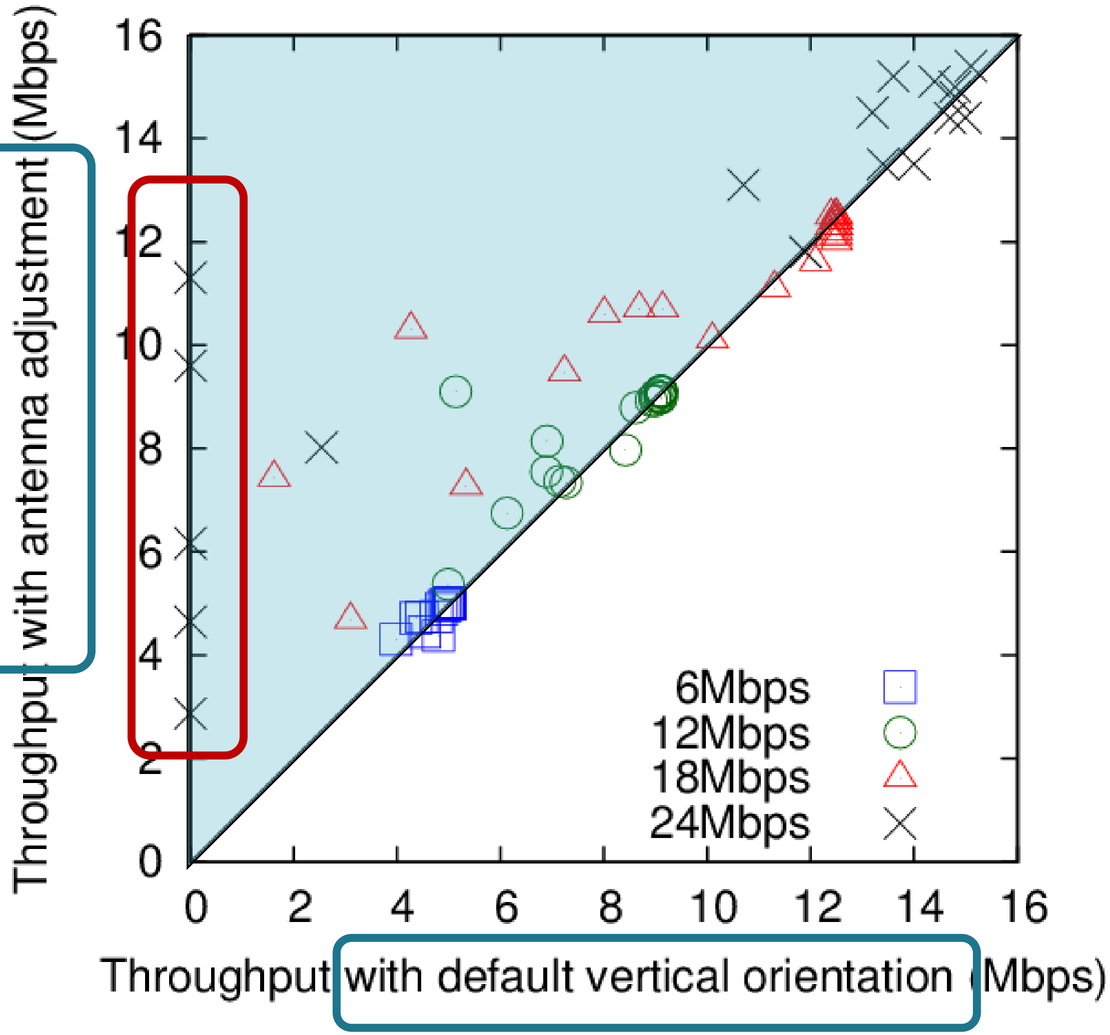
Dyntenna node may have more than one neighbor

- Take the sum, and get “Aggregate RSSI Map”
- Ignore the orientations that may break a link, e.g. RSSI < 9dB

Evaluations

- 3D 20-node urban mesh testbed
- MIT Roofnet (Srcr) as the routing protocol
- **How much throughput improvement can Dyntenna achieve?**
  - Single-hop Single-flow (92 samples)
  - Multi-hop Single-flow (260 samples)
  - Single-hop Multi-flow (15 samples)

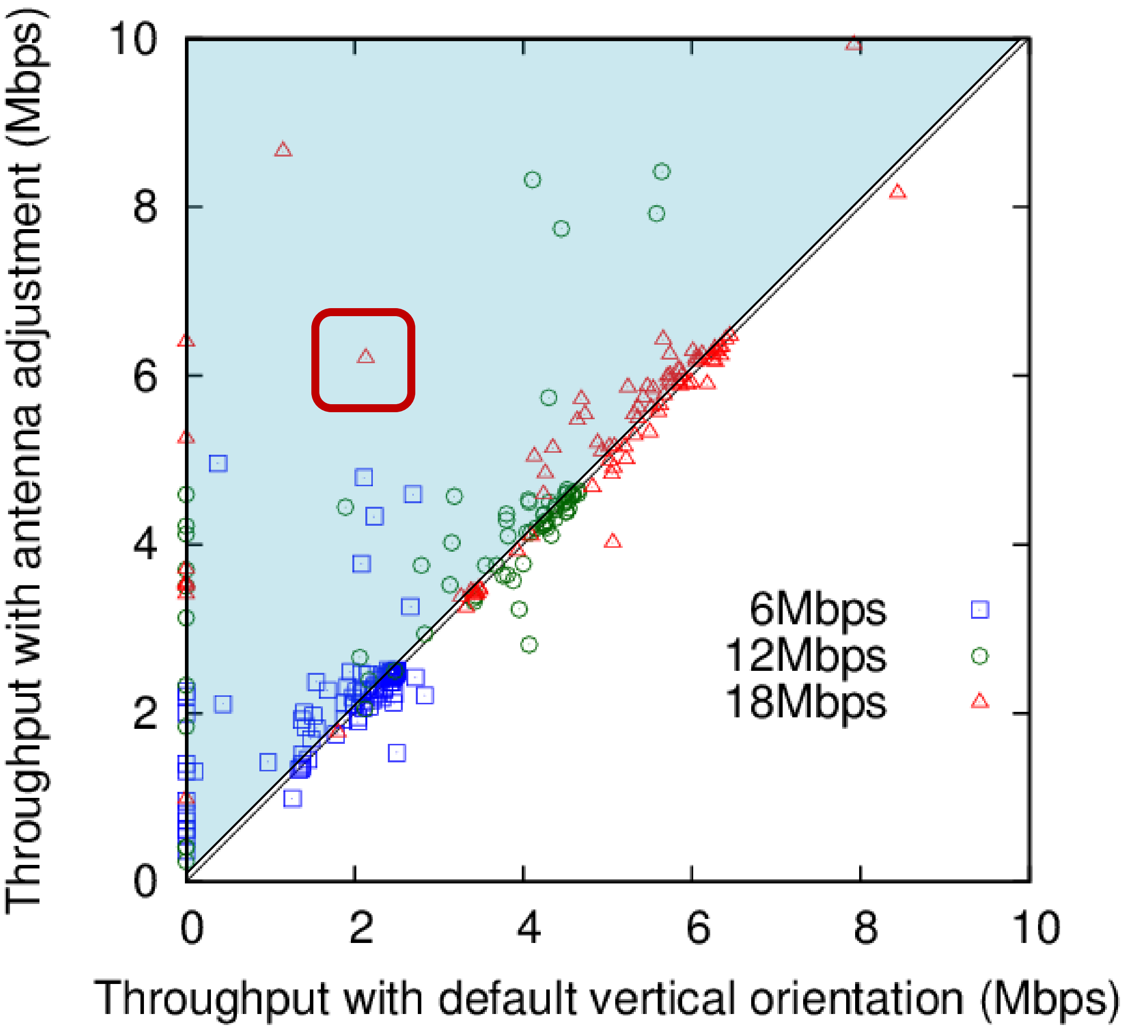
Evaluations



Single-hop, Single-flow

- 92 samples
- 26% of them have median throughput improvement of 31%

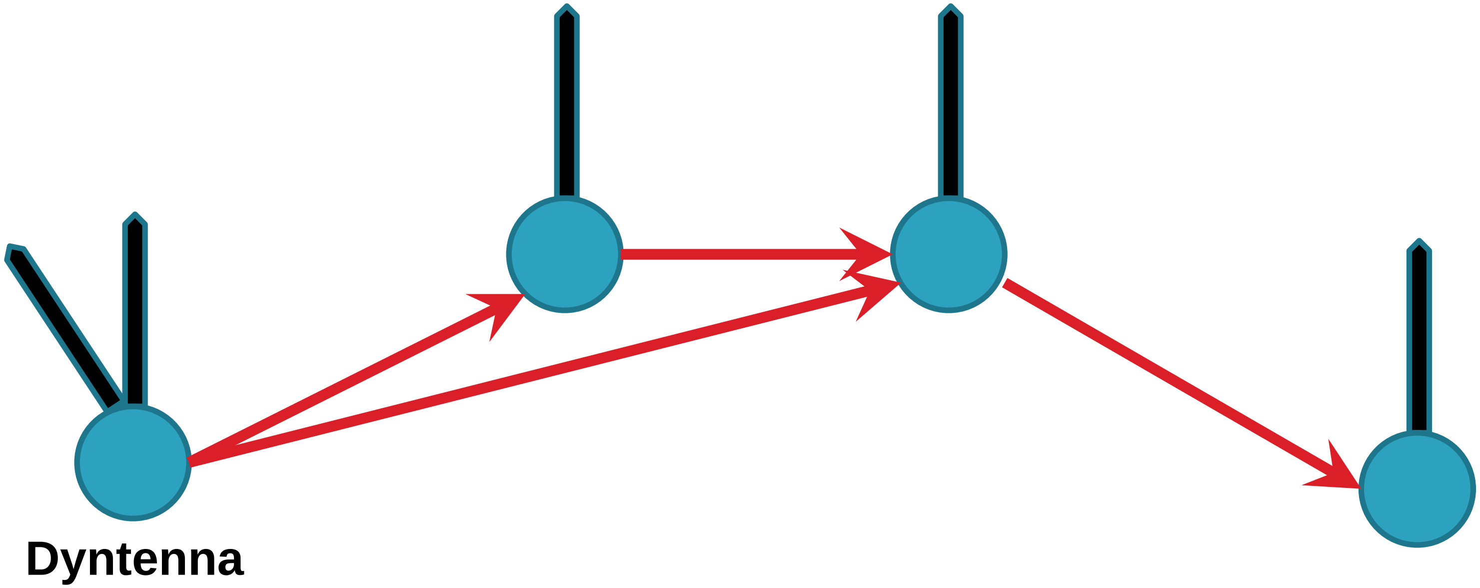
Evaluations



Multi-hop, Single-flow

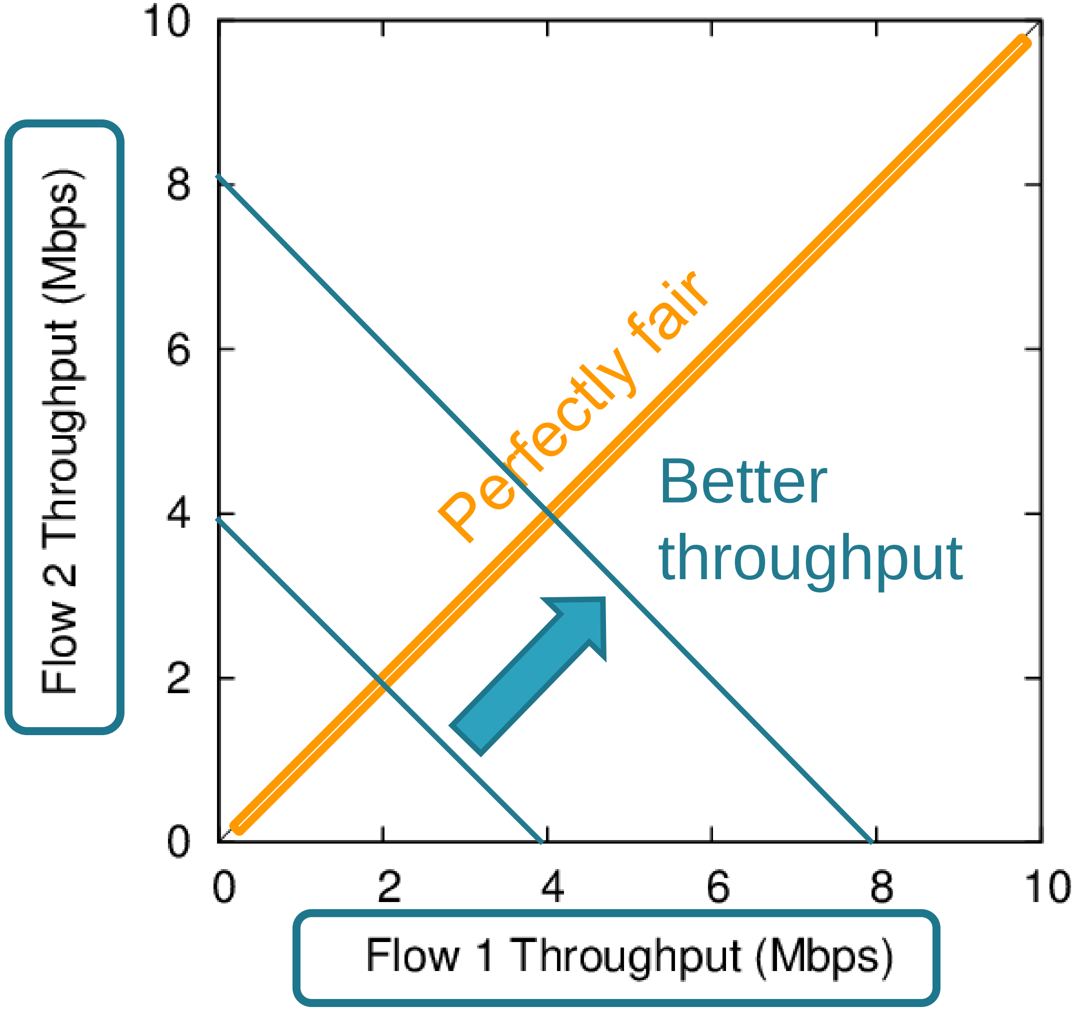
- 260 samples
- 35% of them have median throughput improvement of 46%.

Evaluations



- Originally 3-hop route by Roofnet
- After antenna adjustment, Roofnet finds a better 2-hop route

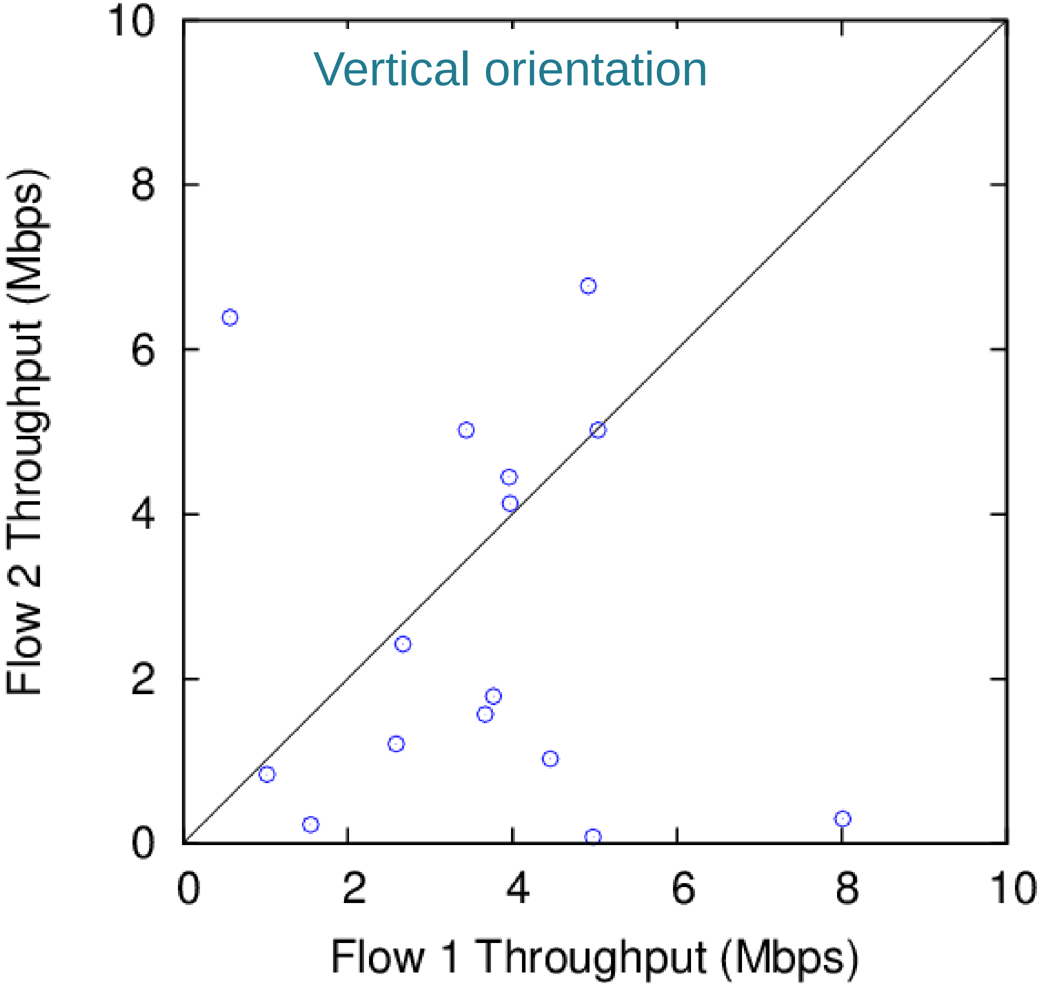
Evaluations



Single-hop, two-flow

- 15 link-pairs

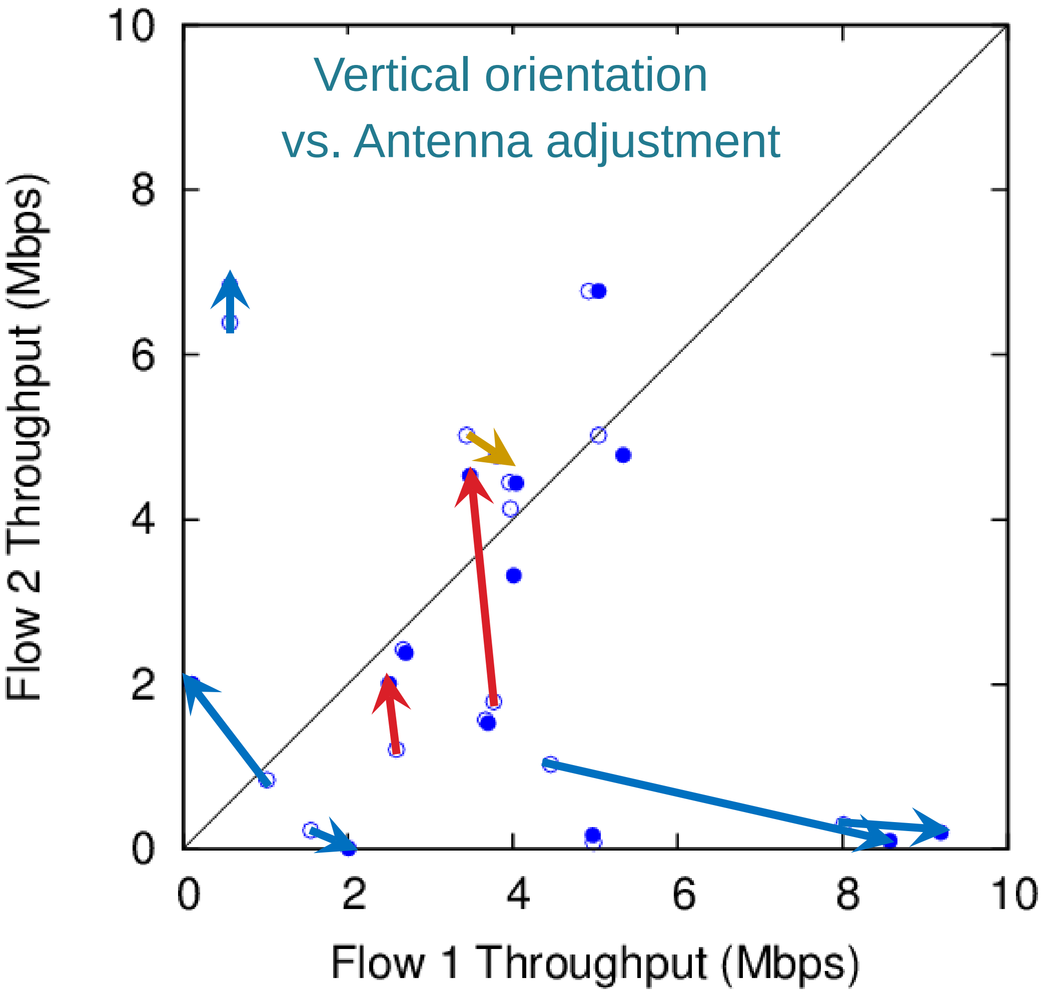
Evaluations



Single-hop, two-flow

- 15 link-pairs

Evaluations



Single-hop, two-flow

- 15 link-pairs
- Dyntenna can improve throughput or fairness or both.

Conclusion

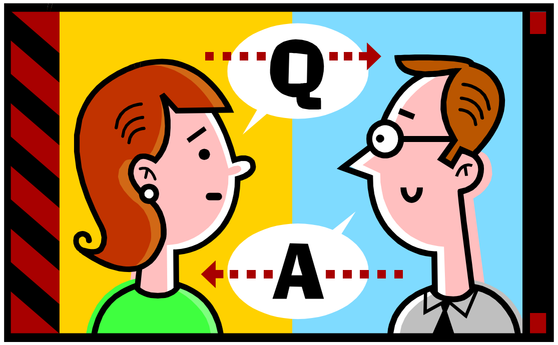
- Default vertical antenna orientation is rarely optimal for 3D urban mesh network.
- We design and implement Dyntenna to automatically find a good orientation.
- Dyntenna can sometimes greatly increase throughput by choosing the orientation with max RSSI.

Future Work

- Multi-hop multi-flow
- Integration with routing protocol (and rate adaptation)
- Simultaneous adjustment of multiple Dyntenna nodes
- Application to 802.11n radio with multiple antennas

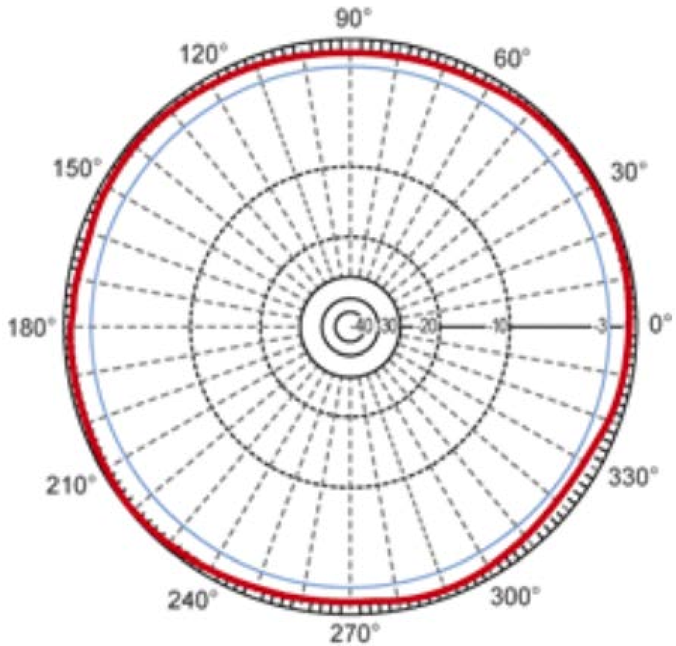
Thank you!

Questions?

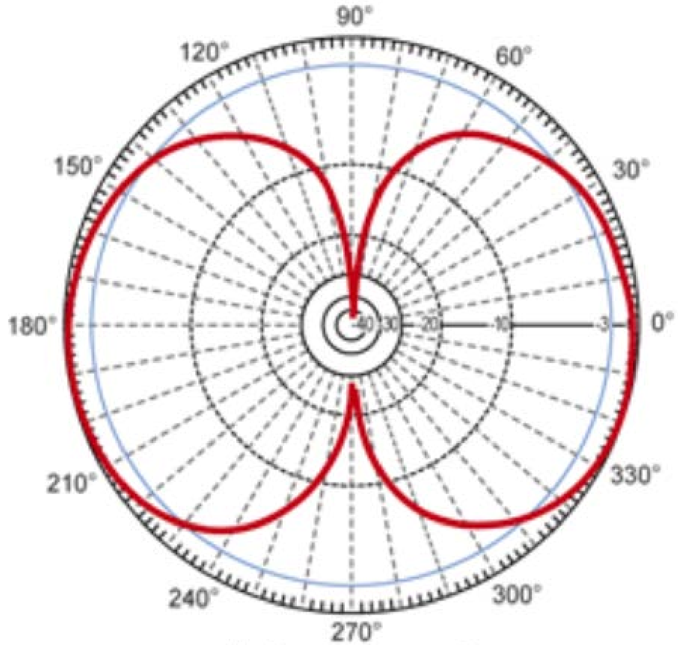


Antenna Radiation Pattern

- Omni-directional, but in 2D only.

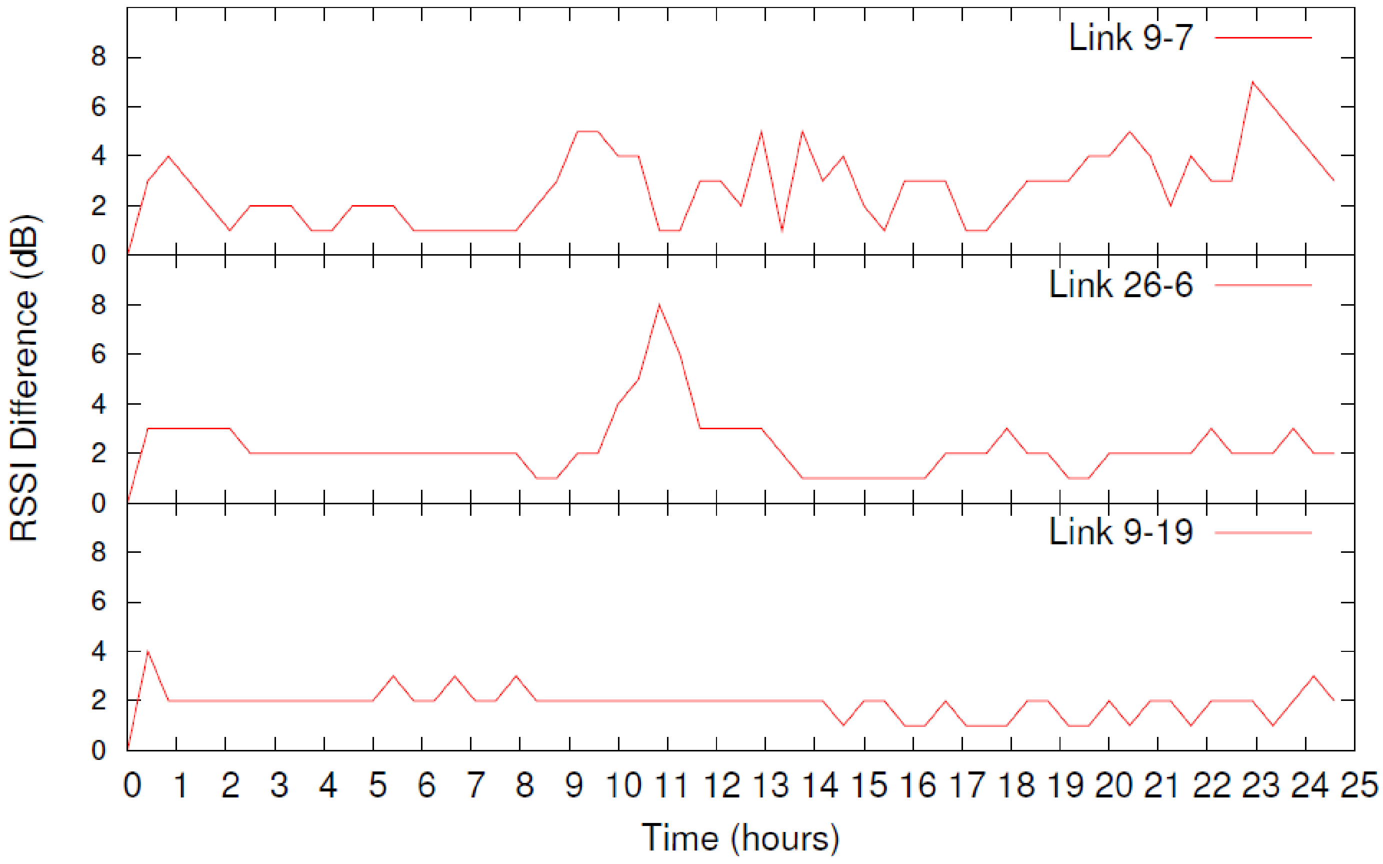


Horizontal

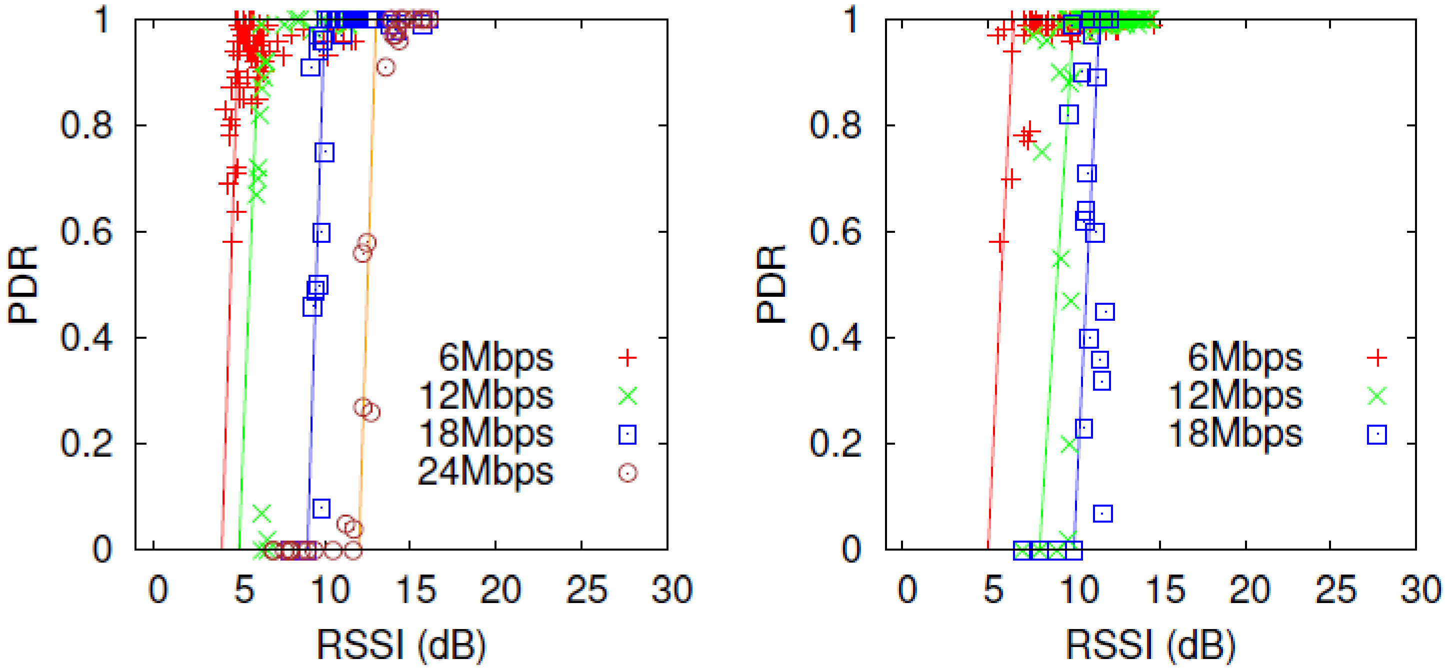


Vertical

RSSI is Stable



RSSI of 9dB as cutoff



(a) Link 9→7 (b) Link 9→10

When to stop?

- Local Minima → Still carry on probing, even if no improvement of max-RSSI
- Stop probing if no improvement in last ***K*** probes
- ***K=3***, according to simulation
- On average, need about 10 steps.

TODO

- Flow chart between pg 10 and 11.
- Check “Optimal”
- Mention “LOCK Dyntenna node”