# 5G: Opportunities and Challenges

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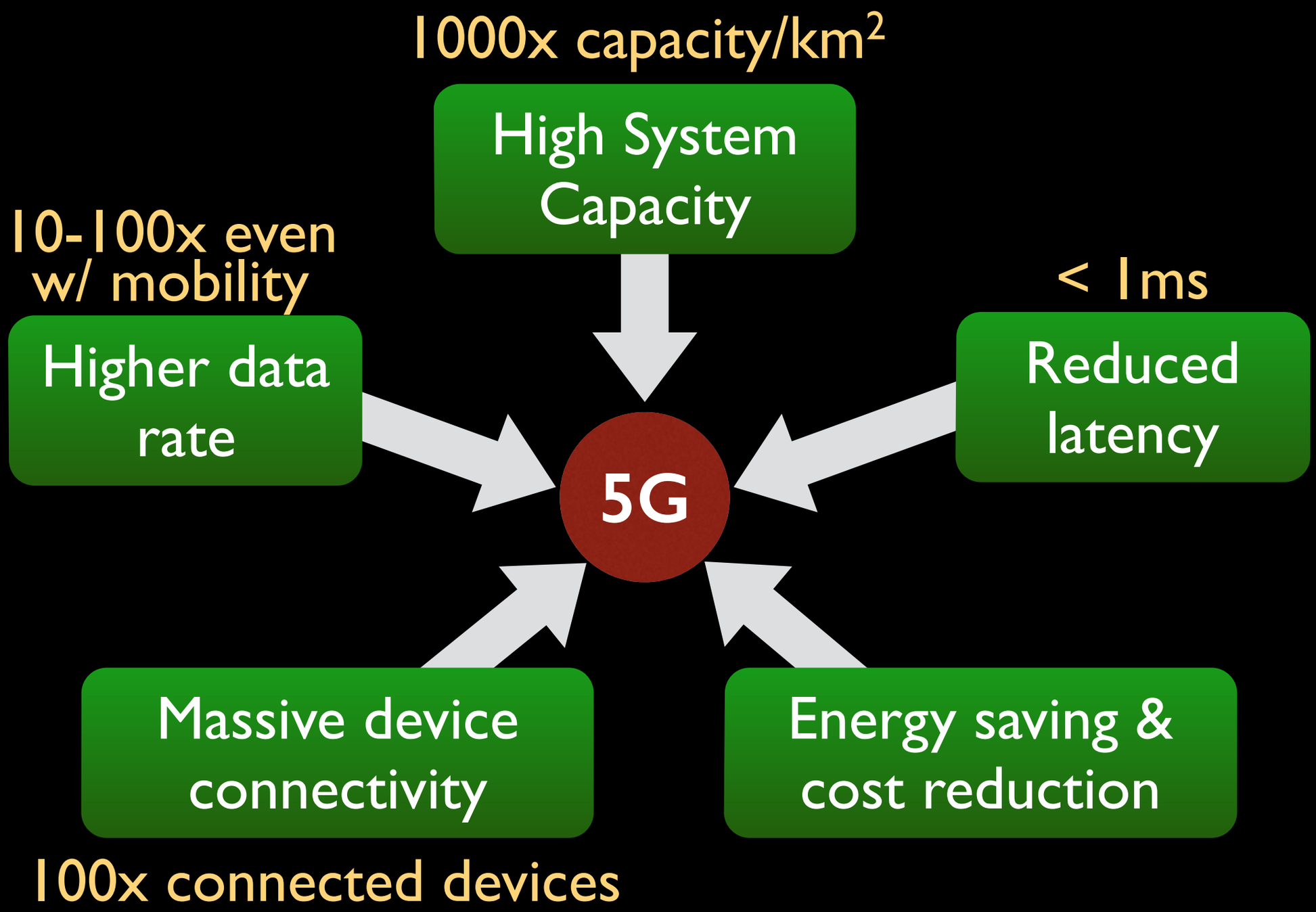
# Key Trend (2013-2025)

- Exponential traffic growth
- Wireless traffic dominated by video multimedia
- Expectation of ubiquitous broadband access
- Expectation of Gbps, low latency access
- Emerging internet of things devices

source: Intel, Sept. 2013

# 5G Targets




source: NTT DoCoMo, Inc. 2014

# Disruptive Technologies

- Millimeter wave (mmWave)
- Massive MIMO
- Full-duplex communication
- Device-to-device (D2D) communications
- Heterogeneous networks

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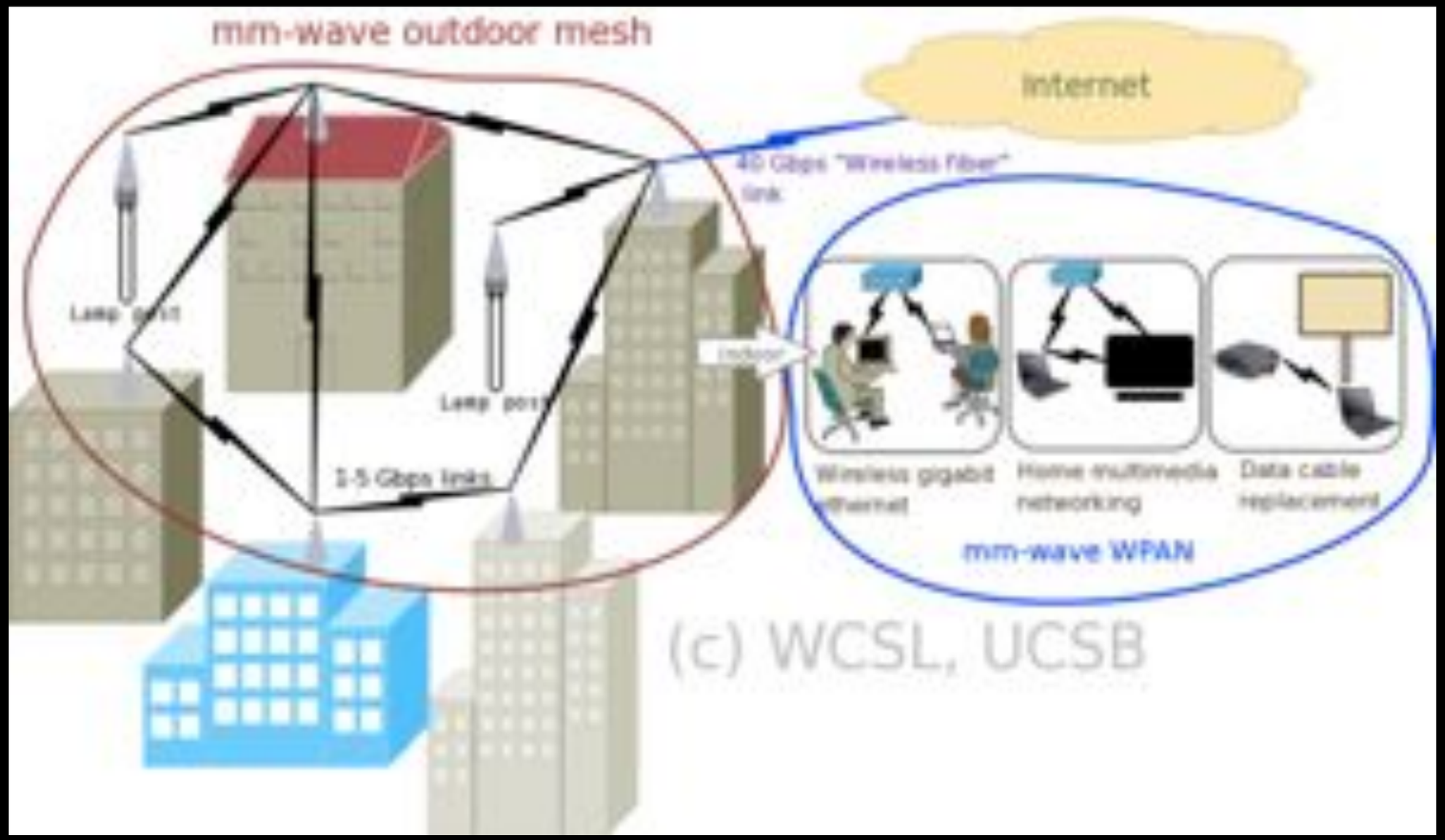
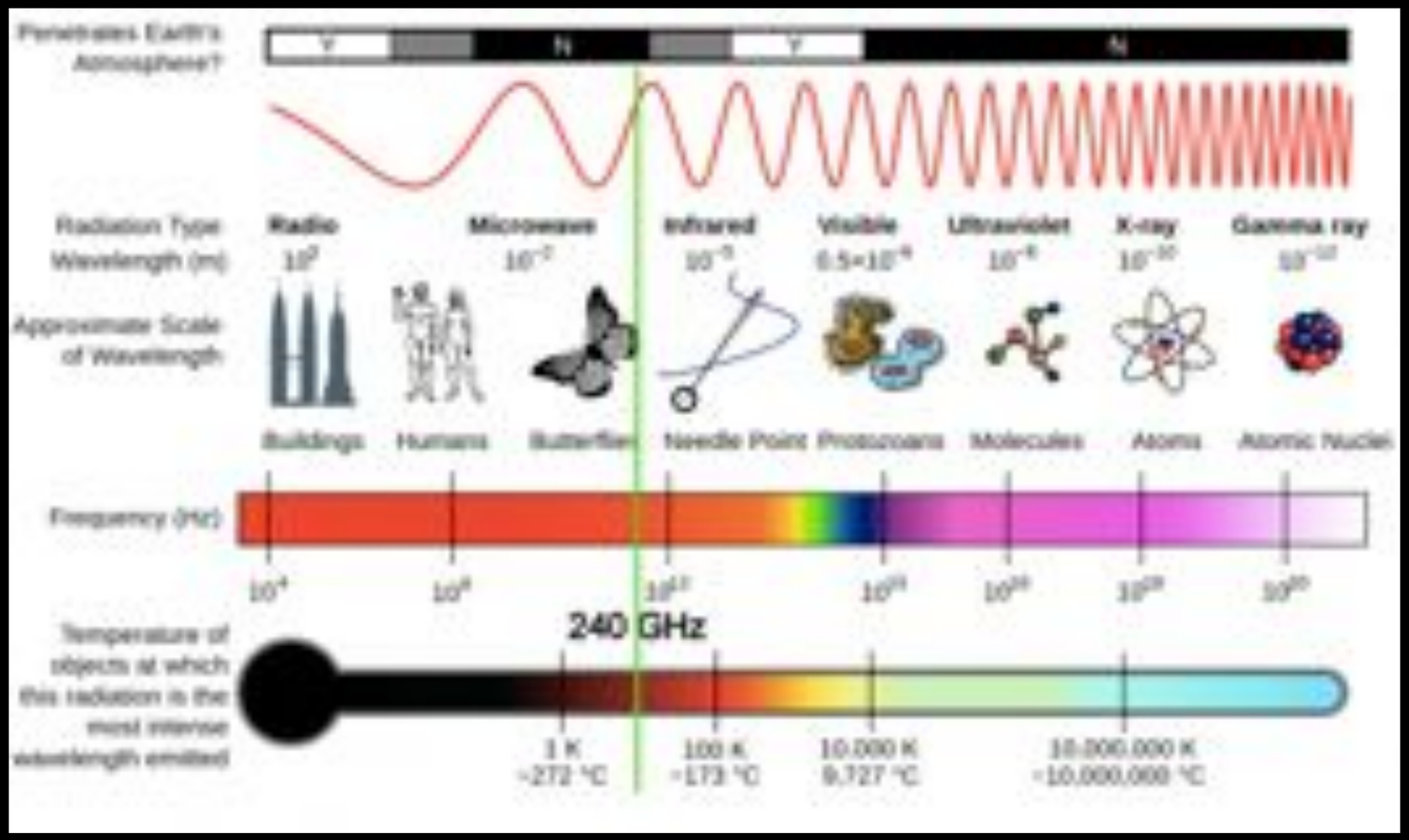
# mmWave Scenarios




source: http://www.ece.ucsb.edu/wcsl/mmwcsresearch

# Millimeter Wave




- Ranging from 3 to 300 GHz
  - e.g., license-free band at 60 GHz

# mmWave Standardization

- IEEE 802.11ad
  - Short-range services
  - 60GHz
  - Beamforming antenna
  - OFDM modulation
  - Maximum data rate: 7Gbps
  - Typical distance: 1-10m

# mmWave's Properties

- Properties similar to microwave frequencies
  - Distance-dependent path loss
  - Possibility of non-light-of-sight communication
- Properties different from microwave frequencies
  - Sensitivity to blockage
  - High power consumption of ADC/DAC

# mmWave's Key Feature

## Antenna Array

- Keep the antenna aperture constant
- Eliminate the frequency dependence of path loss
- Counter the larger thermal noise
- Reduce the impact of interference by adaptive array with narrow beams

New random access protocols are required due to directional transmission/reception

# Recent work on mmWave

- Millimeter Wave (mmWave) Wireless @ NYU
  - http://faculty.poly.edu/~tsr/mmwave.php
- Millimeter Wave Communication Systems Research @ UCSB
  - http://www.ece.ucsb.edu/wcsl/mmwcsresearch/doku.php
- Millimeter Wave Cellular Systems @ UTAustin
  - http://www.profheath.org/research/millimeter-wave-cellular-systems/

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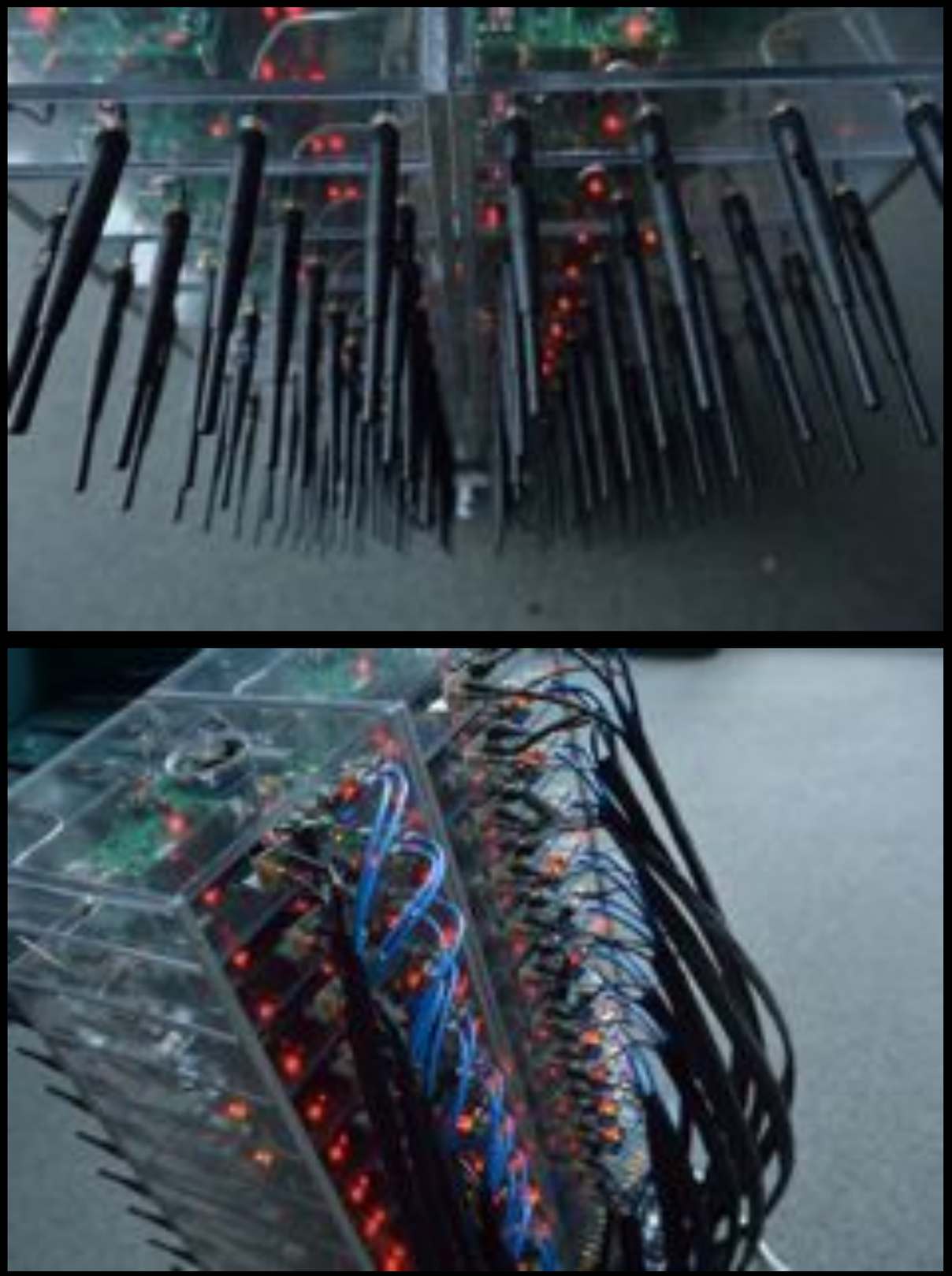

http://argos.rice.edu/

# Massive MIMO

- Support a much larger number of antennas, e.g., one hundred or more
- If **N** grows large and all other system parameters are assumed constant, the transmit power per user can be reduced proportionally to $1/N$ and $1/\sqrt{N}$ for perfect and imperfect CSI knowledge, respectively

H. Q. Ngo, E.G. Larsson, T.L. Marzetta, "Energy and Spectral Efficiency of Very Large Multiuser MIMO Systems," IEEE Trans. on Comm., vol. 61, no. 4, pp. 1436--1449, Apr. 2013.

# Massive MIMO: Challenges

- Scalability of precoding and detection
  - Traditional zero-forcing  beamforming requires non-trivial baseband processing
- CSI estimation
  - How to efficiently collect full CSI?
- Accurate synchronization
- Cost, size, and power consumption

- Reading list
  - http://www.idc.lnt.de/en/forschung/massive-mimo-systems/
  - http://www.massivemimo.eu/research-library
  - http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6798744
  - http://www.comsoc.org/best-readings/topics/massive-mimo

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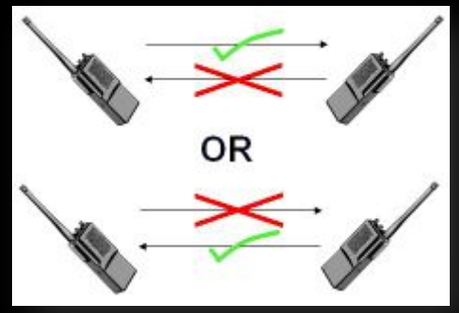
# What is Duplex?

- Simplex

- Half-duplex

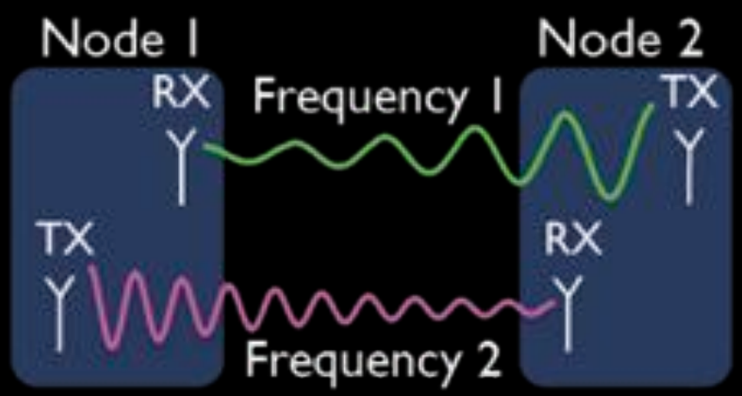



- Full-duplex

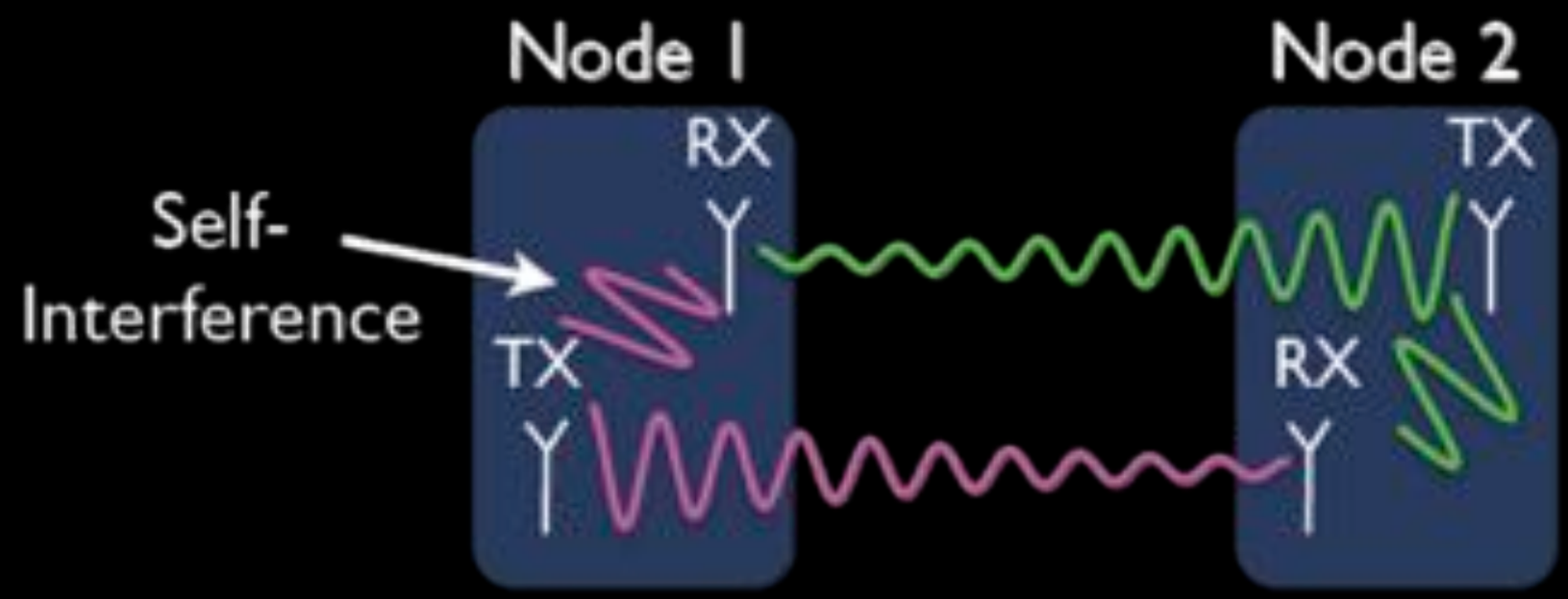
# How Half-duplex Works?

- Time-division half-duplex


- Frequency-devision half-duplex



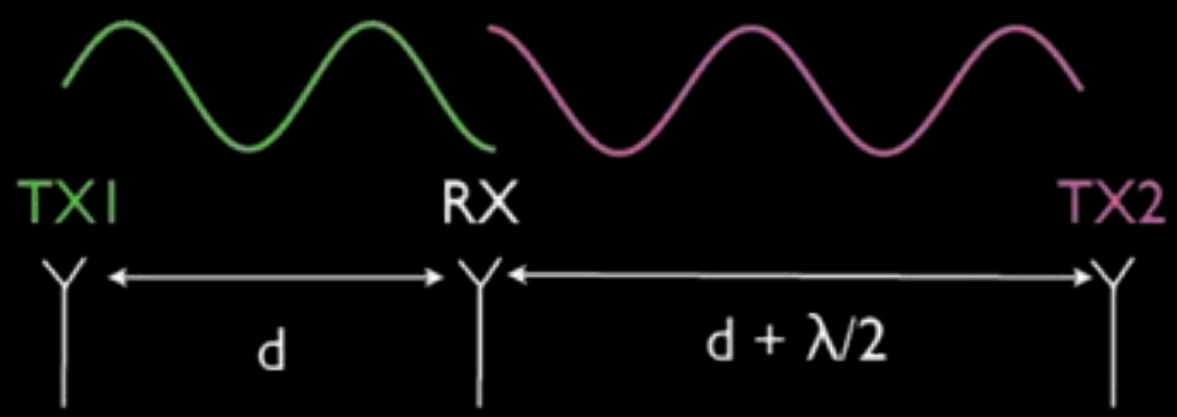
# Co-Channel (In-band) Full-duplex




Very strong self-interference (~70dB for 802.11)

# Self-Interference Elimination

- Analog interference cancellation (RF cancellation, ~25dB reduction)
- Digital interference cancellation (baseband cancellation)
- Antenna cancellation (~20dB reduction)
  - Separate the antennas such that the two signals become deconstructive
- Performance degrades when the bandwidth increases



# Applications

- Reducing hidden terminals
- Multi-hop wireless networks
- Wireless relaying (repeaters)
- Cognitive radio (spectrum sensing)

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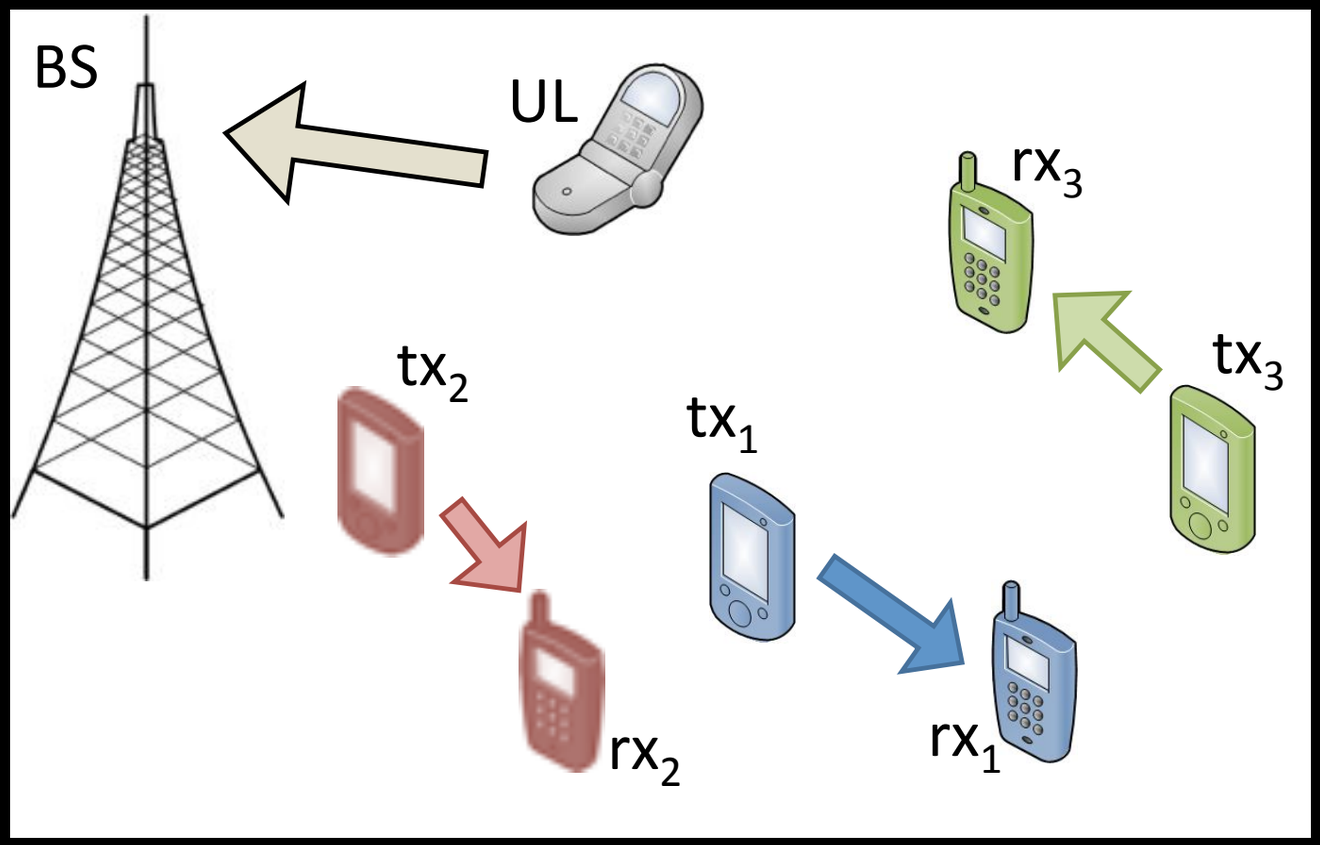
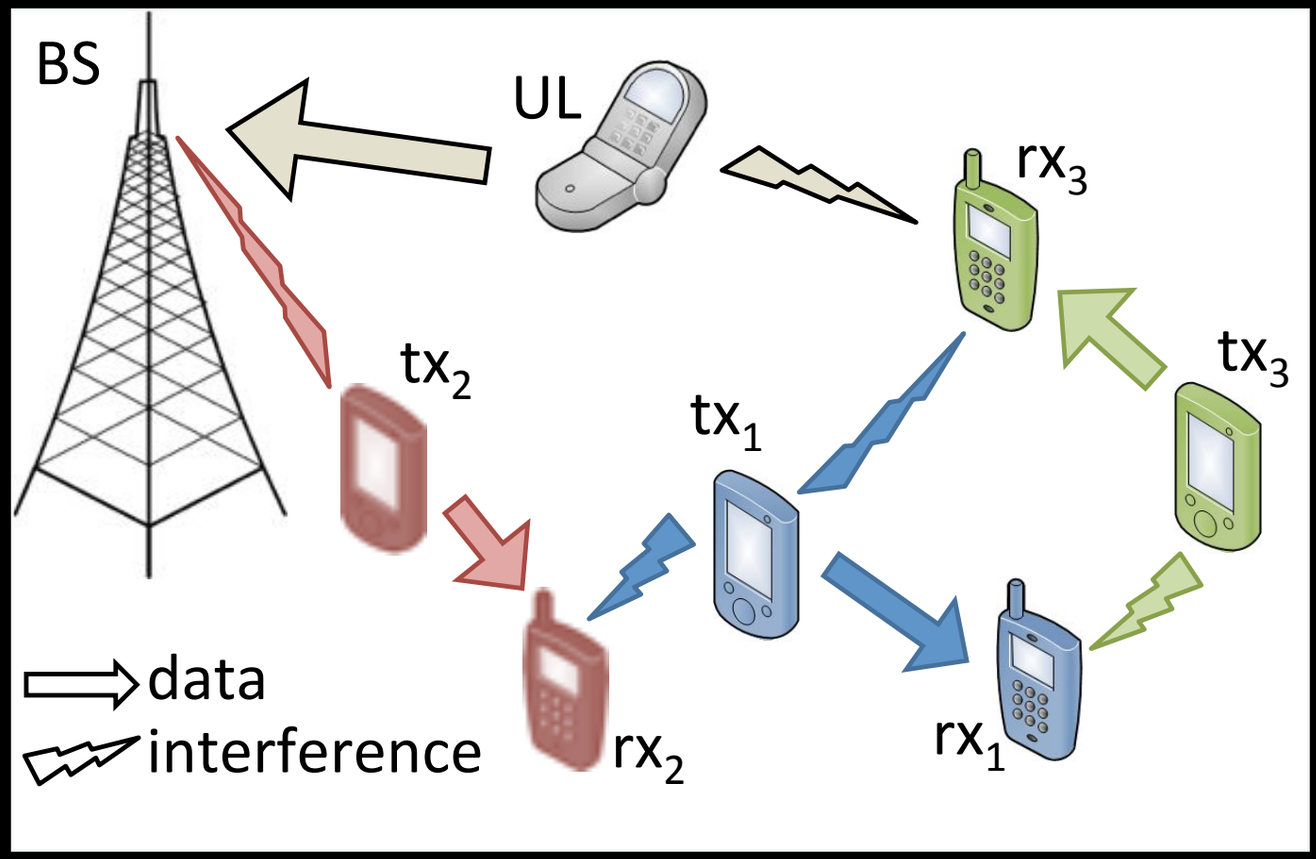
# D2D Communications




- Co-located devices share content directly, without going through a base station
- Offload proximity data exchange from a congested cellular system

# Inter-link Interference in D2D




- D2D links might interfere with each other
- D2D clients might also interfere cellular transmissions

# D2D Interference Management

- Possible solutions
  - Resource allocation (OFDMA)
    - Throughput maximization
    - Revenue maximization
    - Energy consumption
    - Incentive
  - MIMO techniques, such as interference alignment

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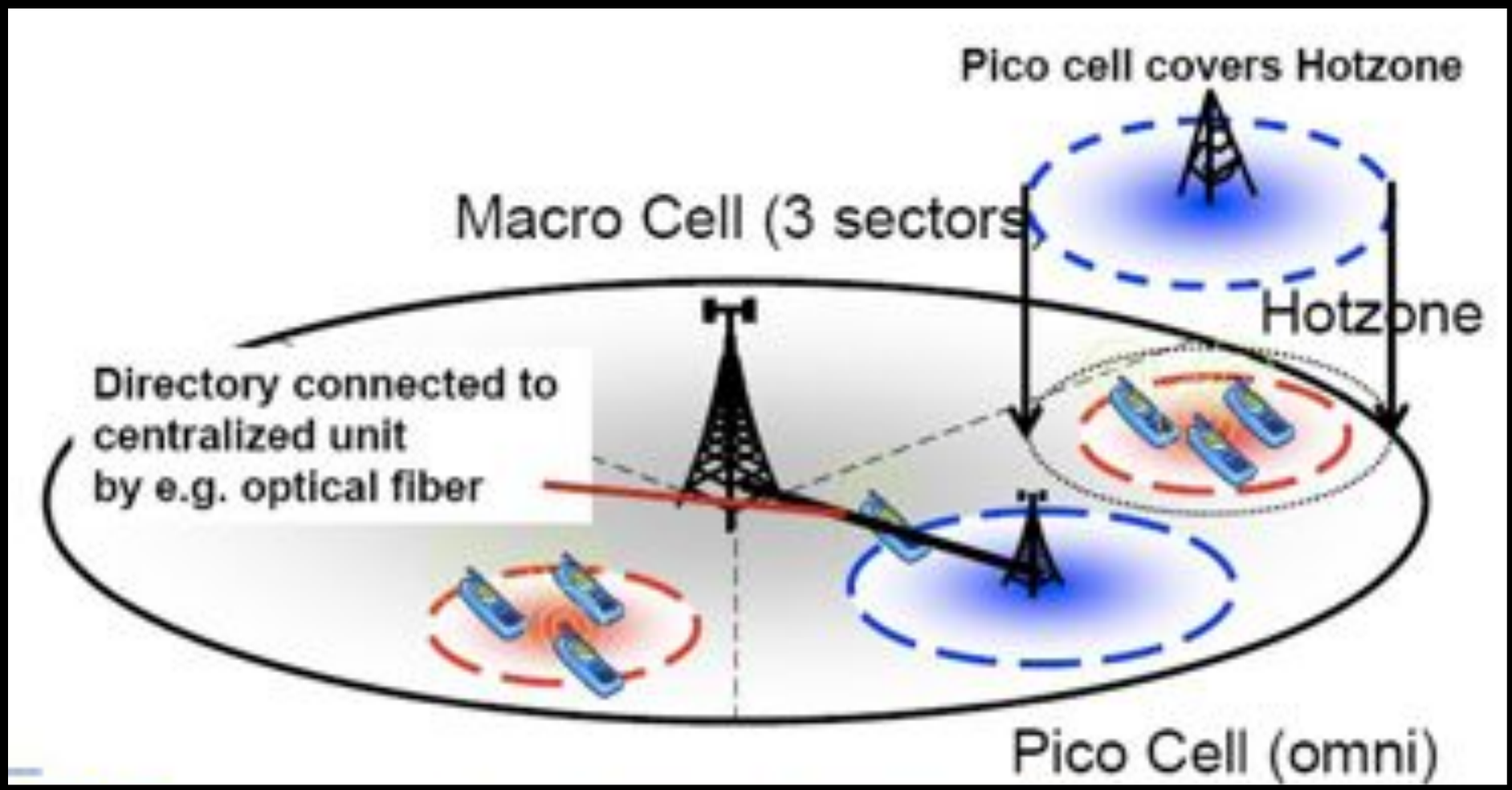
# Heterogeneous Networks

macro cell + femto cell + pico cell




source: http://blog.3g4g.co.uk/

# Advantages and Challenges

- Reduce the cell size, and improve spatial reuse
  - larger capacity per device
- Challenges
  - Resource allocation and interference management
  - Backhaul bandwidth management
  - Latency and QoS guarantee
  - Pricing