Beamforming on mobile devices: A first study

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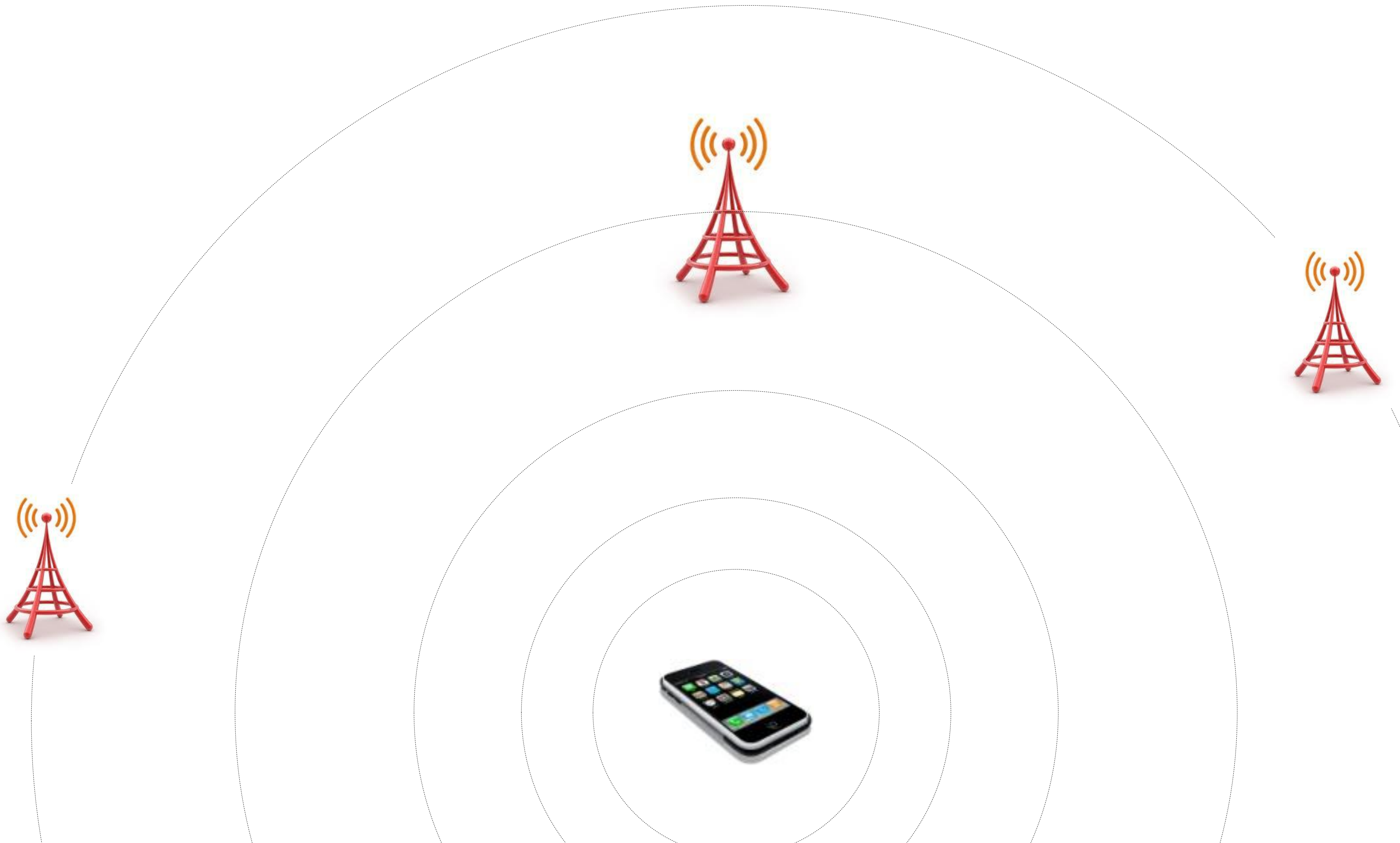
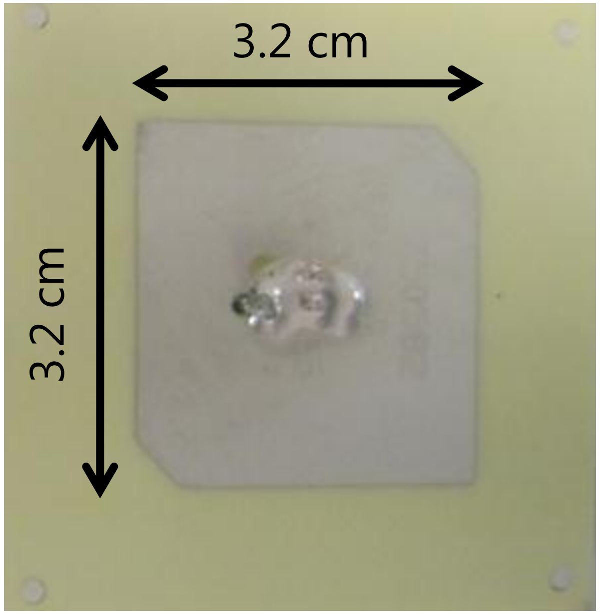
http://www.recg.org

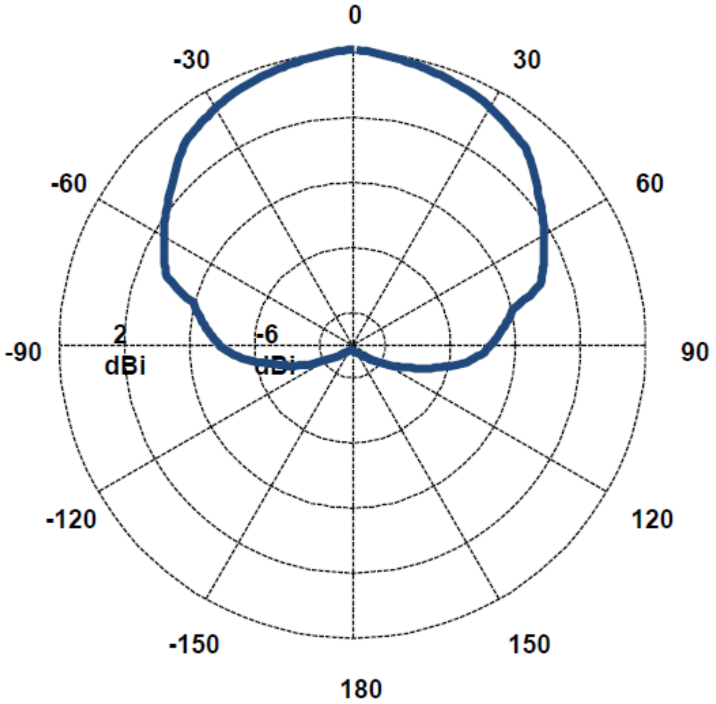
Two invariants for wireless

- Spectrum is scarce
- Hardware is cheap and getting cheaper



Passive directional antennas

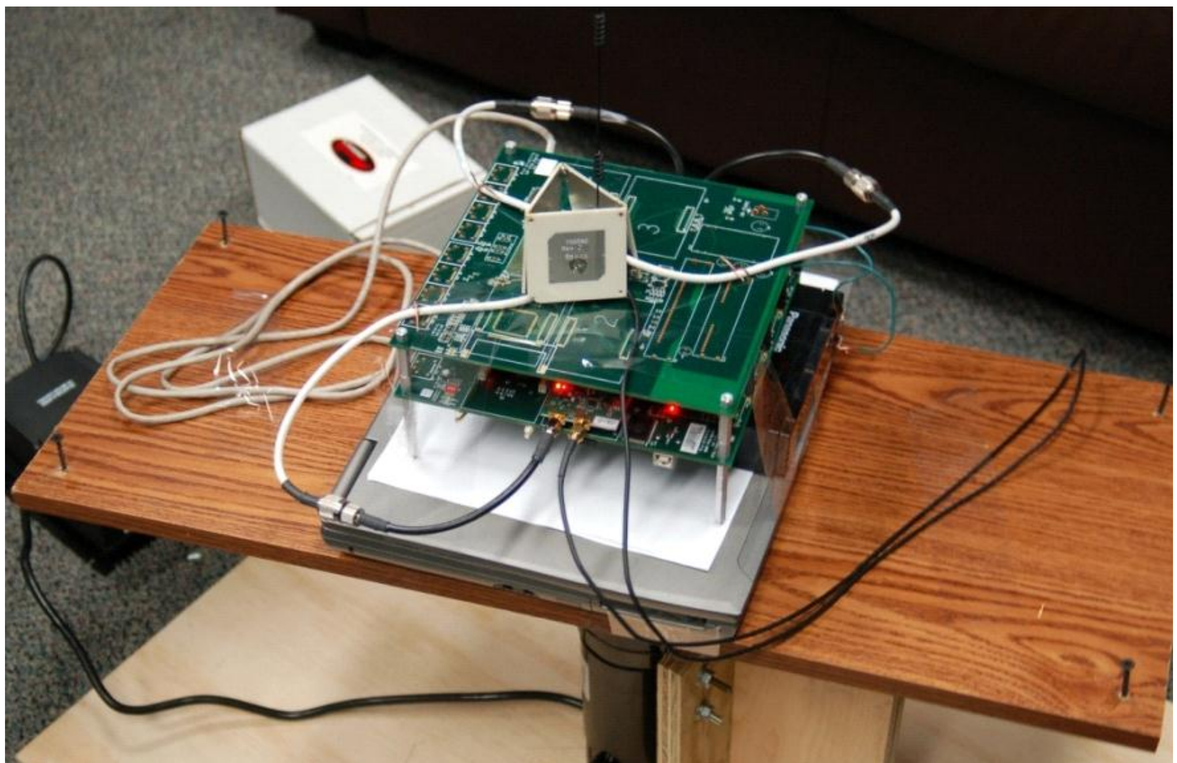




Ardalan Amiri Sani, Lin Zhong, and Ashutosh Sabharwal, "Directional antenna diversity for mobile devices: characterizations and solutions," in *Proc. ACM MobiCom*, September 2010.

Findings: ~3 dB gain

- Multifold throughput increase at network edge
- ~50% TX power reduction at network center



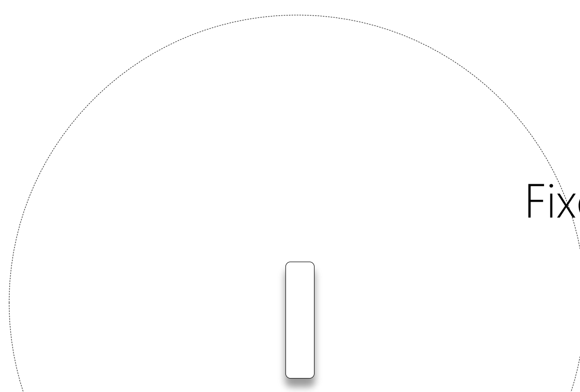
Can we go beyond 3 dB?

Beamforming?

- Studied in the past for use on cellular base station, 802.11 access points, vehicles, and even wireless sensor nodes, e.g., MobiSteer (MobiSys'07), R2D2 (MobiSys'09), DIRC (SIGCOMM'09)

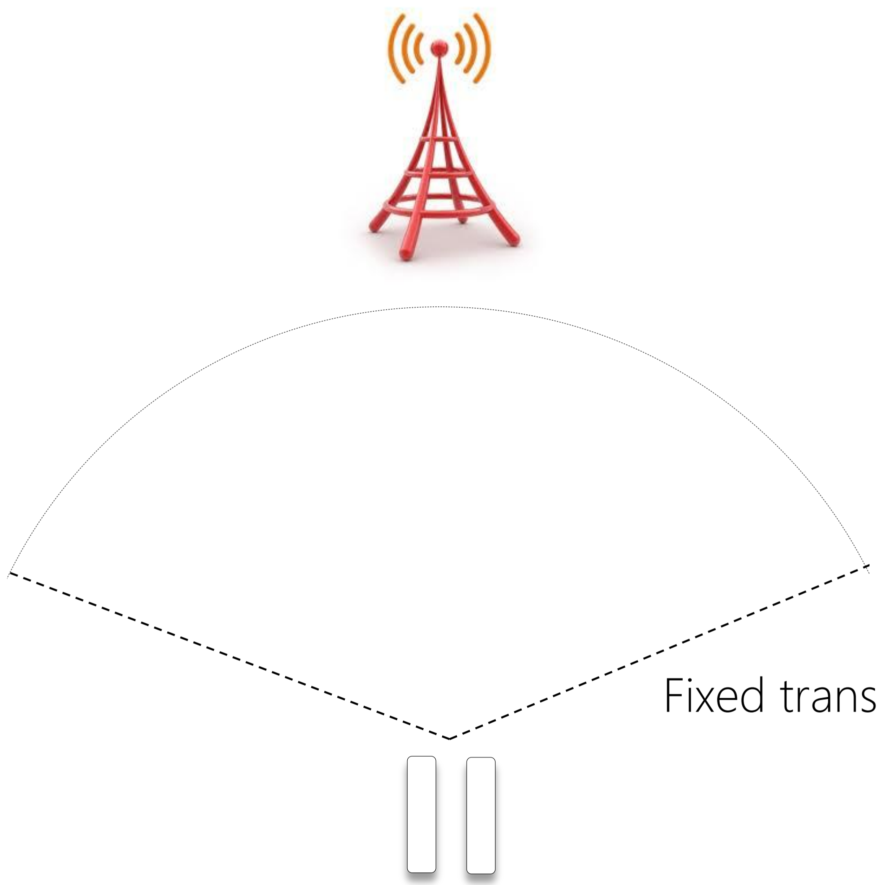
Beamforming primer

Beamforming primer



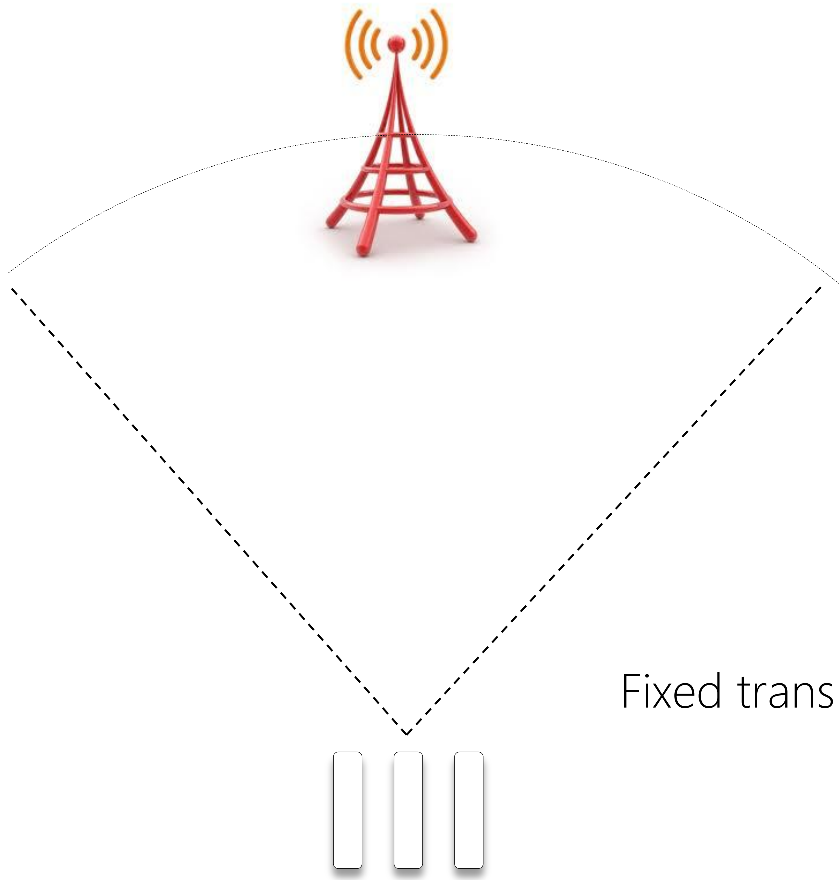
Fixed transmission power

Beamforming primer



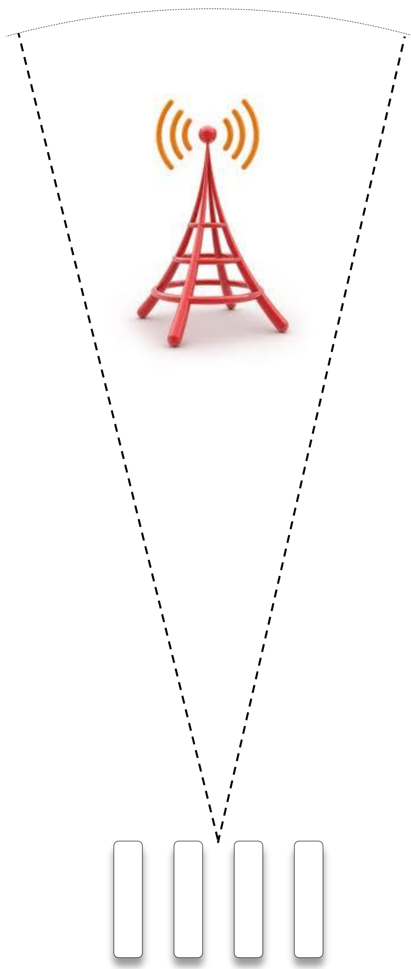
Fixed transmission power

Beamforming primer



Fixed transmission power

Beamforming primer

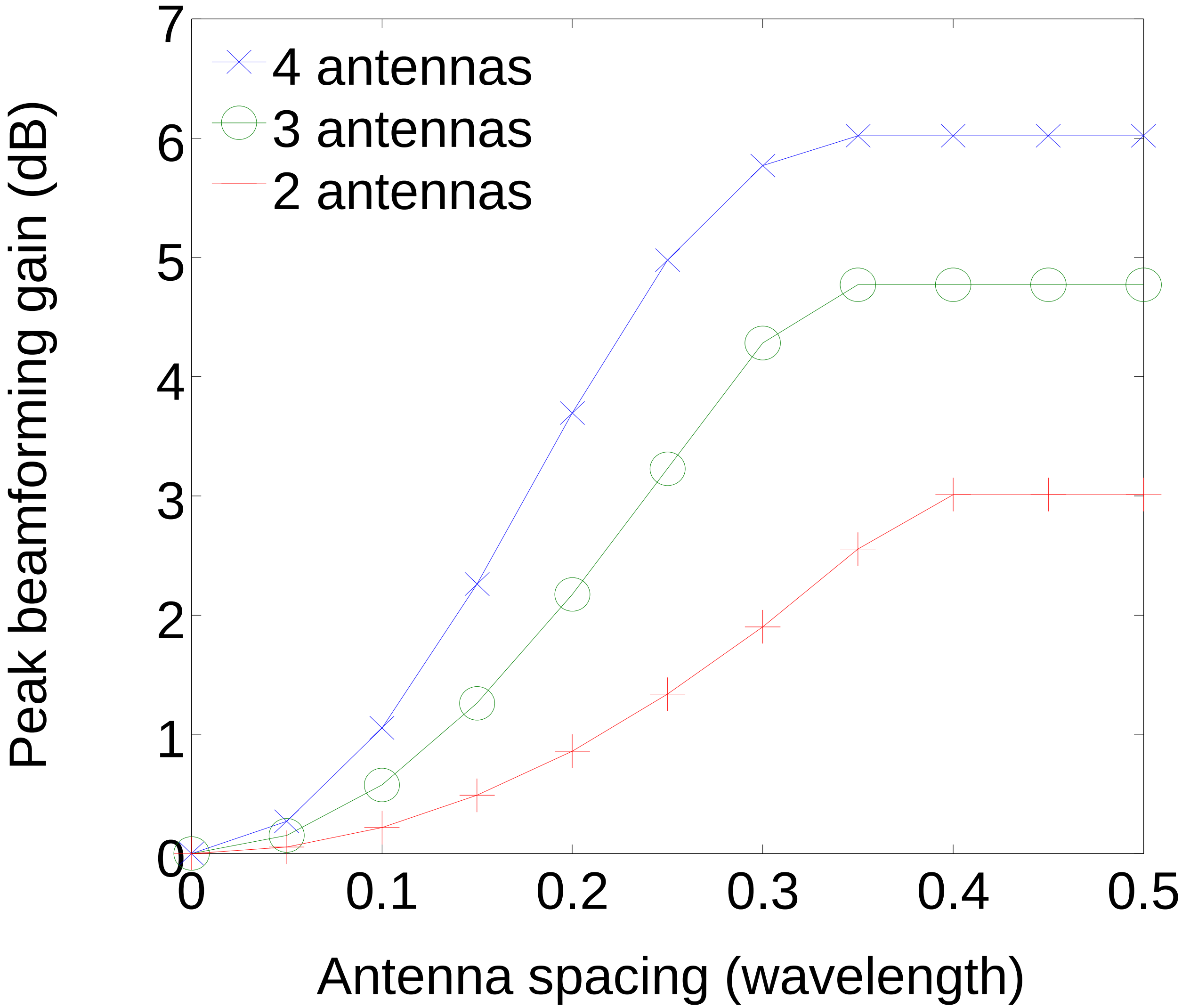


Fixed transmission power

Is beamforming practical?

- Beamforming
  - Antenna array
  - Narrow beam
  - Power hungry
- Mobile devices
  - Small form factor
  - Rotate and move
  - Battery powered

Form factor?

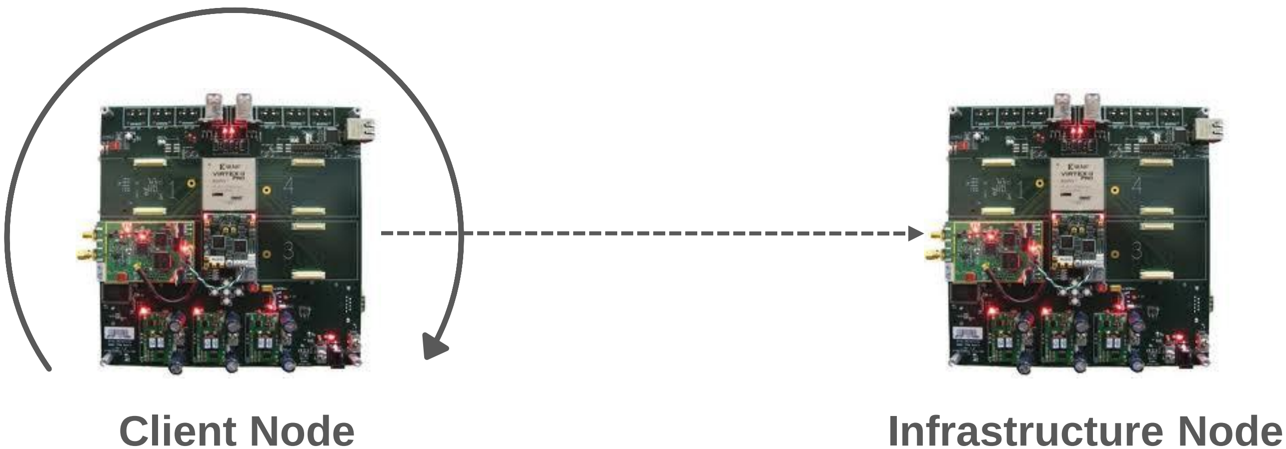


0.3-0.4 λ : 4.5-6 cm at 2 GHz

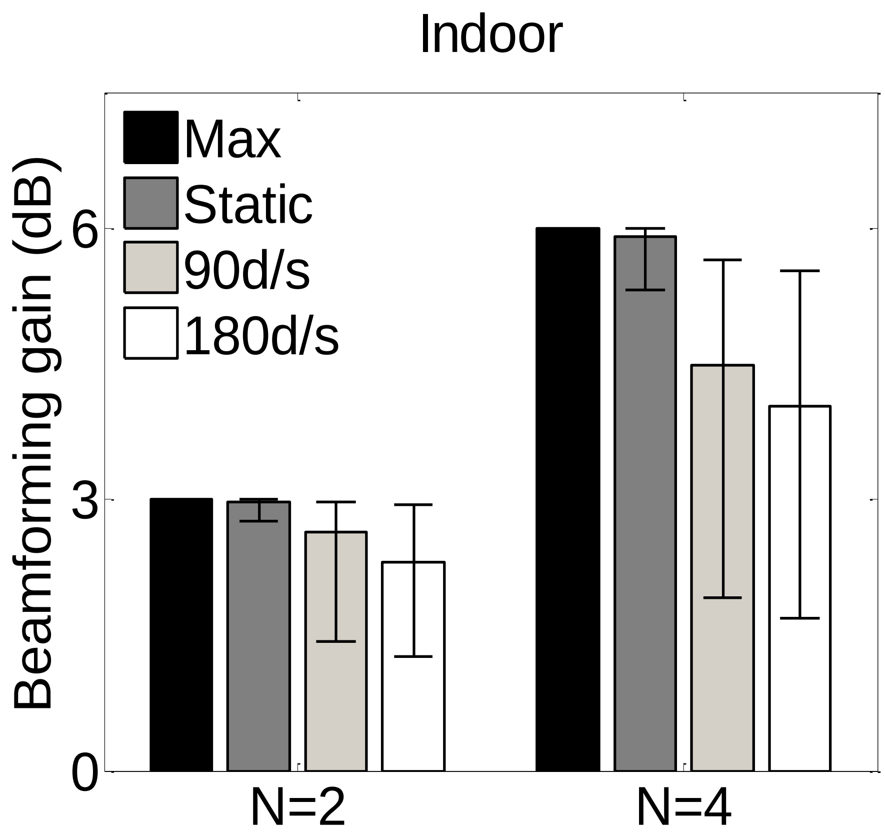
Form factor!

0.3-0.4 λ (4.5-6 cm at 2 GHz)

Rotation?

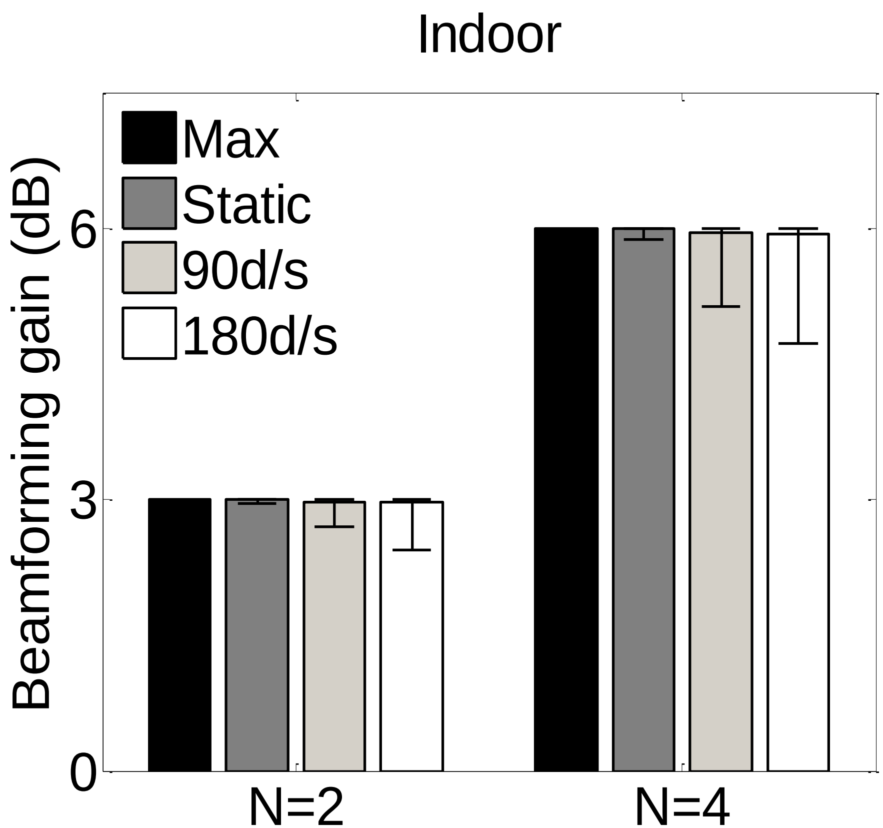


Rotation?



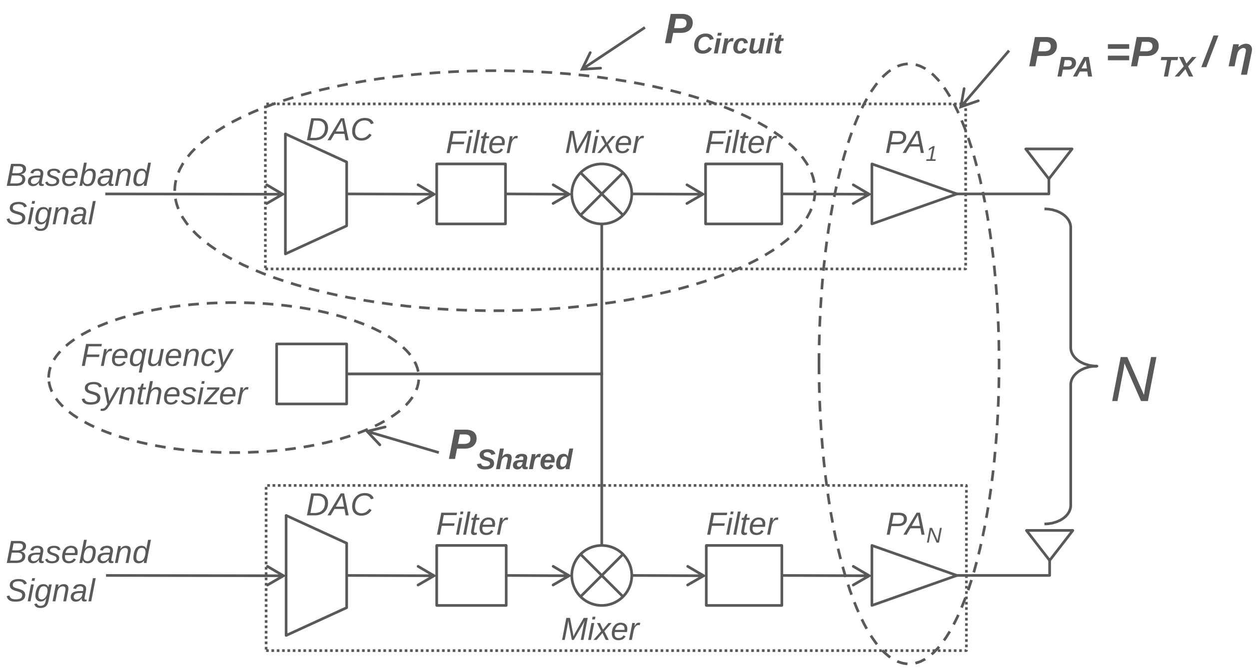
CSI estimation every **100** ms

Rotation!



CSI estimation every **10** ms

Power? (uplink only)



$$P = \boxed{P_{shared} + N \cdot P_{Circuit}} + \boxed{P_{TX} / \eta}$$

Tradeoff No. 1

$$\mathrm{P} = P_{shared} + 1 \cdot P_{Circuit} + P_{TX} / \eta$$

Tradeoff No. 1

$$P = P_{shared} + 2 \cdot P_{Circuit} + P_{TX} / \eta$$

Fixed receiver SNR

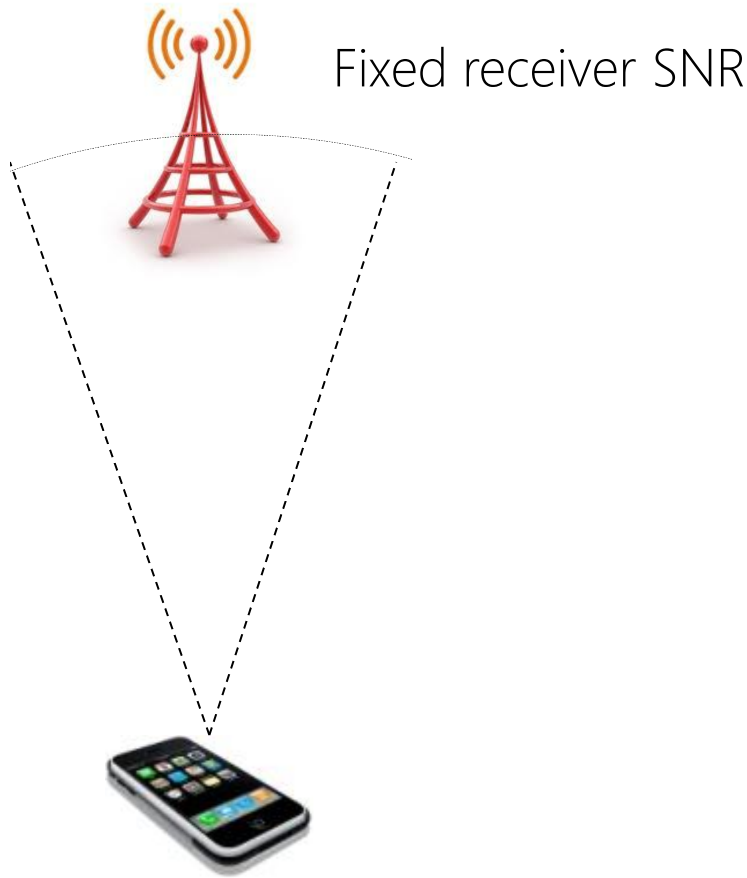
Tradeoff No. 1

$$P = P_{shared} + 3 \cdot P_{Circuit} + P_{TX} / \eta$$

Fixed receiver SNR

Tradeoff No. 1

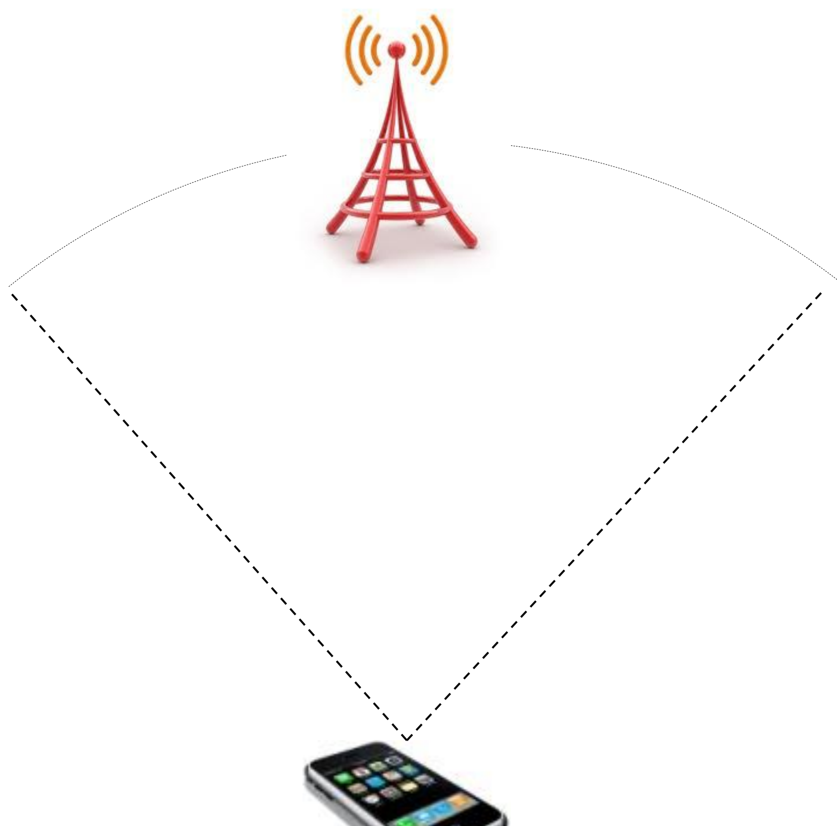
$$P = P_{shared} + 4 \cdot P_{Circuit} + P_{TX} / \eta$$



Tradeoff No. 1

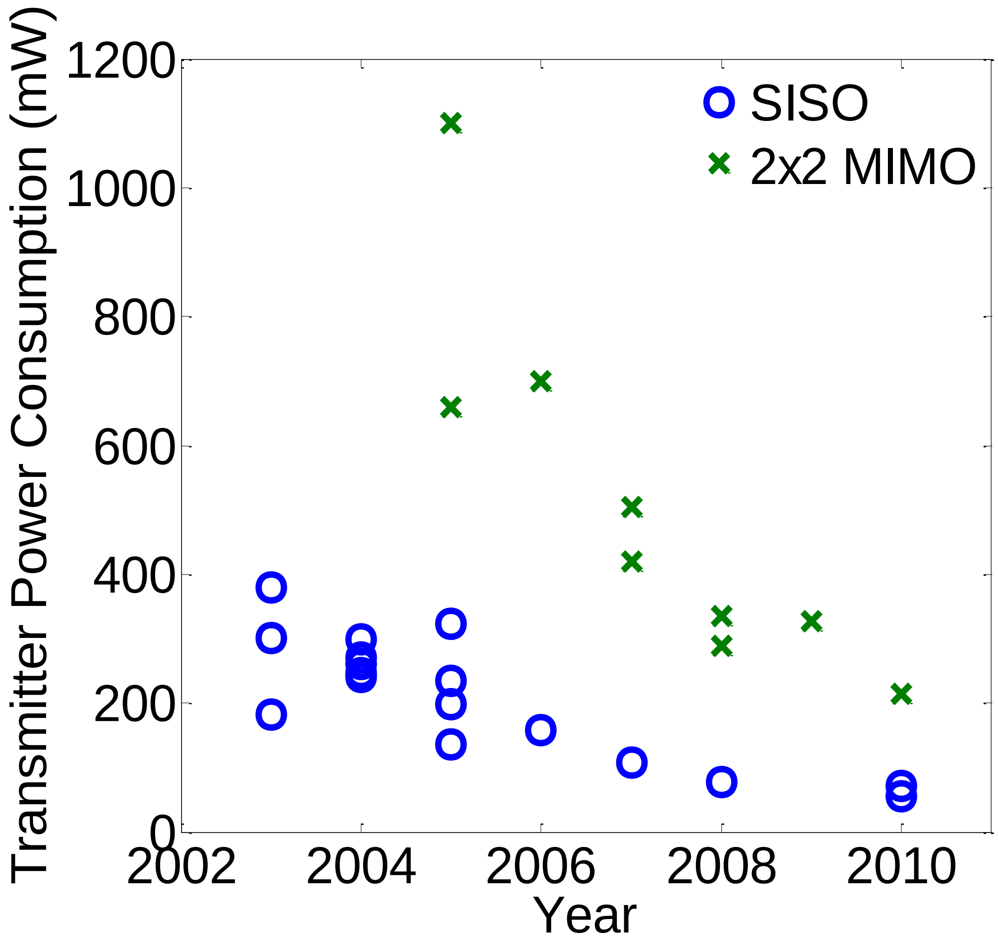
- Optimal number of antennas for efficiency

$$N_{opt} = a \cdot \sqrt{P_O / P_{Circuit}} - b \cdot P_O$$



Hardware is cheap & getting cheaper

$$P = \boxed{P_{shared} + N \cdot P_{Circuit}} + P_{TX} / \eta$$

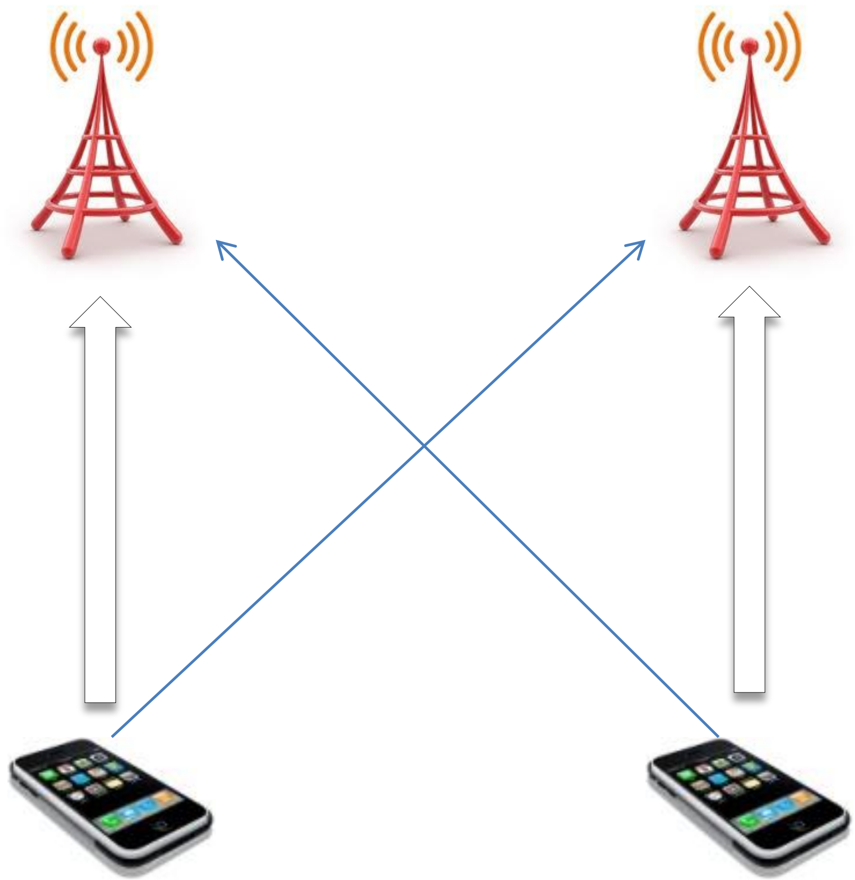


Sources: IEEE Int. Solid-State Circuits Conferences (ISSCC) and IEEE Journal of Solid-State Circuits (JSSC)

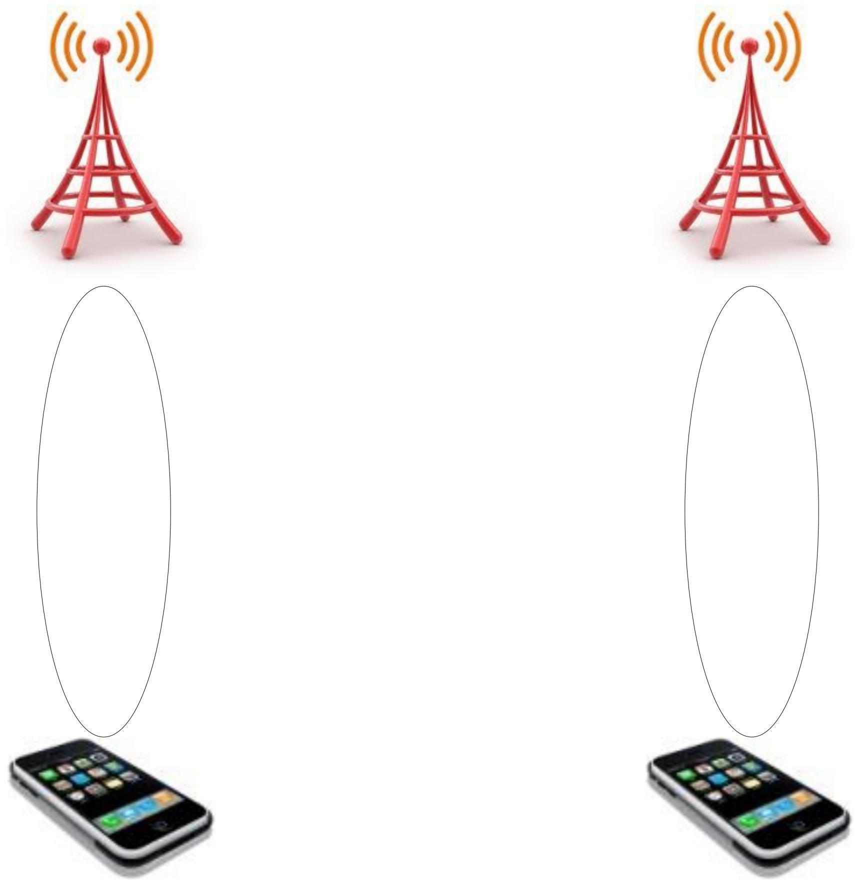
Power!

- Beamforming with state-of-the-art multi-RF chain realization is already more efficient!
- Tradeoff No. 1 is increasingly profitable!

Beyond a single link

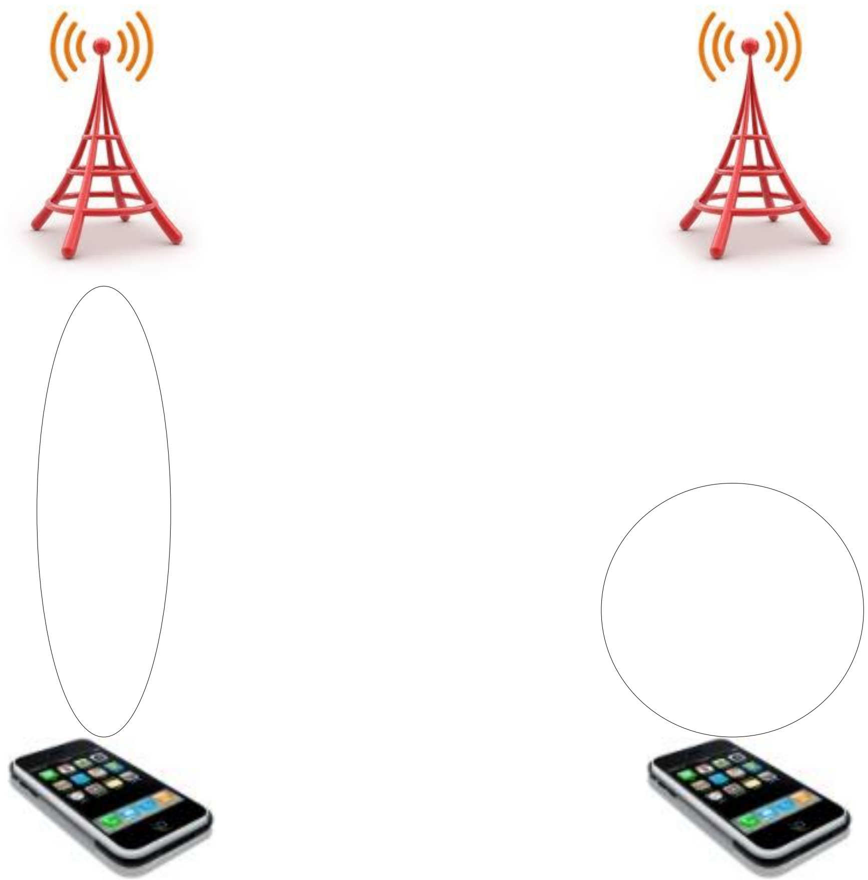


What the carrier wants:
Use all your antennas!



What you want:

$$N_{opt} = a \cdot \sqrt{P_O / P_{Circuit}} - b \cdot P_O$$



Tradeoff No. 2

- Network capacity vs. client efficiency

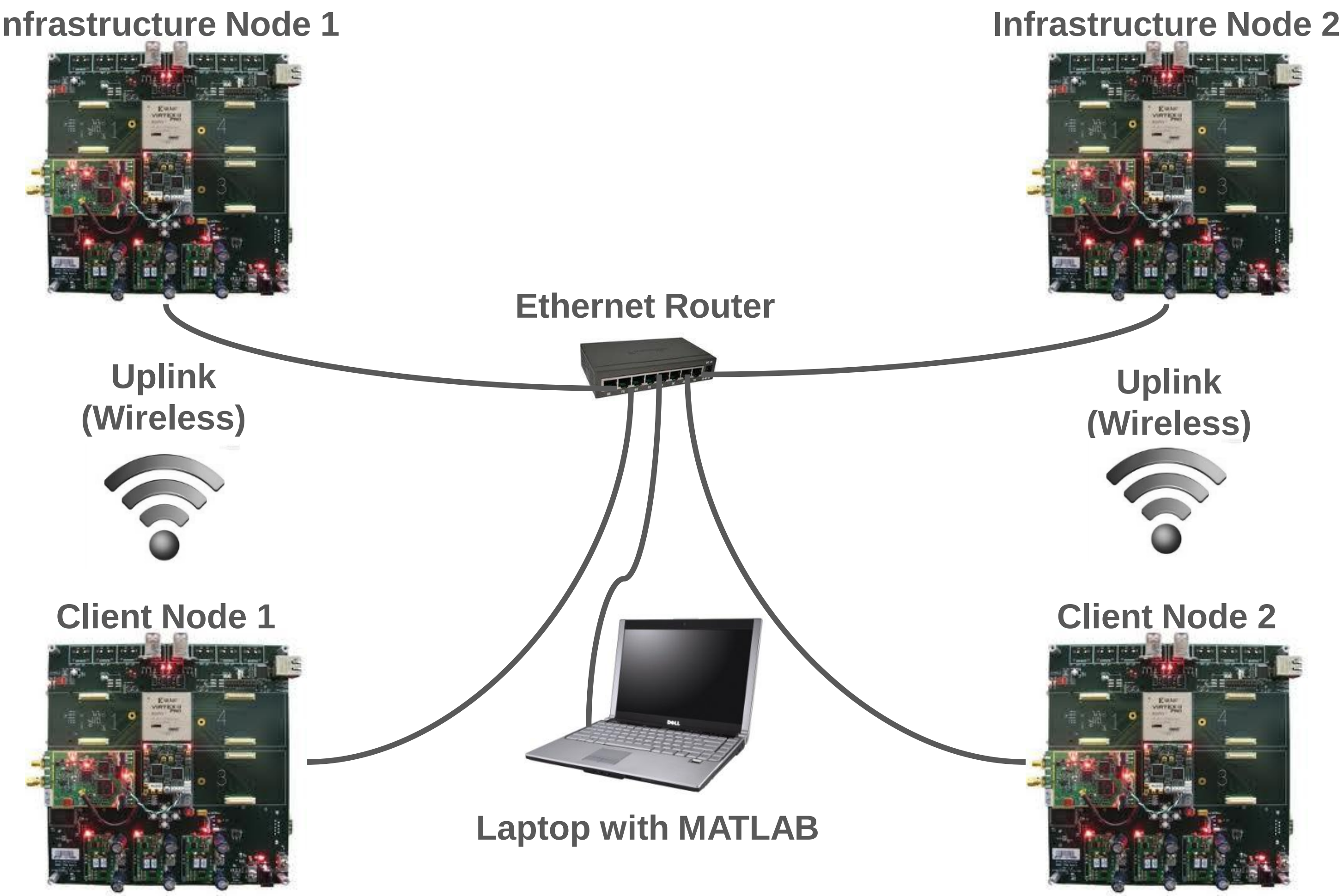
How can clients figure out its *N* without talking to each other?

BeamAdapt

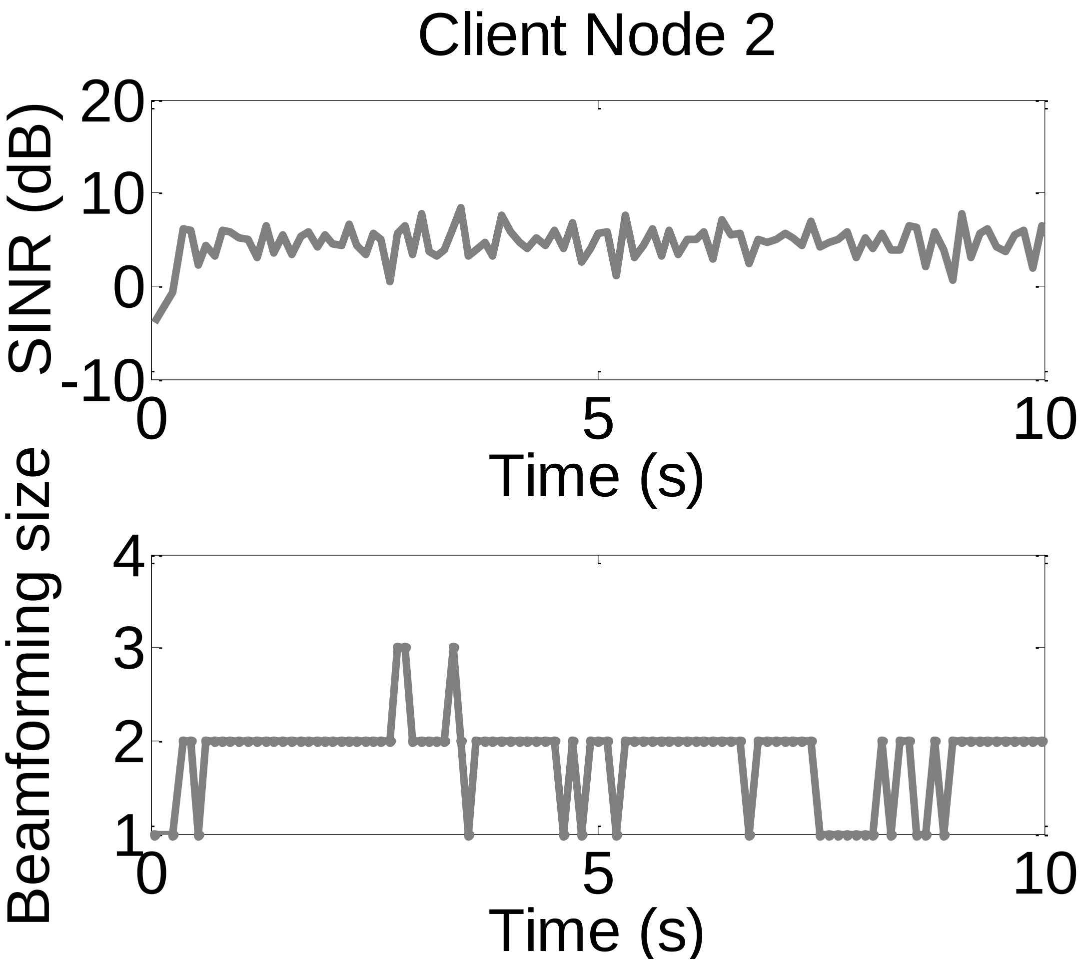
- Distributed algorithm to minimize TX power under uplink capacity constraints
  - No explicit inter-client cooperation
  - Iterative
  - Guaranteed to converge
  - Converge in a few iterations in practice
  - Converge to a good solution in practice

- Can be built on top of uplink power control in cellular networks

WARPLab-based prototype

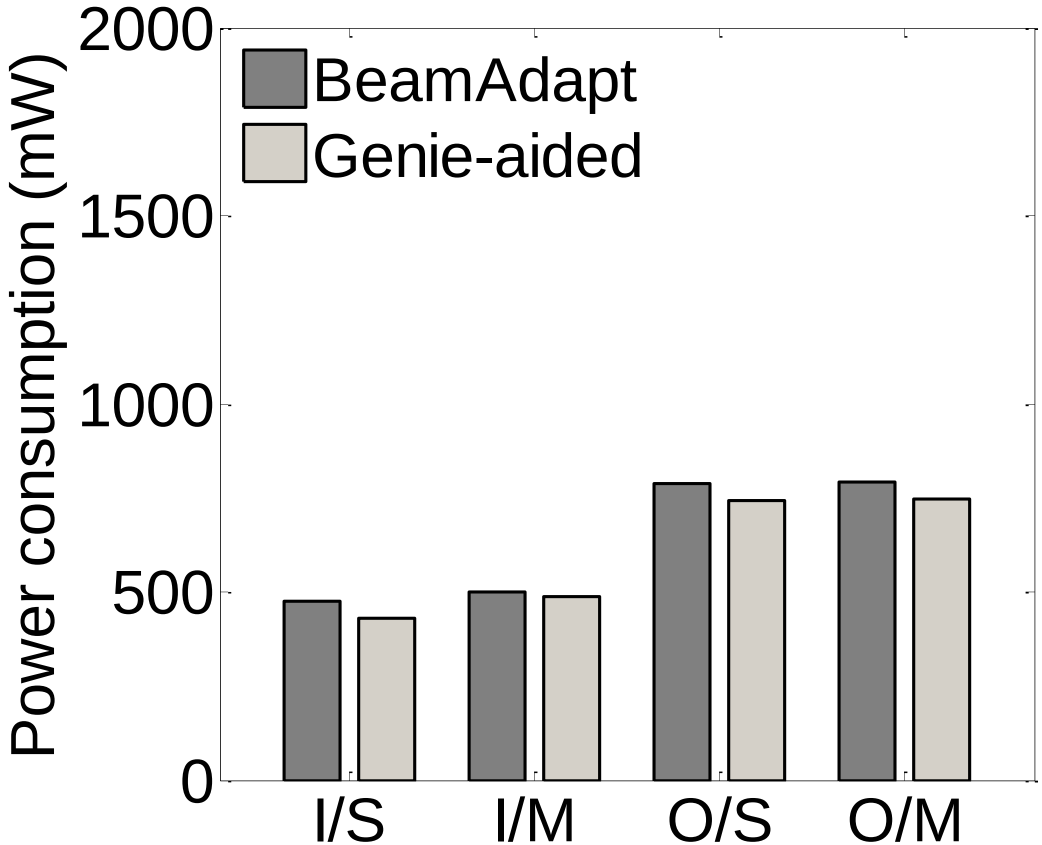


Received SNR stable



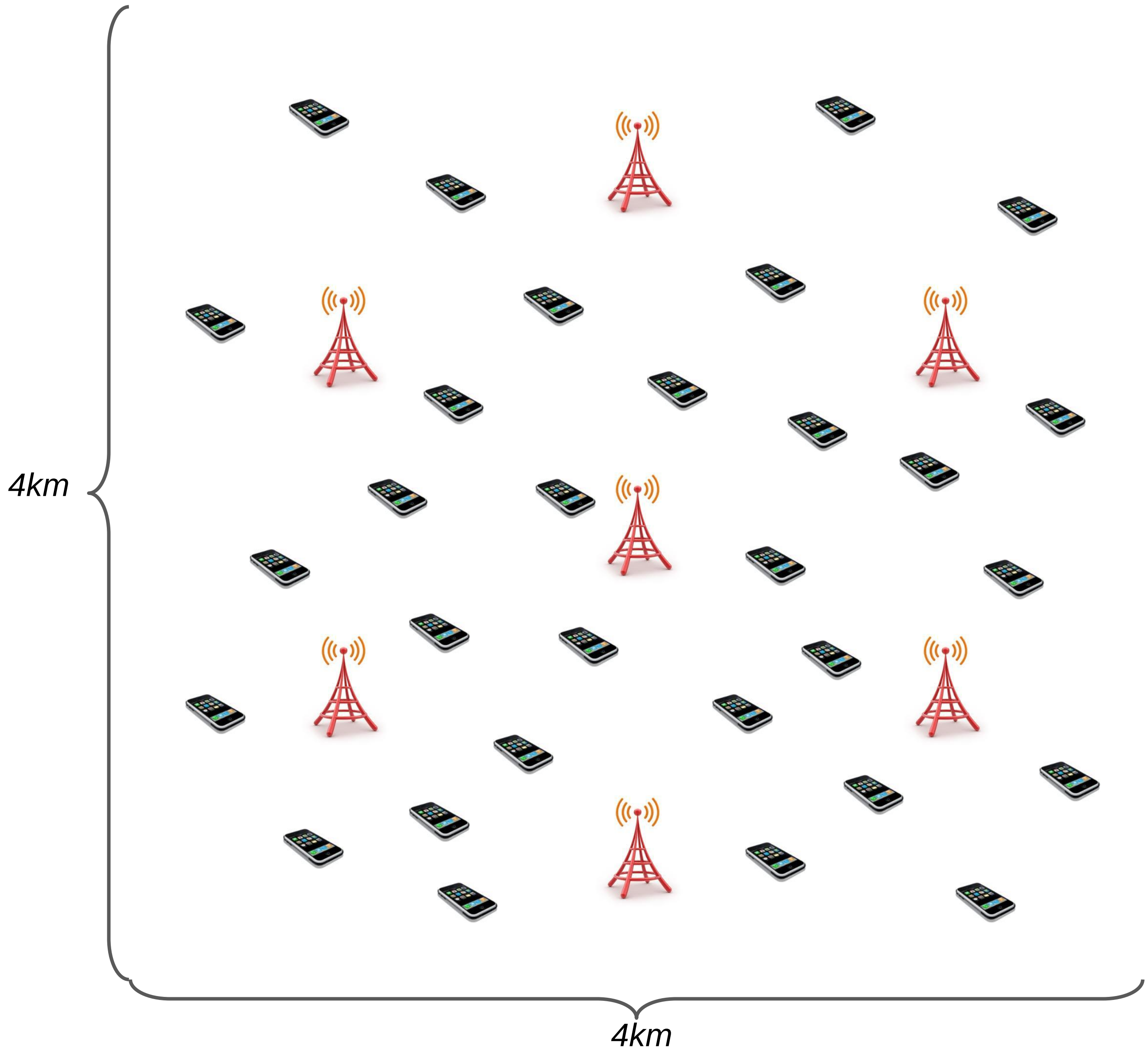
Link SNR constraint: 5 dB

Power close to optimal



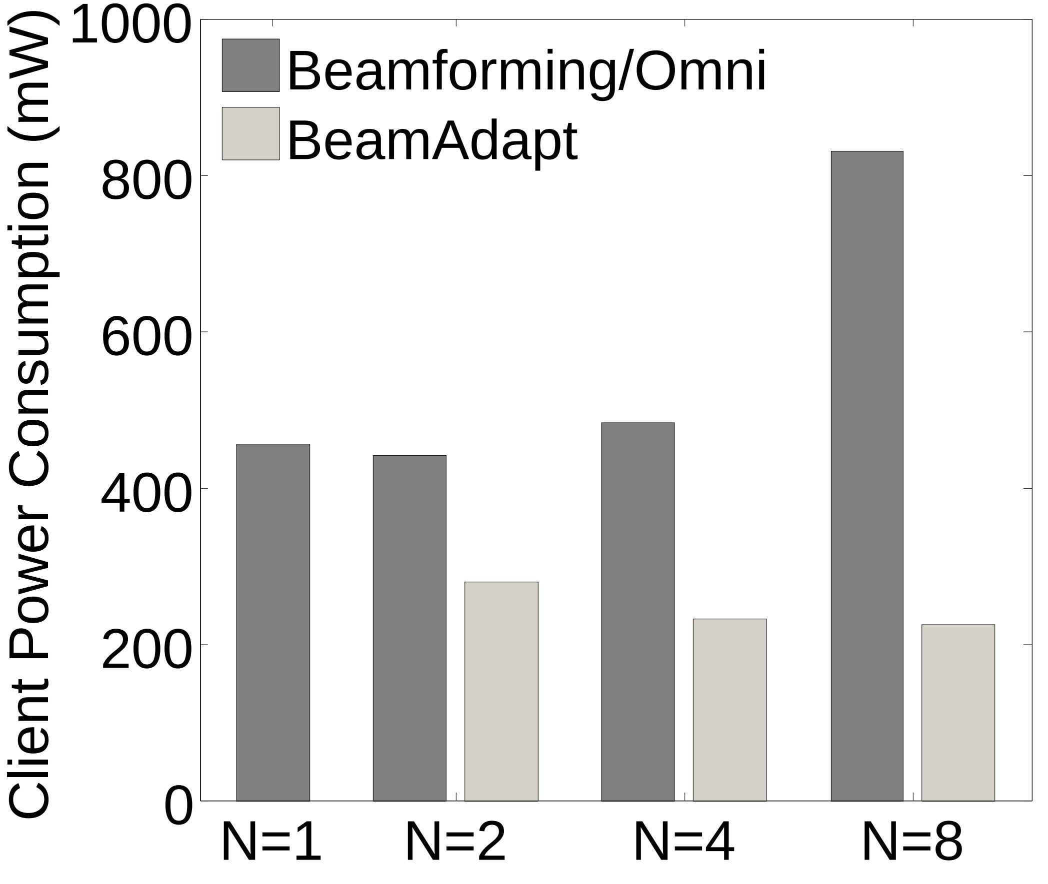
I: Indoor O: Outdoor S: Stationary M: Mobile / Rotational

Link SNR constraint: 5 dB



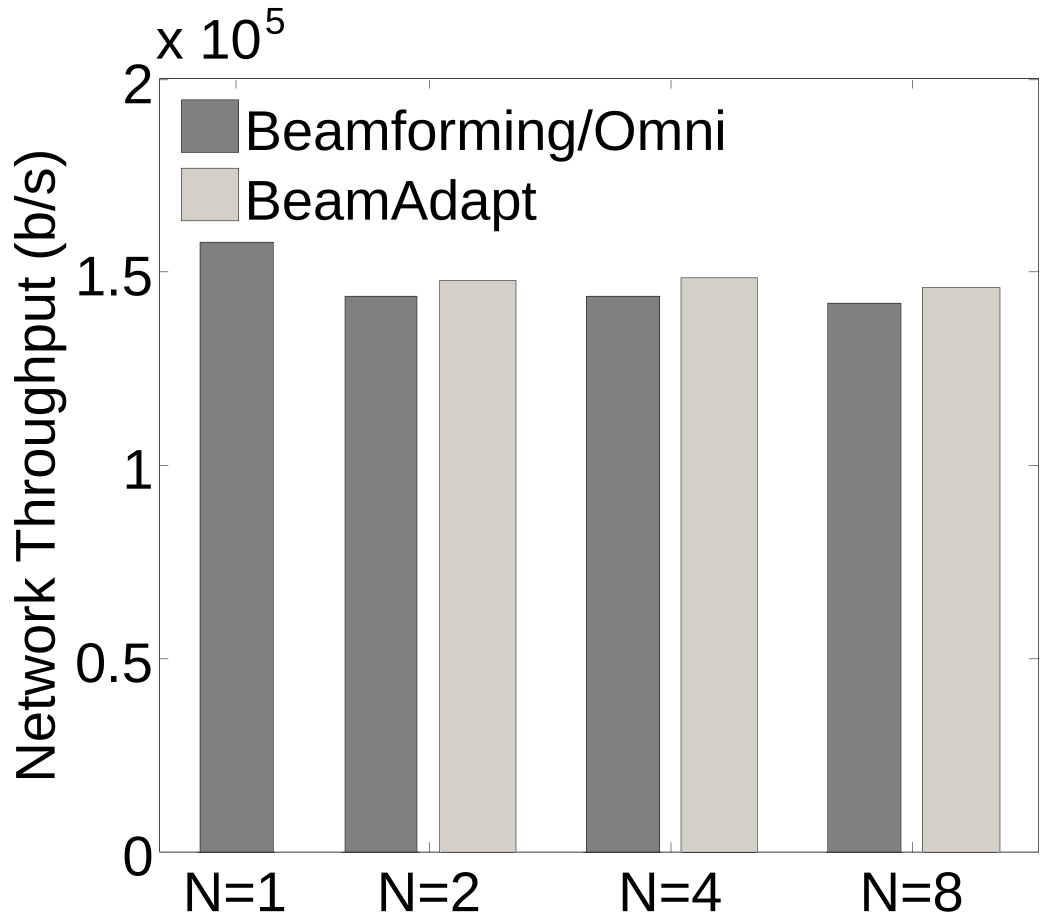
UMTS; Client movement: 0-70 mph; Client rotation: 0-120 °/s

Power reduced



CBR traffic

Network throughput maintained



CBR traffic

Conclusions

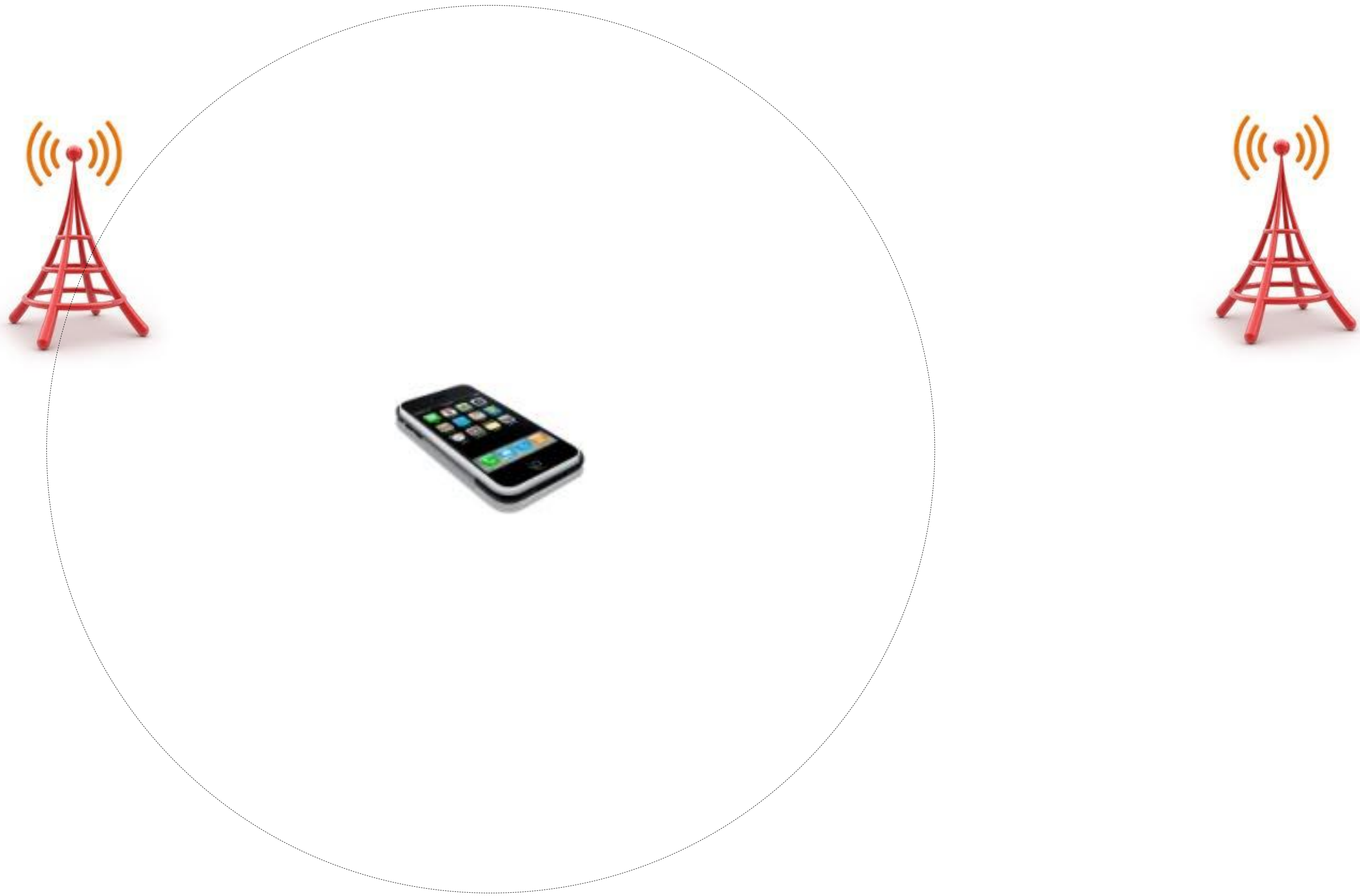
- Beamforming is feasible for mobile devices
  - Lower-power uplink for mobile devices
- Distributed optimization feasible

Looking forward

- Benefits of beamforming orthogonal to other spectrum efficiency technologies such as network MIMO

- Network capacity implications

Treating interference as noise



Strong interference regime:
Far from optimal from information theoretic perspective

Treating interference as noise

Weak interference regime:
Existing architecture yields close to optimal capacity

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