

Demystifying 60GHz Outdoor Picocells

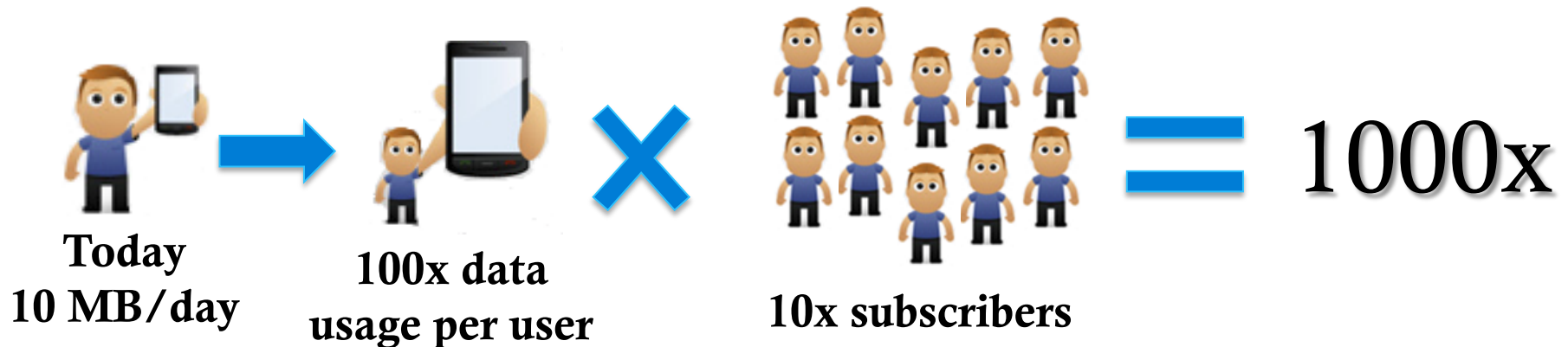
Yibo Zhu, Zengbin Zhang, Zhinus Marzi, Chris Nelson,
Upamanyu Madhow, Ben Y. Zhao and Haitao Zheng

University of California, Santa Barbara

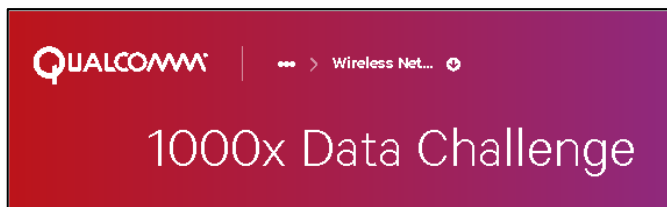
yibo@cs.ucsb.edu

Cellular Network Capacity Crisis

- By 2020, bandwidth requirements are predicted to increase by 1000-fold.



- Industry is aware



NOKIA

Technology Vision 2020 - support up to 1000 times more capacity

September 12, 2013

Current Solutions Are Limited

- To meet the 1000x requirement, we could..
 - Buy more spectrum: (LTE) 100MHz → 100GHz
 - Massively large MIMO arrays: 1000-element array
- In reality, hopefully 2x licensed spectrum and 20x gain from MIMO by 2020
 - Still far from 1000x
- Need drastically different approaches to speed up!



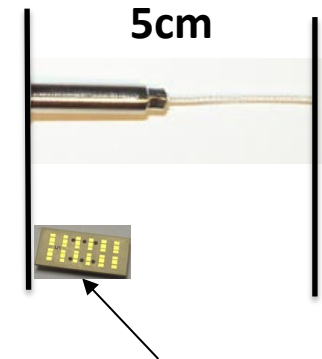
The Promise of 60GHz

- Large *unlicensed* spectrum available.
 - E.g. 7GHz free spectrum at 60GHz band
- Compressed arrays create highly directional beams
 - Narrow beams minimize interference
- Leverage 802.11ad as a great start-point
 - 802.11ad: IEEE indoor 60GHz standard
 - Support **three channels**, up to **6.76Gbps** data rate per channel



Rails for *free*

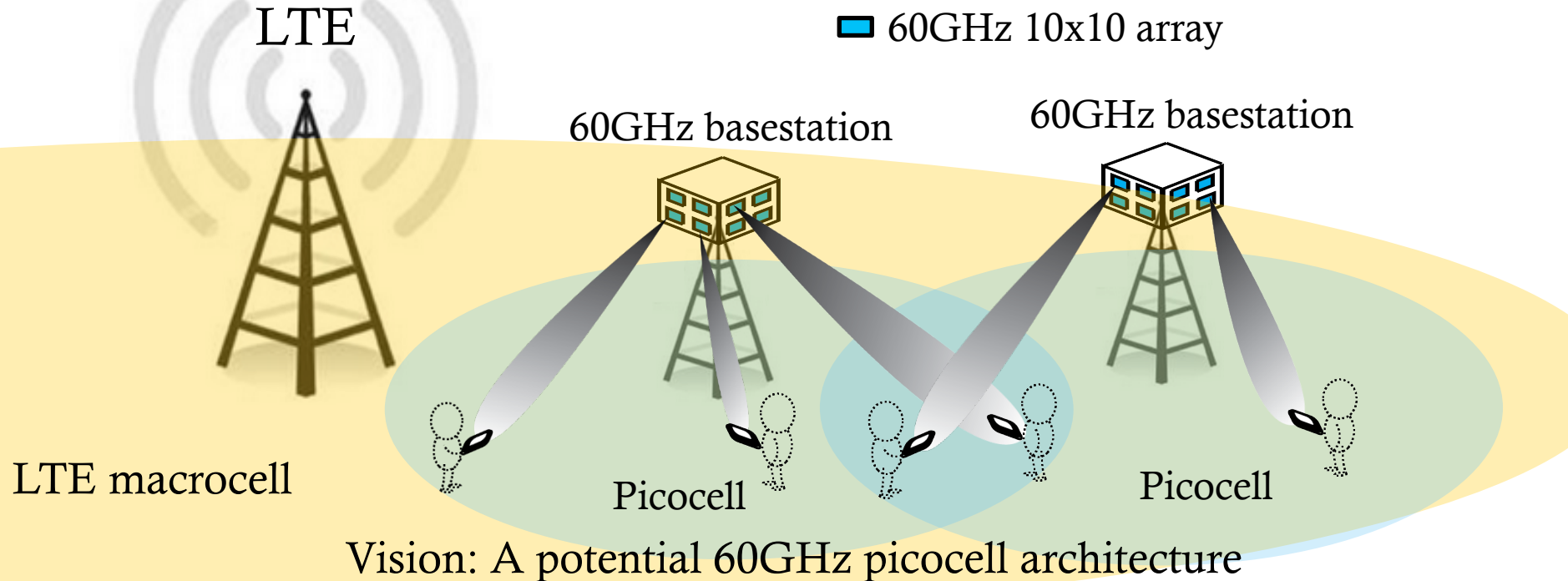
Single element
2.4GHz antenna



60GHz 32-element
Array¹, 1.8cm × 0.8cm

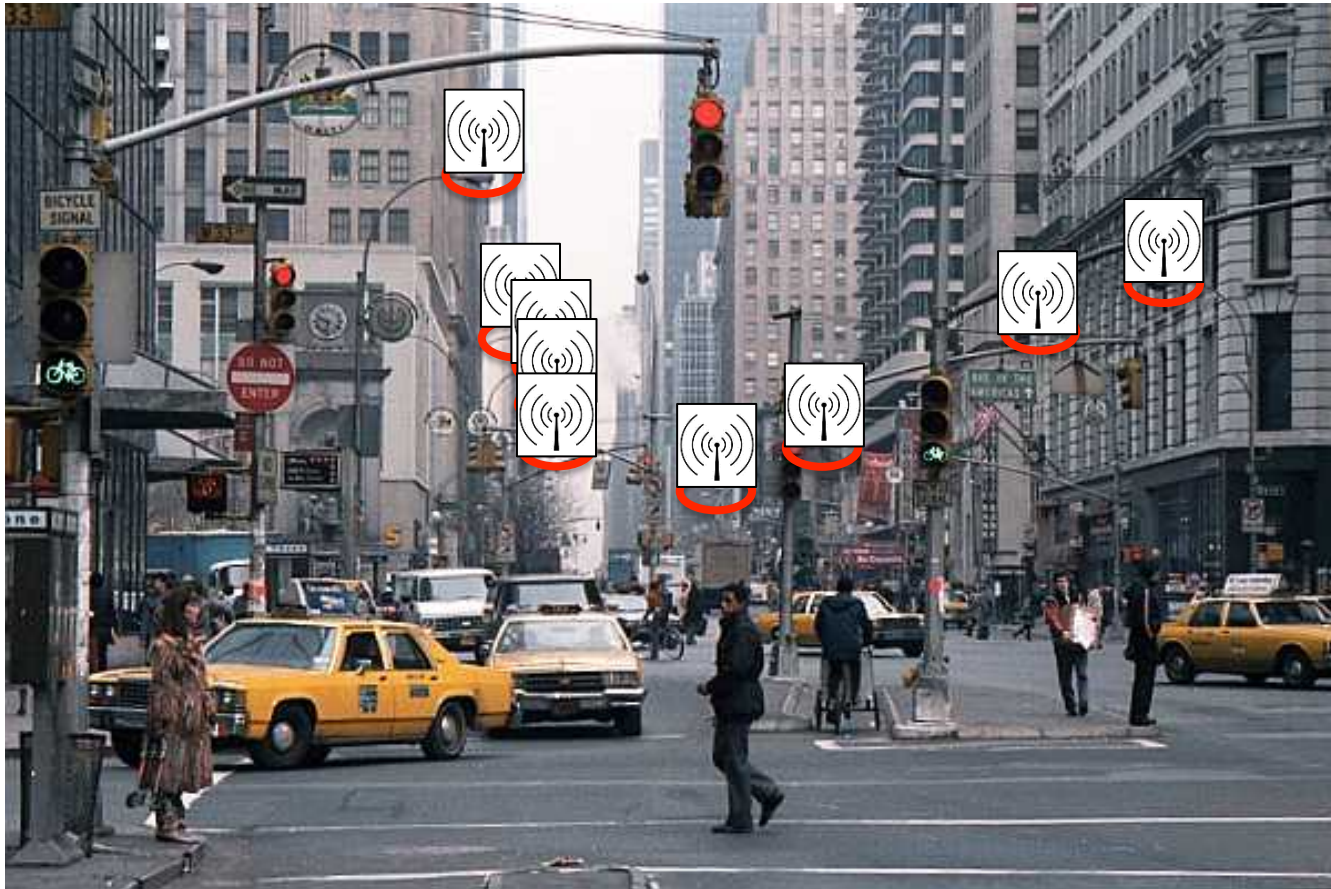
¹Beyond 802.11ad – Ultra High Capacity and Throughput WLAN, IEEE 11-13/0408r0

If We Could Bring 60GHz to Outdoor



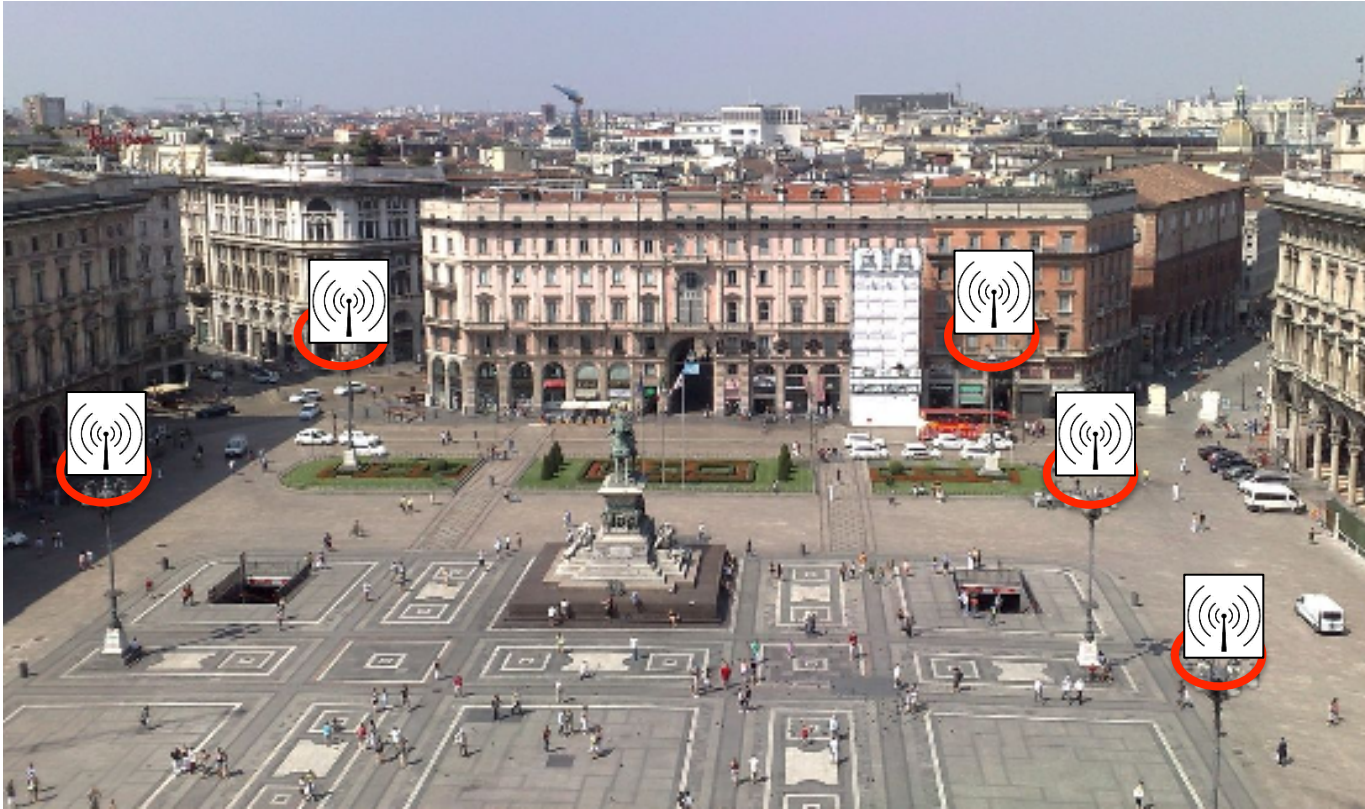
- One array for one user, e.g. transmit @2Gbps
- A picocell: 4 faces, each face 36 arrays → **288Gbps** downlink!
 - Each face is only **15cm × 15cm** large
- Narrow beamforming → minimal inter-picocell interference → capacity scales with picocell density

Real Life Examples



Lamppost-based deployment easily covers downtown streets and intersections.

Real Life Examples (cont.)



Lamppost-based deployment also easily covers plazas.

60GHz Picocell Pros

Many arrays transmit simultaneously
→ ~288Gbps capacity *per basestation*

Spectral Efficiency

Very narrow beam
→ Small interference
→ Dense cells (every 20m)

Cell Density

Amount of Spectrum

7GHz unlicensed spectrum
→ Up to 6.76Gbps link rate

Dimensions of Capacity

Cons (Common Concerns)

- 60GHz oxygen absorption → range too small
- High frequency → sensitive to blockage
- Narrow beam → user motion breaks connection

We perform detail measurements to understand all these concerns.

Outline

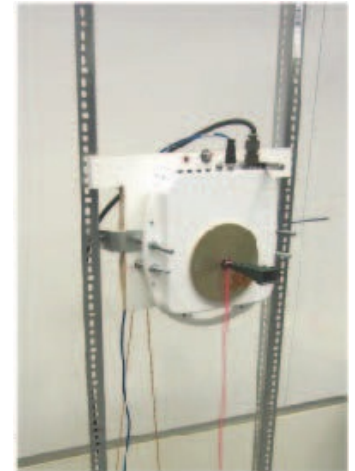
- Motivation
- Measurements for demystifying 60GHz picocells
 - Controlled environment measurements
 - Range
 - Blockage
 - Motion
 - Spatial reuse
 - Real-life scenarios measurements
- Large-scale simulation
- Conclusion & future directions

Measurement Methodology

- Two testbeds
 - Wilocity: 802.11ad, 2x8 arrays
 - HXI: horn antenna
 - Emulate the main beam of 10x10 arrays
- Both controlled and real-life environment



Wilocity
2x8 today



HXI emulate
10x10 future

Basestation

Client



Real-life environment

Range

- Concern: 60GHz range too small for outdoor

Radio Type	Weather	Minimum Link Rate (Mbps)		
		385	1155	2310
Wilocity 2x8 EIRP=23dBm	Clear	23m	15m	10m
	Heavy rain	22m	-	-
HXI 10x10 EIRP=40dBm ¹	Clear	178m	124m	93m
	Heavy rain	139m	102m	79m

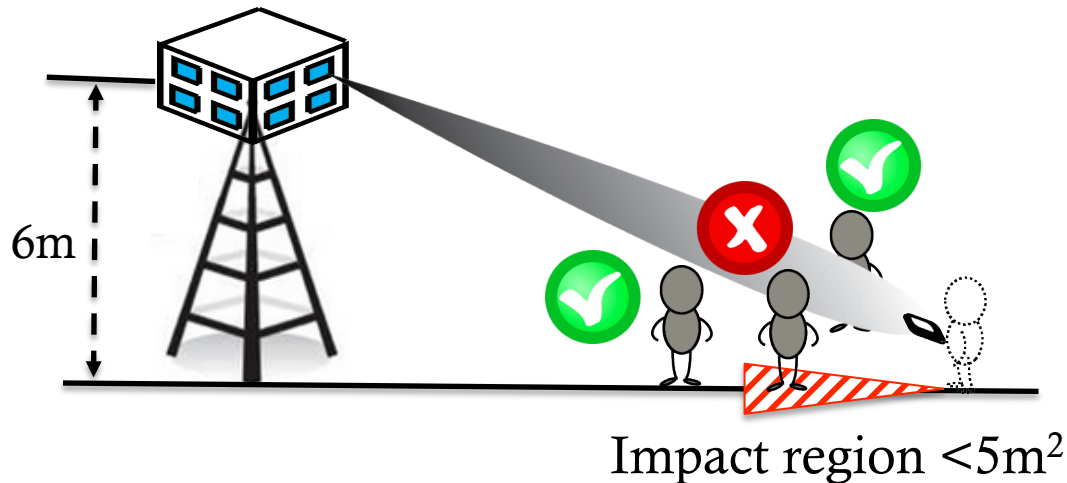
Range measurement results

- Wilocity small array + low power → ~20m
- Larger array + higher power → 1Gbps at >100m
 - Align with theoretical link budget calculation

¹40dBm EIRP is under FCC regulation.

Robustness to Blockage

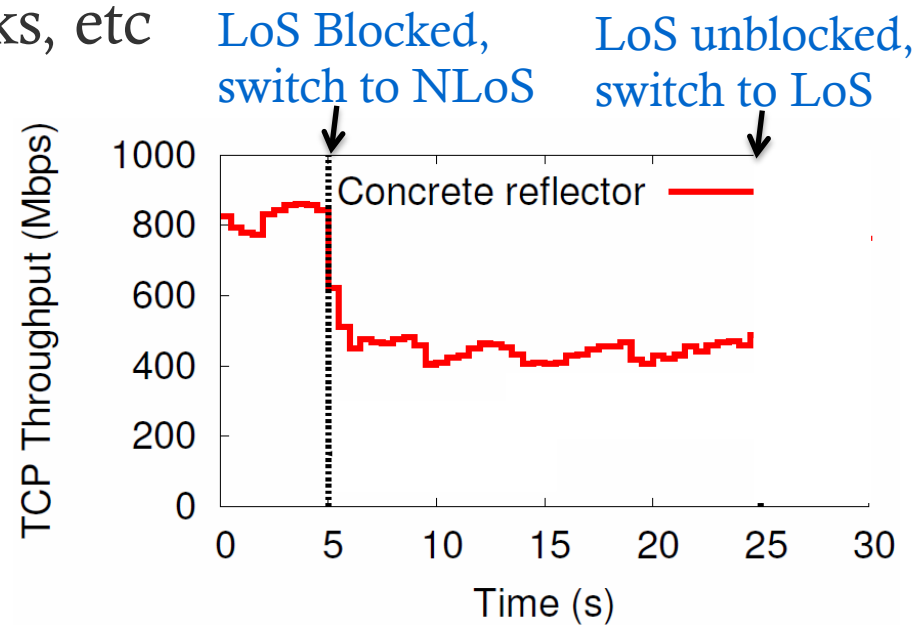
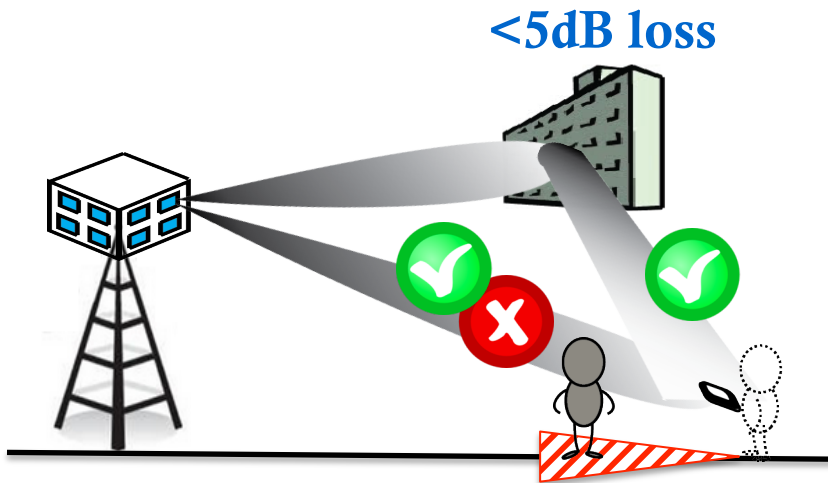
- Concern 2: pedestrians easily block the signal



- Blockage impact region is small ($<5\text{m}^2$)
 - The peer must be close enough to block
 - Higher basestation \rightarrow smaller impact region

Handling Blockage via Reflection

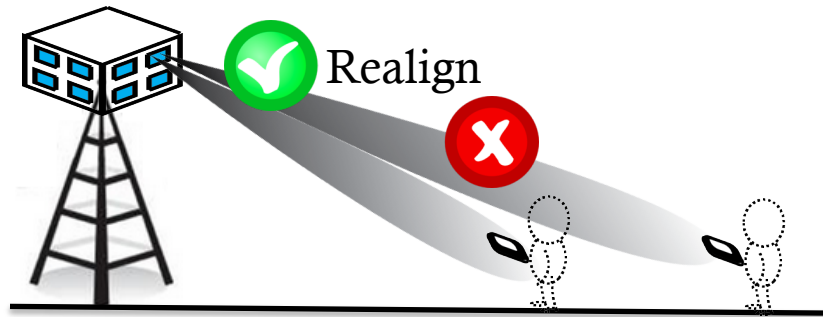
- We can use NLoS path when LoS is blocked
- Most outdoor materials have $<5\text{dB}$ reflection loss
 - Metal, plastic, wood, bricks, etc



Wilocity chipsets already handle blockage via reflection.

User Motion

- Concern 3: user motion breaks 60GHz connection

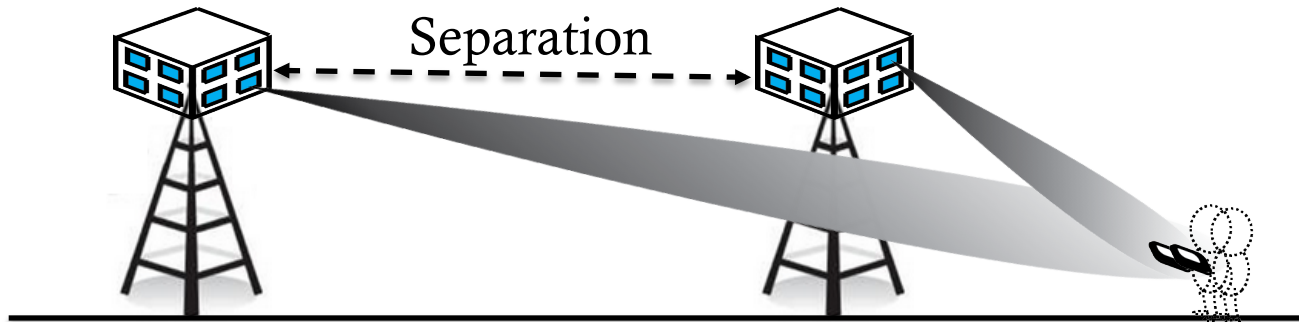


Realign beam to adapt user motion

- Realign the beam every $\sim 2s$ maintains $>50\%$ throughput in worst cases (details in paper)
 - Wilocity realign fast enough
 - Longer distance even easier

Interference and Spatial Reuse

- What is the minimal basestation separation for low interference?
 - “Worst-case” scenario: two collocated users



- 10x10 arrays \rightarrow ~20m separation is enough
- Transmission range 100m \gg 20m separation \rightarrow high spatial reuse
 - Picocells can largely overlap

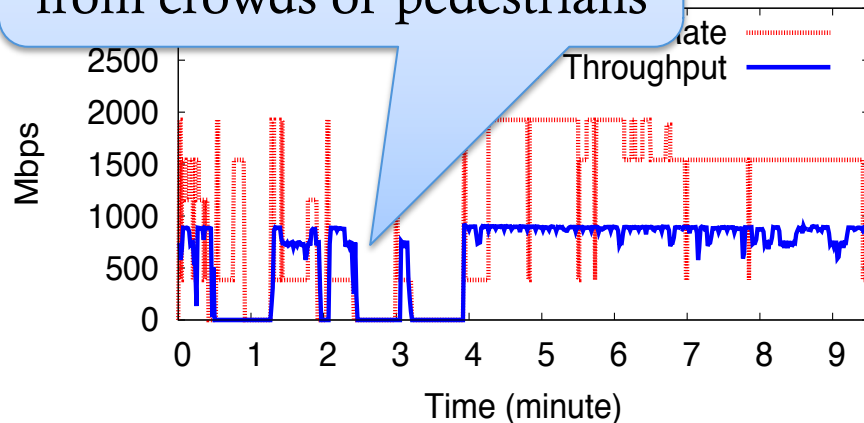
Real-life Performance

- 10 locations w/ random pedestrians

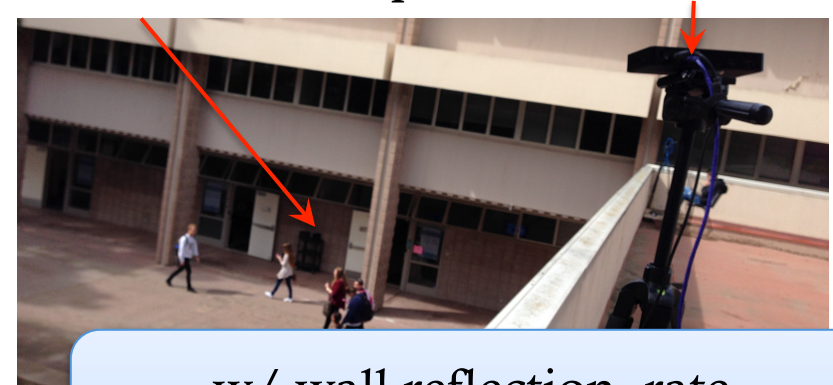
Shopping Mall



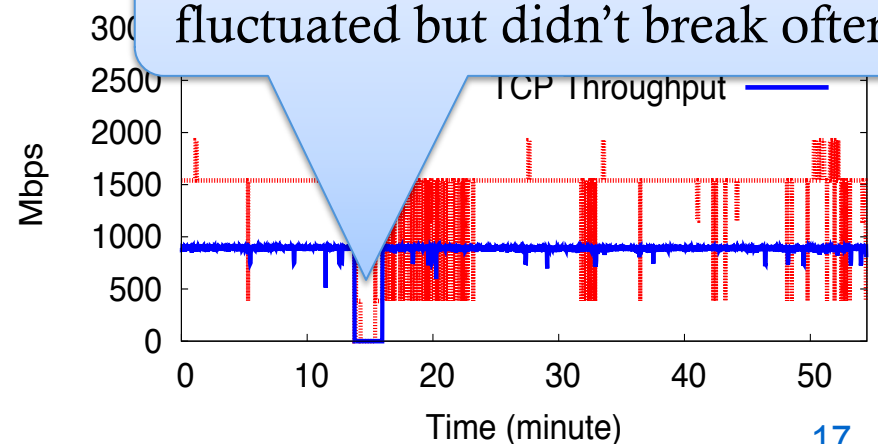
Link broke due to blockage from crowds of pedestrians



Campus Plaza

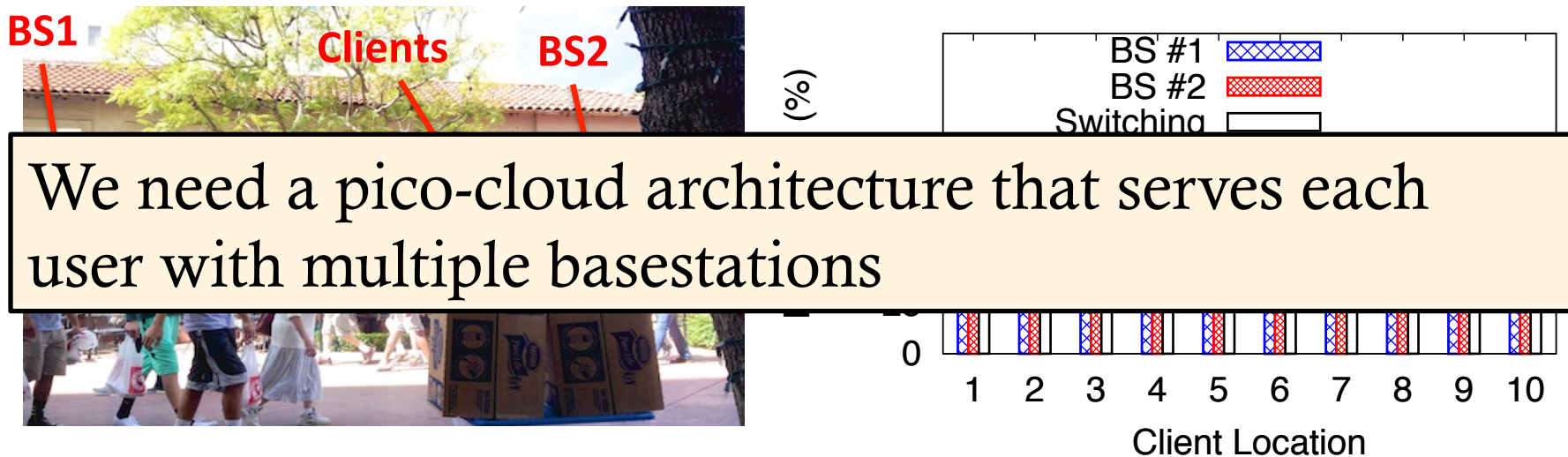


w/ wall reflection, rate fluctuated but didn't break often



Real-life Performance (cont.)

- Test two basestations simultaneously
 - Dense deployment \rightarrow multiple basestations in range



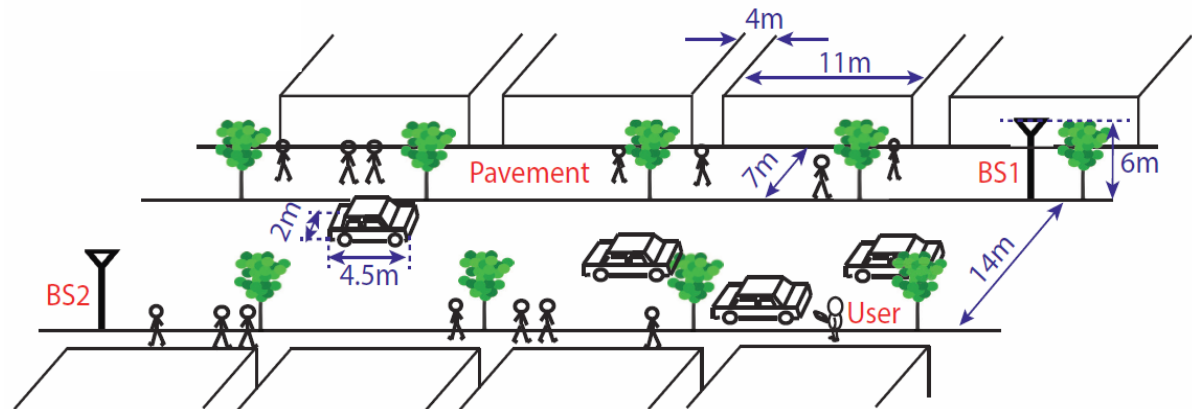
- Switching between two basestations \rightarrow nearly 100% availability!

Large-scale Simulation

- Examine street locations every m^2

Simulated NYC Street

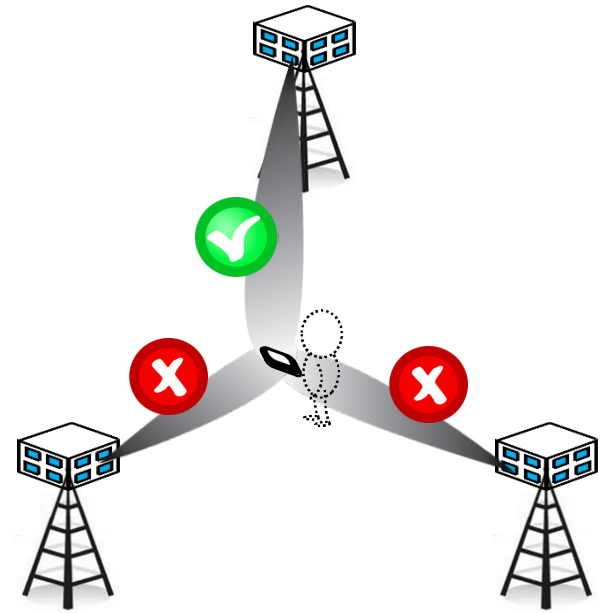
- Buildings & trees from Google Map
- Pedestrians & cars from surveys



- Availability: two basestations \rightarrow nearly 100%
 - Confirm the real-life measurement
- Interference: 20m basestation separation \rightarrow minimal throughput loss

Conclusion & Future Directions

- Propose 60GHz outdoor picocell
- Measurement verifies the feasibility and potential
- Future research directions
 - Pico-cloud architecture
 - User tracking
 - Cross-layer protocol design
 - Hardware design
 - Energy efficient arrays



Thank you!
Questions?