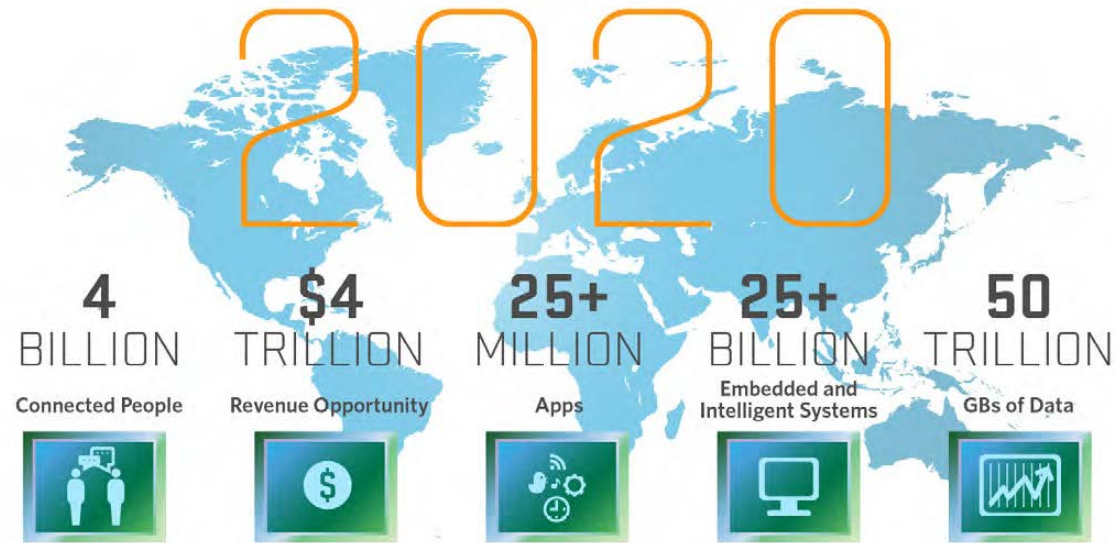


# Wireless Communication Systems @CS.NCTU

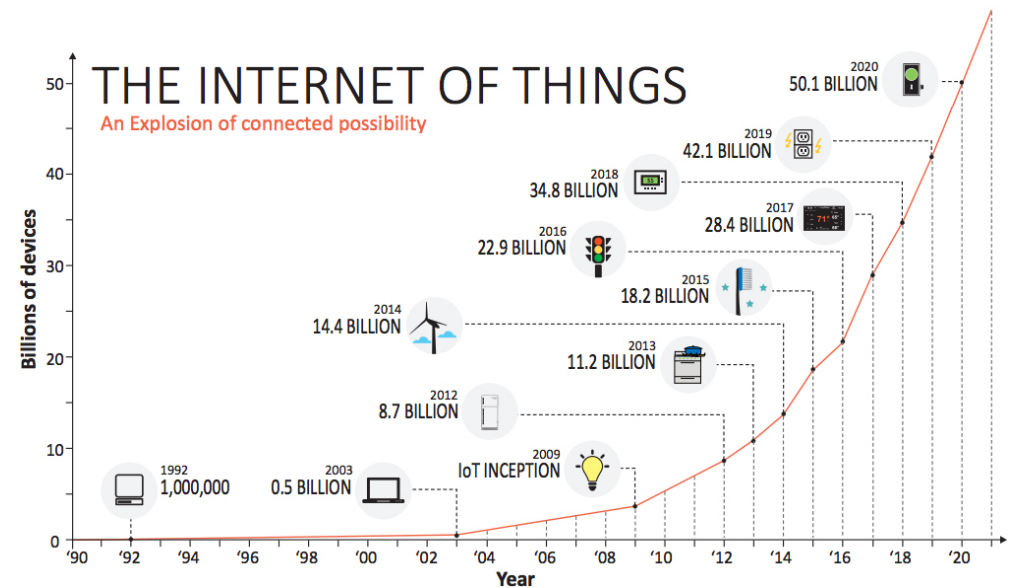
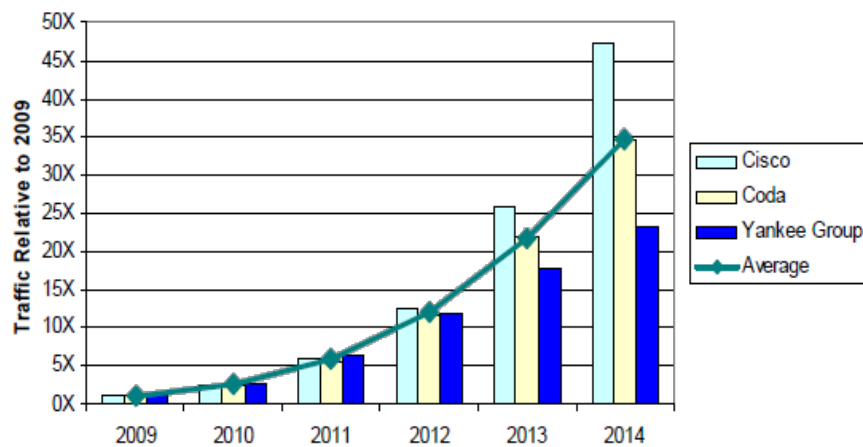
## Lecture 10: 5G

Instructor: Kate Ching-Ju Lin (林靖茹)

# Increasing Demand for Wireless Connectivity



Source: Mario Morales, IDC



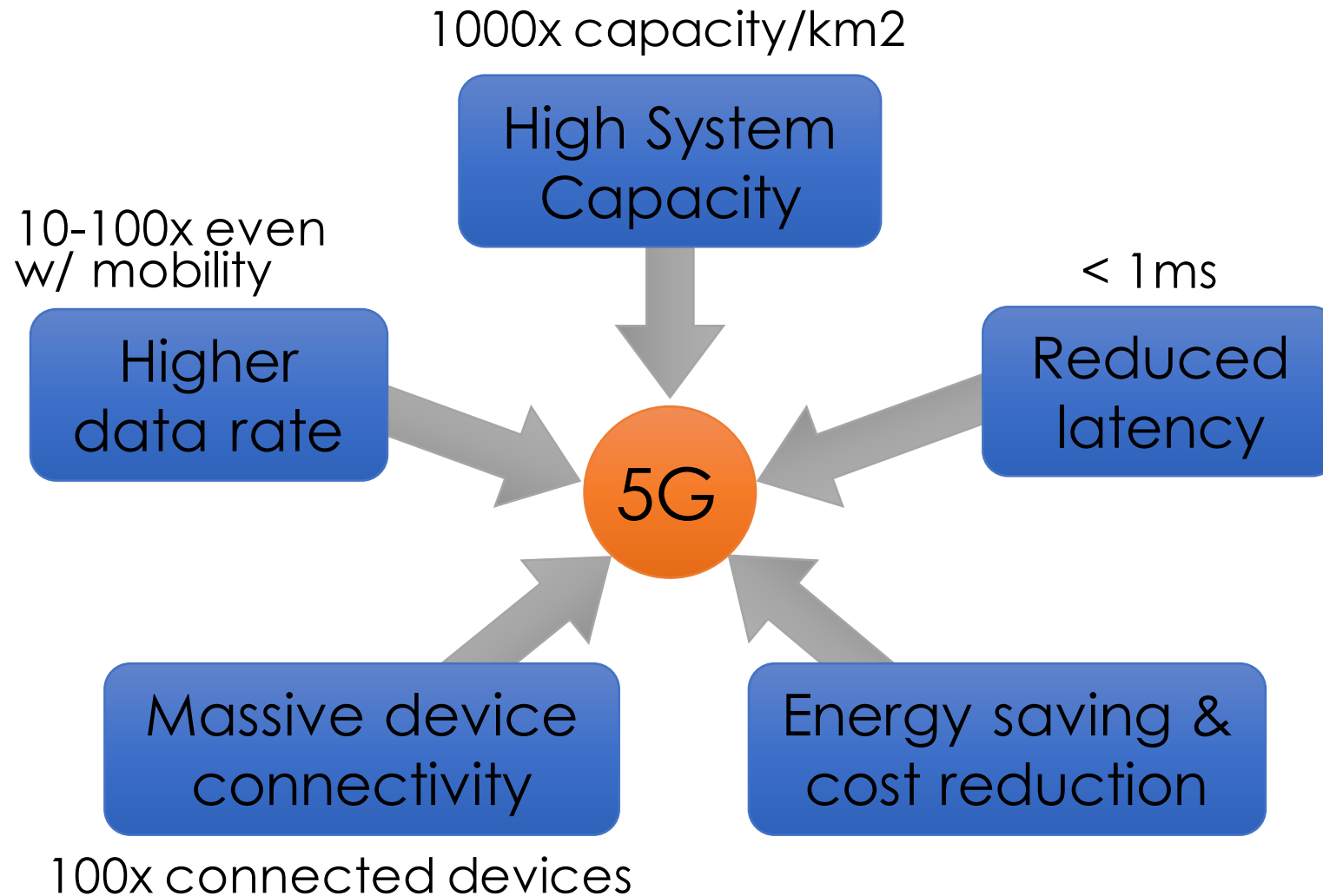
# Key Trend (2013-2025)

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- 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

# 5G Targets

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source: NTT DoCoMo, Inc. 2014



# Disruptive Technologies

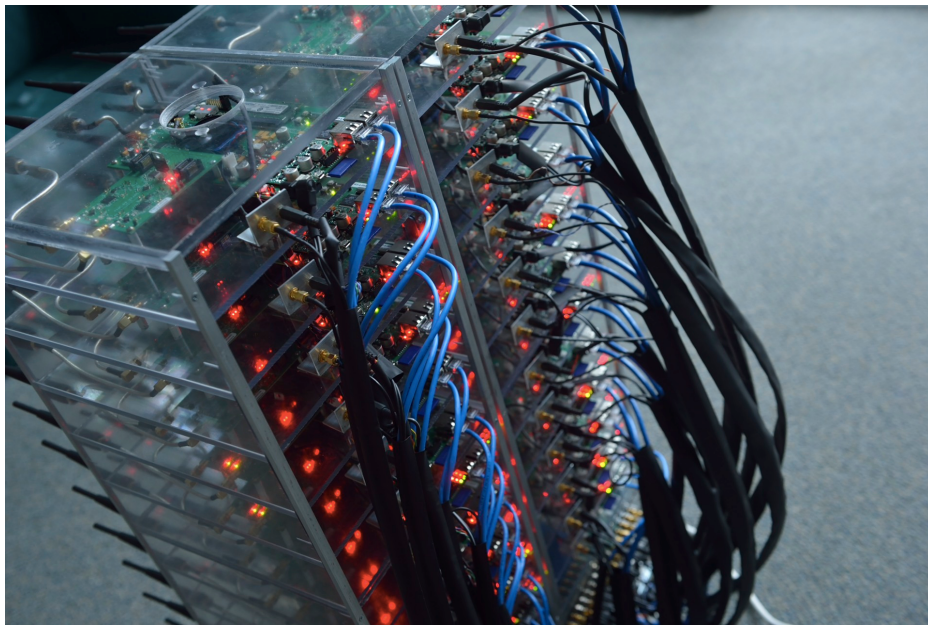
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- Massive MIMO
- Device-to-device (D2D) communications
- Heterogeneous networks
- Full-duplex communication
- Millimeter wave (mmWave)

# Disruptive Technologies

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



<http://argos.rice.edu/>

# Massive MIMO

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- Support a much larger number of antennas, e.g., one hundred or more
- Also known as Large-Scale Antenna Systems, Very Large MIMO, Hyper MIMO, Full-Dimension MIMO
- 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

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- 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

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- <http://www.idc.Int.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>



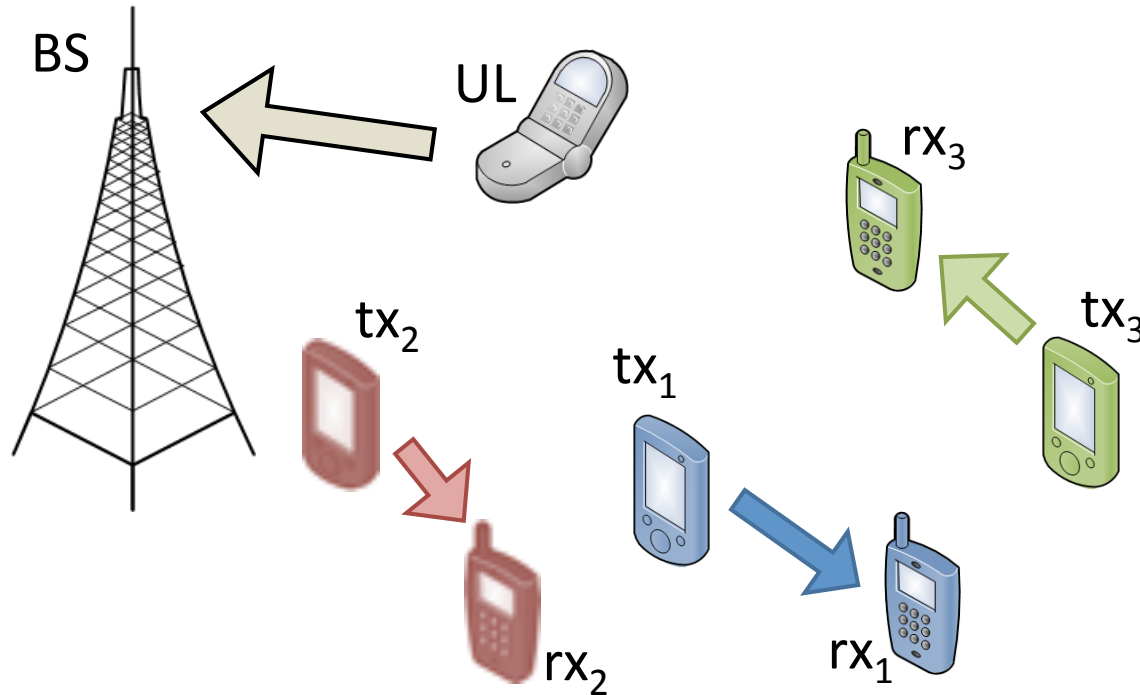
# Disruptive Technologies

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- Massive MIMO
- **Device-to-device (D2D) communications**
- Heterogeneous networks
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# D2D Communications

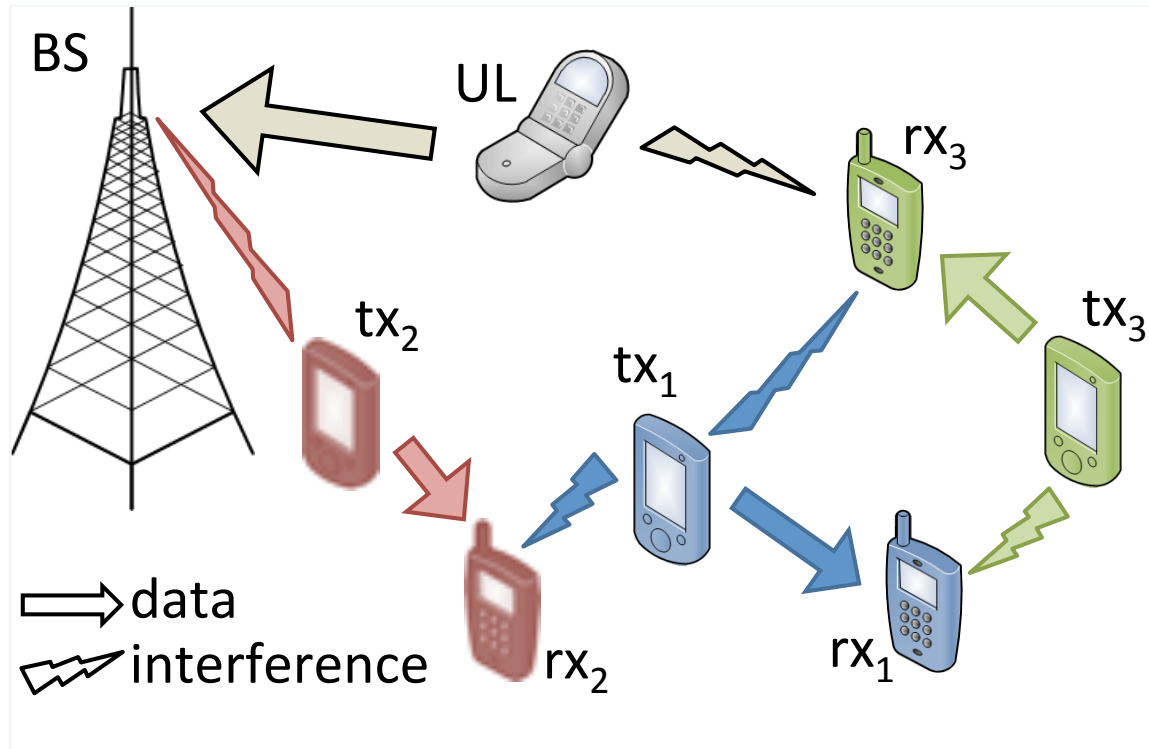
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- Co-located devices share content directly, without going through a base station
- Offload proximity data exchange from a congested cellular system



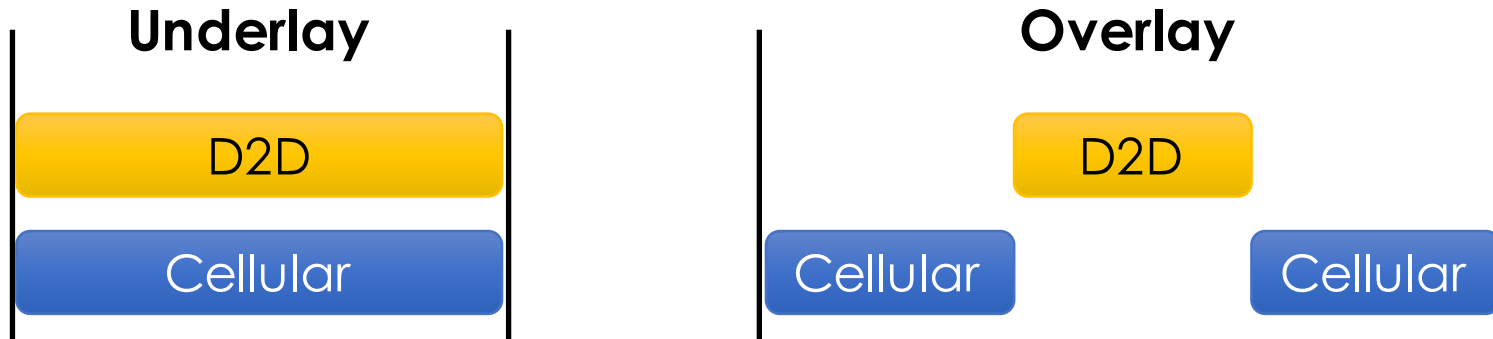
# Inter-link Interference in D2D



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

# Overlay and Underlay D2D

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- Higher spectrum efficiency by spatial reuse
- Need to cope with interference

- Dedicated resources for D2D
- Reduce the concern about interference
- Need explicit resource allocation

# D2D Interference Management

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

# Disruptive Technologies

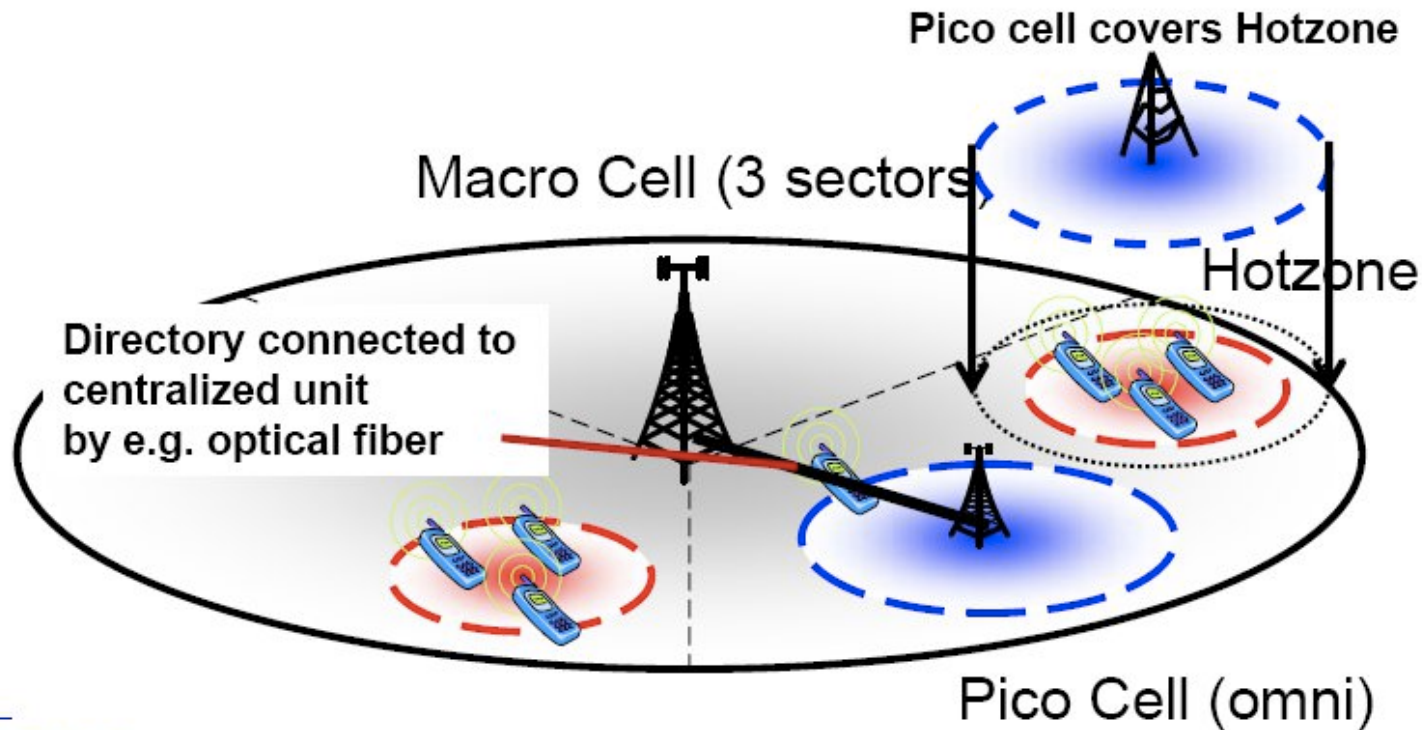
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- Massive MIMO
- Device-to-device (D2D) communications
- **Heterogeneous networks**
- Full-duplex communication
- Millimeter wave (mmWave)

# Heterogeneous Networks

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macro cell + pico cell + femto cell



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

# Comparison

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<b>Aspect</b>	<b>Picocell</b>	<b>Femtocell</b>
Installation	Operator	Customer
Transmission to operator's network	Operator	Customer
Frequency/radio parameters	Centrally planned	Locally determined
Site rental	Operator	Customer

Source: <https://www.thinksmallcell.com/FAQs/whats-the-difference-between-picocells-and-femtocells.html>

# Advantages and Challenges

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- 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

# Disruptive Technologies

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



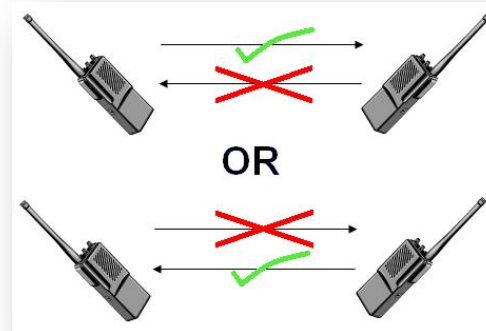
# What is Duplex?

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- Simplex



- Half-duplex



- Full-duplex



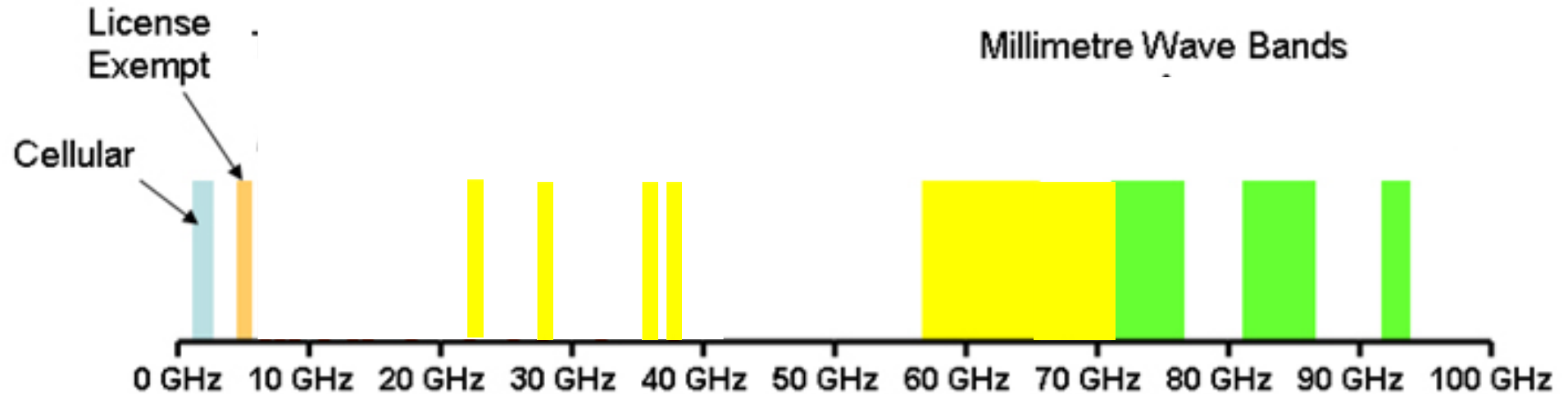
# Disruptive Technologies

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- Massive MIMO
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# Millimeter Wave Bands

- Huge amount of available bandwidth ( $\lambda=C/f$ )



Federal Communications Commission

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## FCC Promotes Higher Frequency Spectrum for Future Wireless Technology

### Full Title

Use of Spectrum Bands Above 24 GHz For Mobile Radio Services

### Description

FCC proposes new rules to make spectrum bands above 24 GHz available for mobile and other services

Document Type: Notice of Proposed Rulemaking

### Document Dates

Released On: Oct 23, 2015

Comment: Jan 26, 2016

Adopted On: Oct 22, 2015

Issued On: Oct 23, 2015

### Document Numbers

DA/FCC: FCC-15-138

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The [Advanced Wireless Research Initiative](#) will sustain United States leadership in wireless communications and tech and development.

The National Science Foundation's (NSF) leadership of this Initiative has three intertwined components:

- Establishing **platforms for advanced wireless research** enabled by a new industry consortium and engagement
- Supporting **fundamental research enabling advanced wireless technologies**; and
- Catalyzing **academic, industry, and community leaders** to work together to prototype innovative wireless applications

These efforts will provide new insights capable of making wireless communication faster, smarter, more responsive, and

# mmWave Wireless Applications



5G Cellular Networks



Wireless Data Centers



Wireless LANs 802.11ad



Wireless Virtual/ Augmented Reality



Connected Vehicles



Gesture Recognition 24