Demystifying 60GHz Outdoor Picocells

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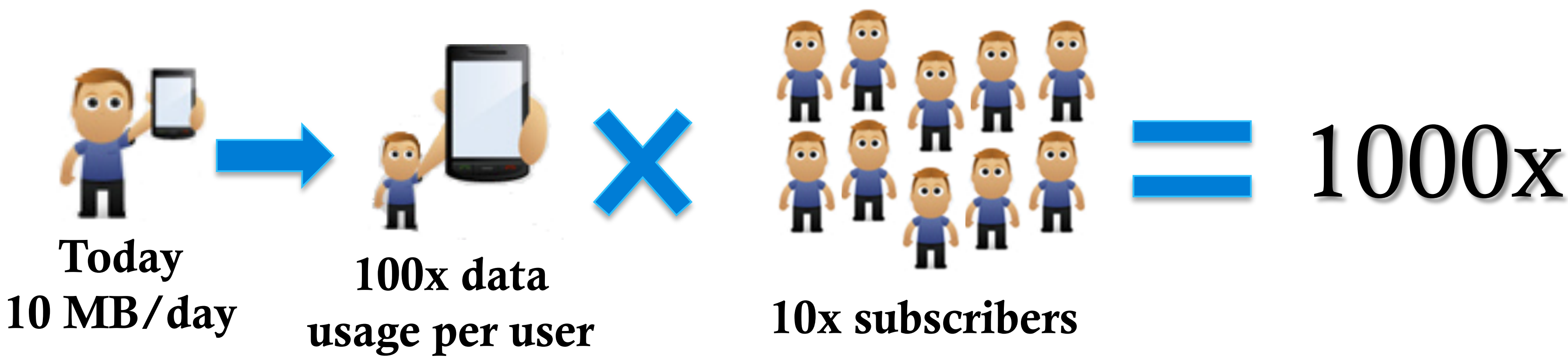
Cellular Network Capacity Crisis

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



- Industry is aware

QUALCOMM | ••• > Wireless Net...

1000x Data Challenge

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 dramatically different approaches to speed up!

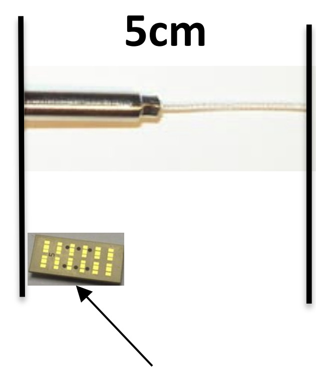
The Promise of 60GHz

- Large *unlicensed* spectrum available.
  - E.g. 7GHz unlicensed spectrum

Rails for *free*

- Compressed arrays create highly directional beams
  - Narrow beams minimize interference

Single element 2.4GHz antenna

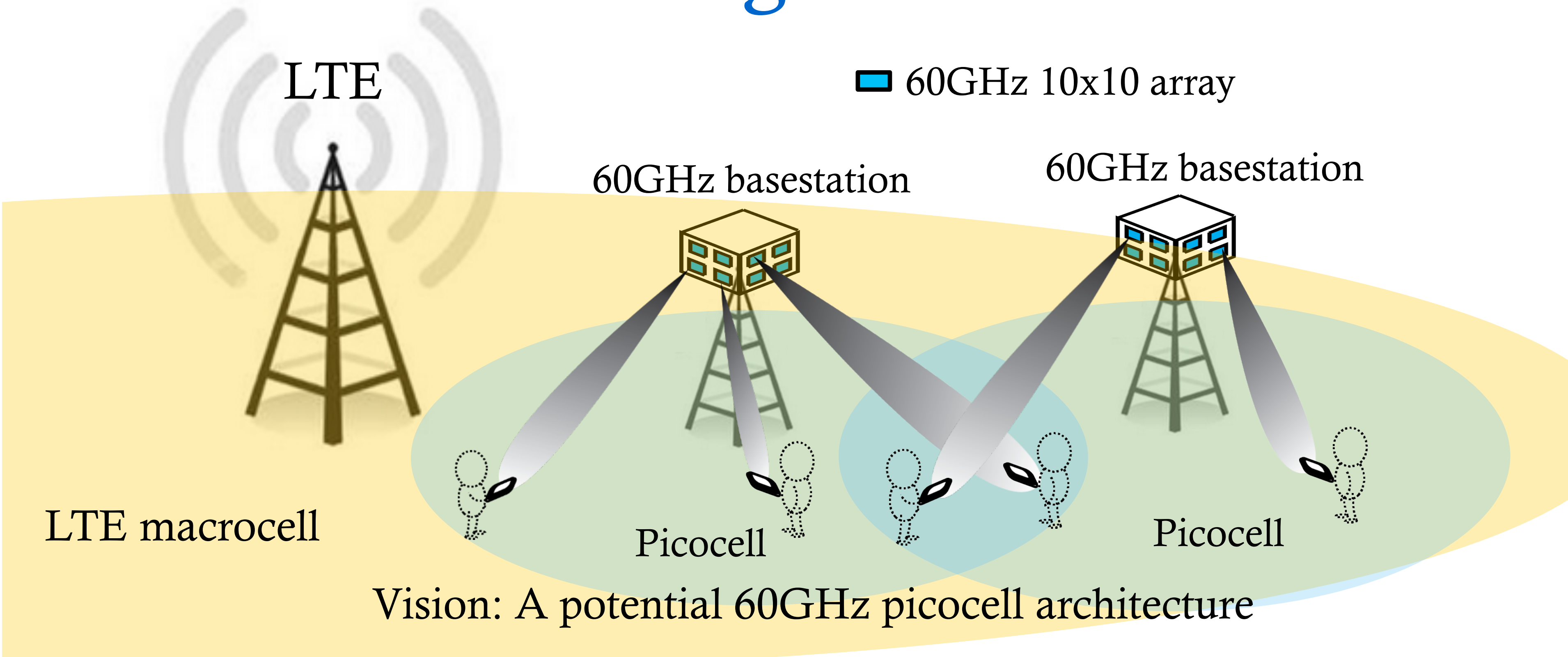


60GHz **32-element** Array[1], **1.8cm × 0.8cm**

- 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

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

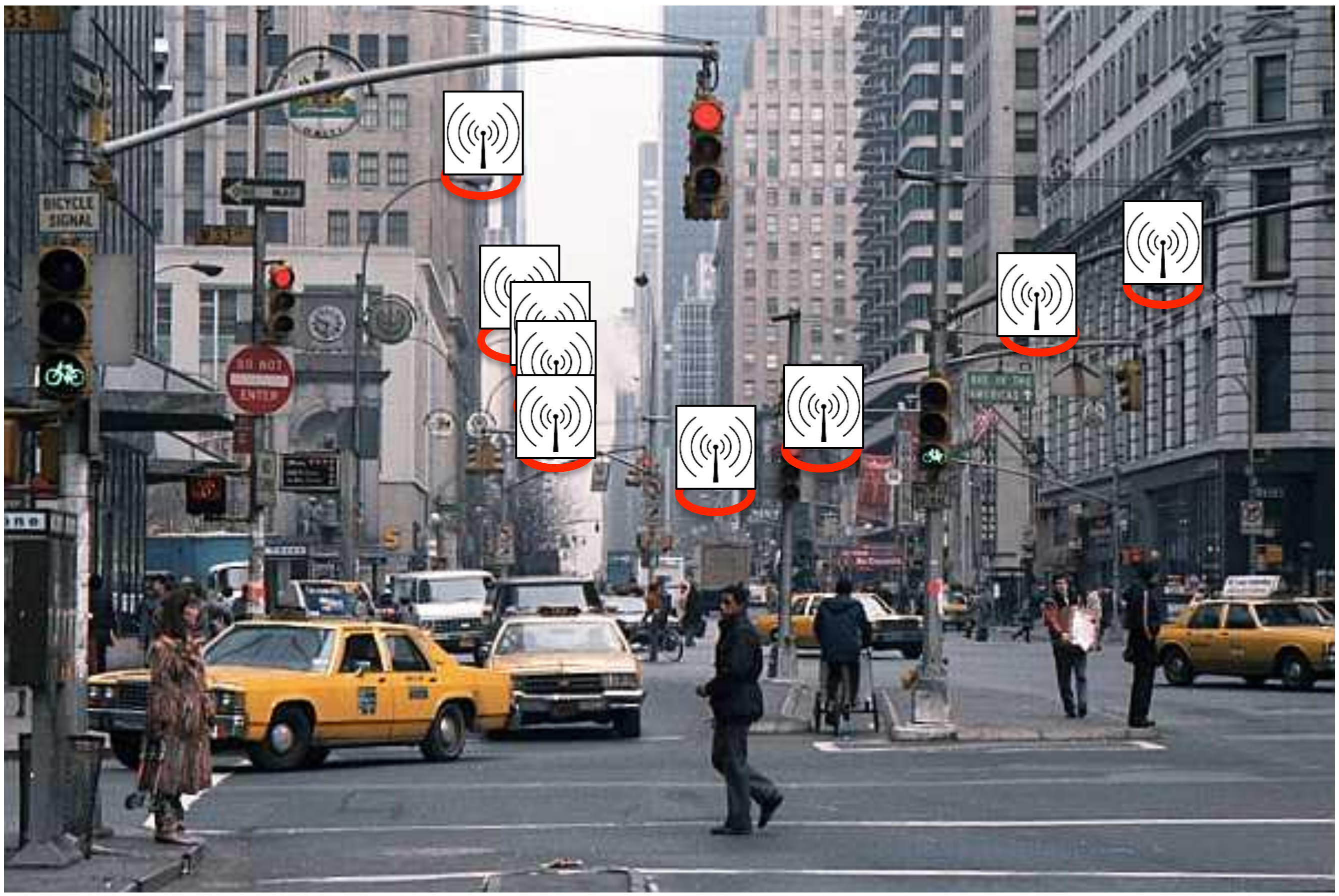
If We Could Bring 60GHz to Outdoor



Vision: A potential 60GHz picocell architecture

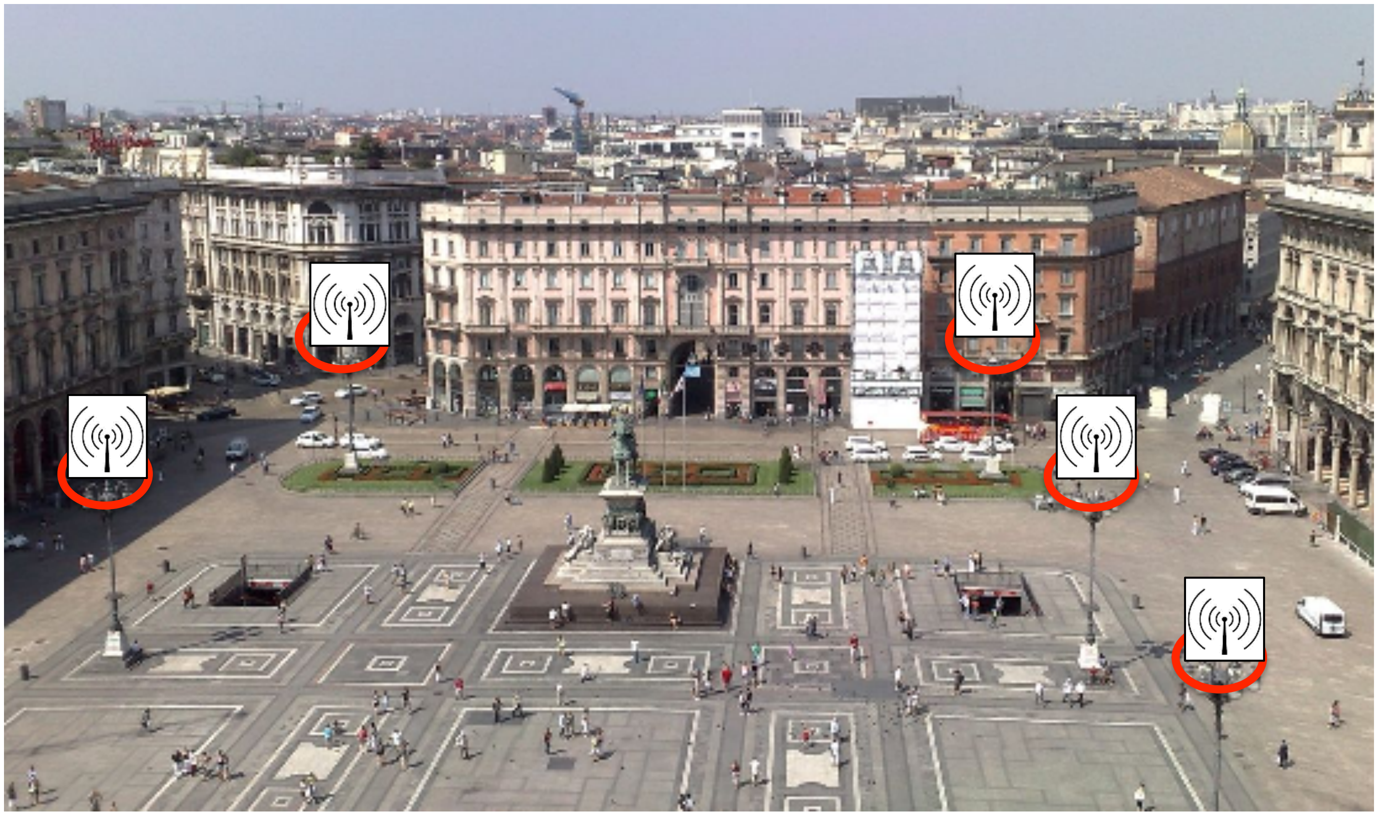
- One array for one user, e.g. transmit @2Gbps
- A picocell: 4 faces, each face 36 arrays → **288Gbps** downlink!
  - Each face is only **15cm × 15cm** large
- Narrow beamforming → minimal inter-picocell interference → capacity scales with picocell density

Real Life Examples



Lamppost-based deployment easily covers downtown streets and intersections.

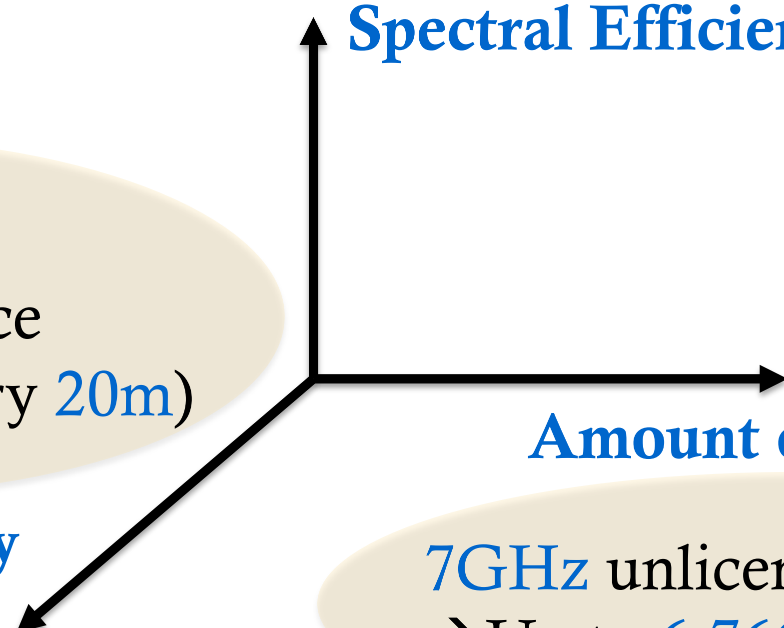
Real Life Examples (cont.)



Lamppost-based deployment also easily covers plazas.

60GHz Picocell Pros

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



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

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.

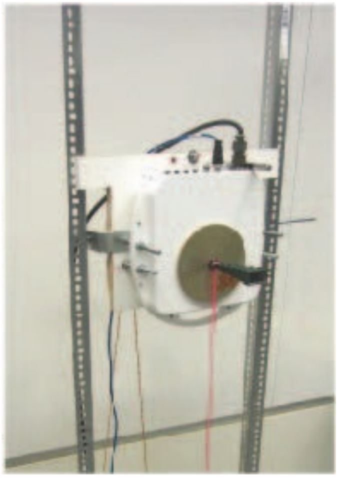
Outline

- 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

Wilocity
2x8 today



HXI emulate
10x10 future

- Both controlled and real-life environment

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

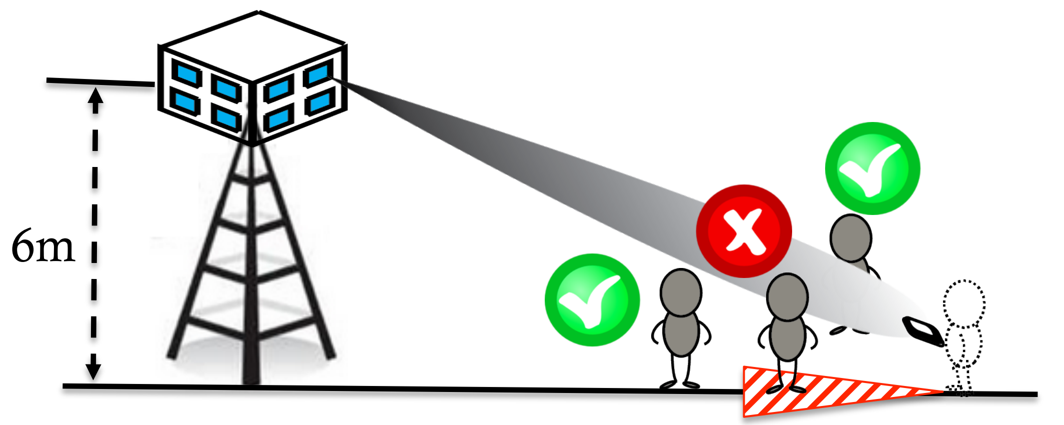
Range measurement results

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

[1]40dBm EIRP is under FCC regulation.

Robustness to Blockage

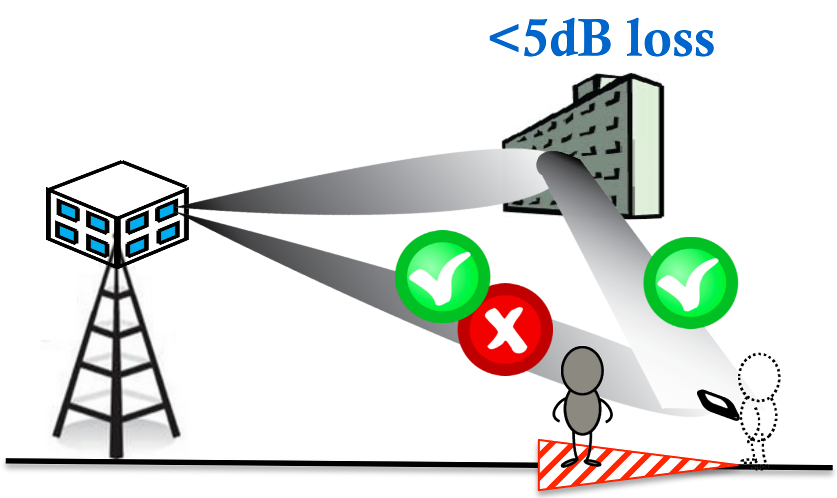
- Concern 2: pedestrians easily block the signal

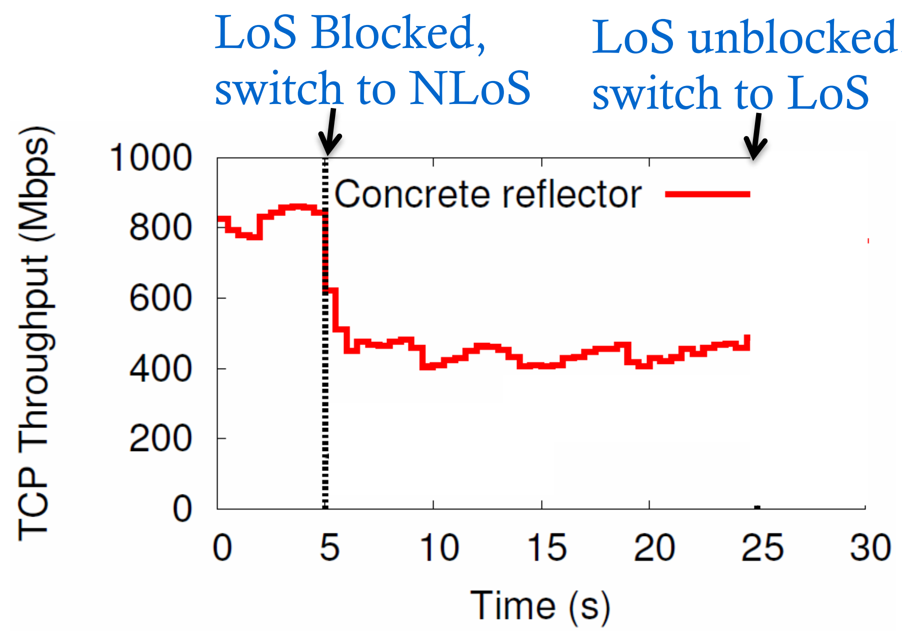


- Blockage impact region is small (<5m^2)
  - The peer must be close enough to block
  - Higher basestation → smaller impact region

Handling Blockage via Reflection

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

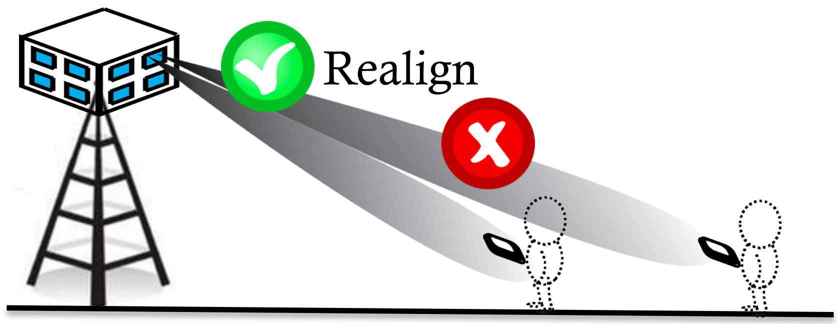




Wilocity chipsets handle blockage via reflection.

User Motion

- Concern 3: user motion breaks 60GHz connection

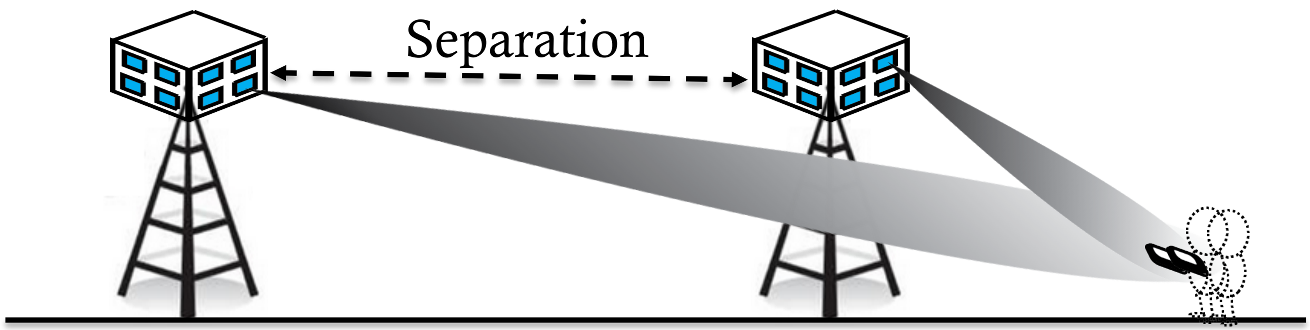


Realign beam to adapt user motion

- Realign the beam every ~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 → ~20m separation is enough
- Transmission range 100m >> 20m separation → high spatial reuse
  - Picocells can largely overlap

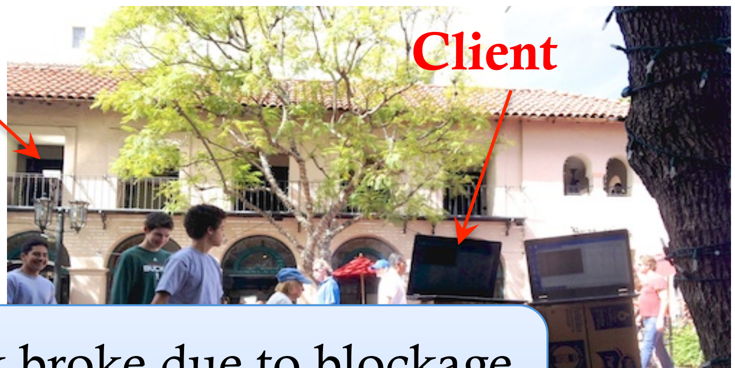
Real-life TCP Performance

- 10 locations w/ random pedestrians

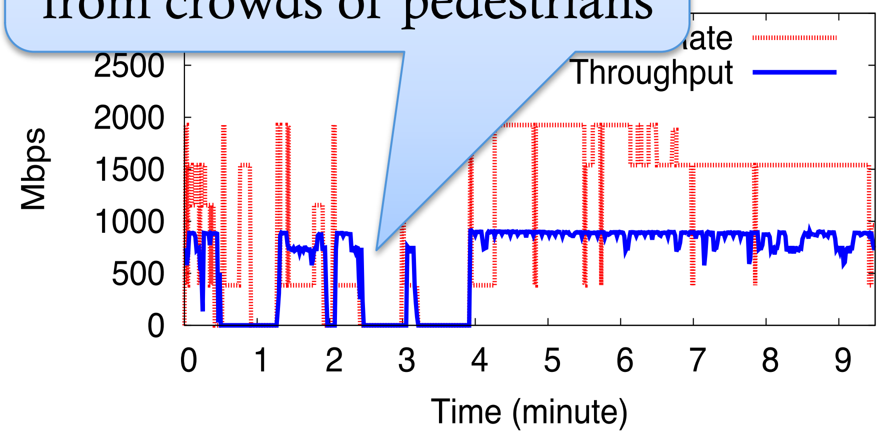
Shopping Mall

BS

Client



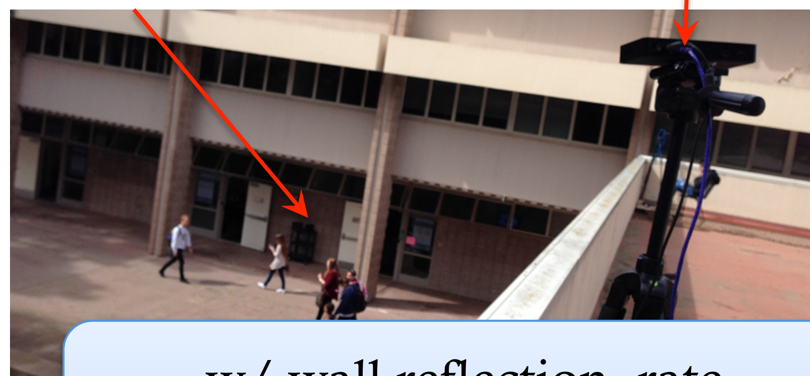
Link broke due to blockage from crowds of pedestrians



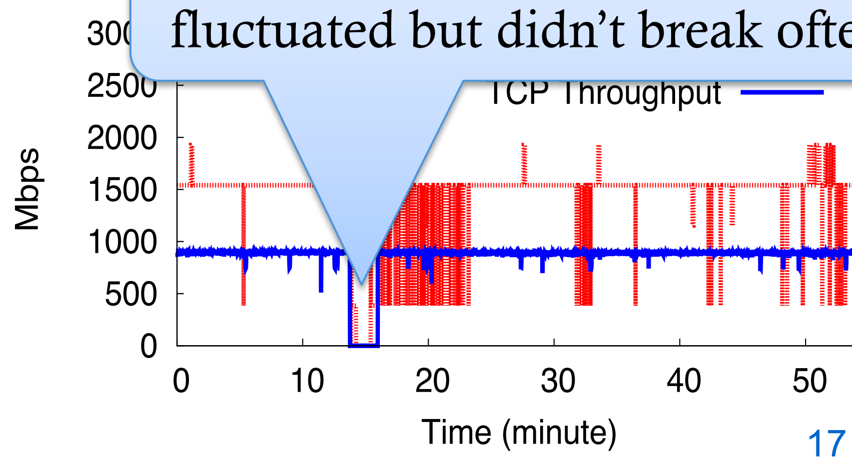
Clients

Campus Plaza

BS

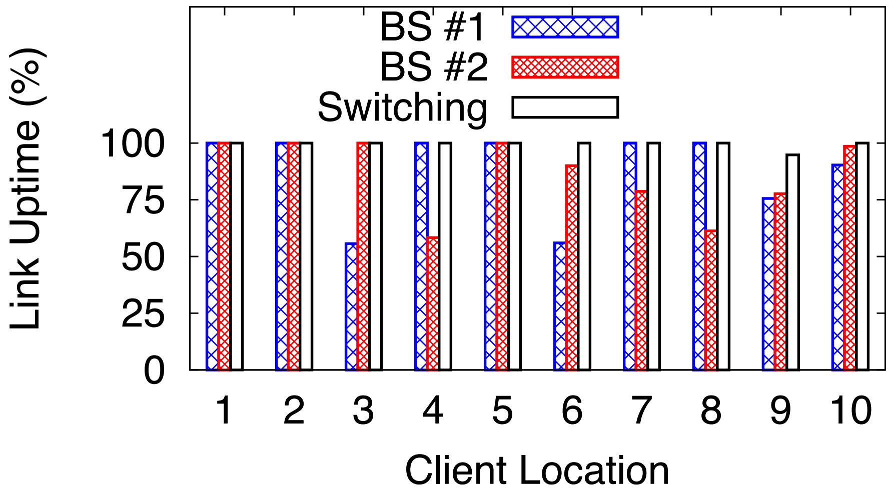


w/ wall reflection, rate fluctuated but didn't break often



Real-life Performance (cont.)

- Test two basestations simultaneously
  - Dense deployment → multiple basestations in range



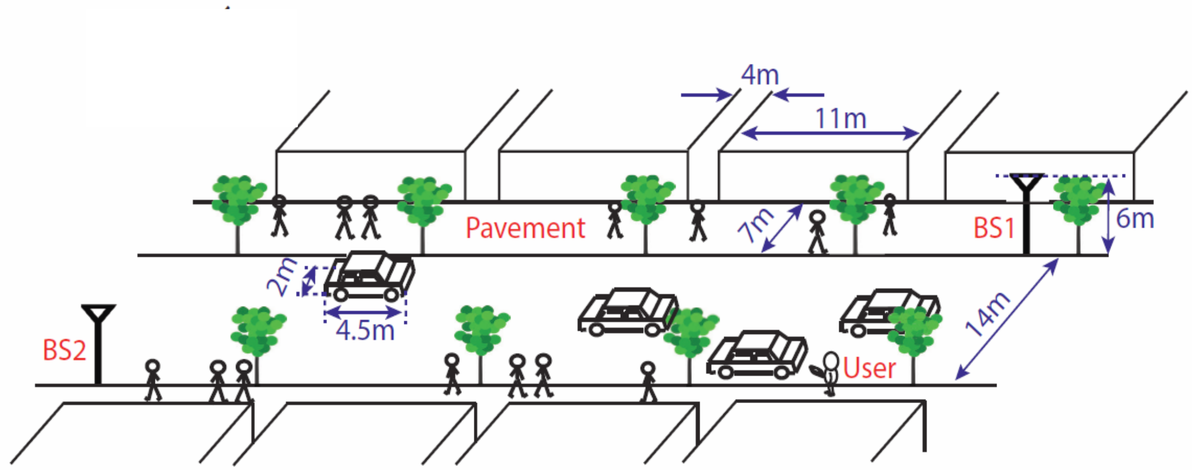
- Switching between two basestations → nearly 100% availability!

We need a pico-cloud architecture that serves each user with multiple basestations.

Large-scale Simulation

- Examine street locations every m^2

Simulated NYC Street
- Buildings & trees from Google Map
- Pedestrians & cars from surveys



- Availability: two basestations → nearly 100%
  - Confirm the real-life measurement
- Interference: 20m basestation separation → 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