Evolution Towards 5G Heterogeneous Wireless Networks: A Resource Allocation Perspective

M. Rasti

Amirkabir University of Technology

Outline

- Part 1: Visions and Requirements for 5G
- Part 2: Key Enabling Technologies for 5G
- Part 3: In-Band Full-Duplexing
- Part 4: Energy Harvesting
- Part 5: D2D Communications
- Part 6: Femto-cell Networks

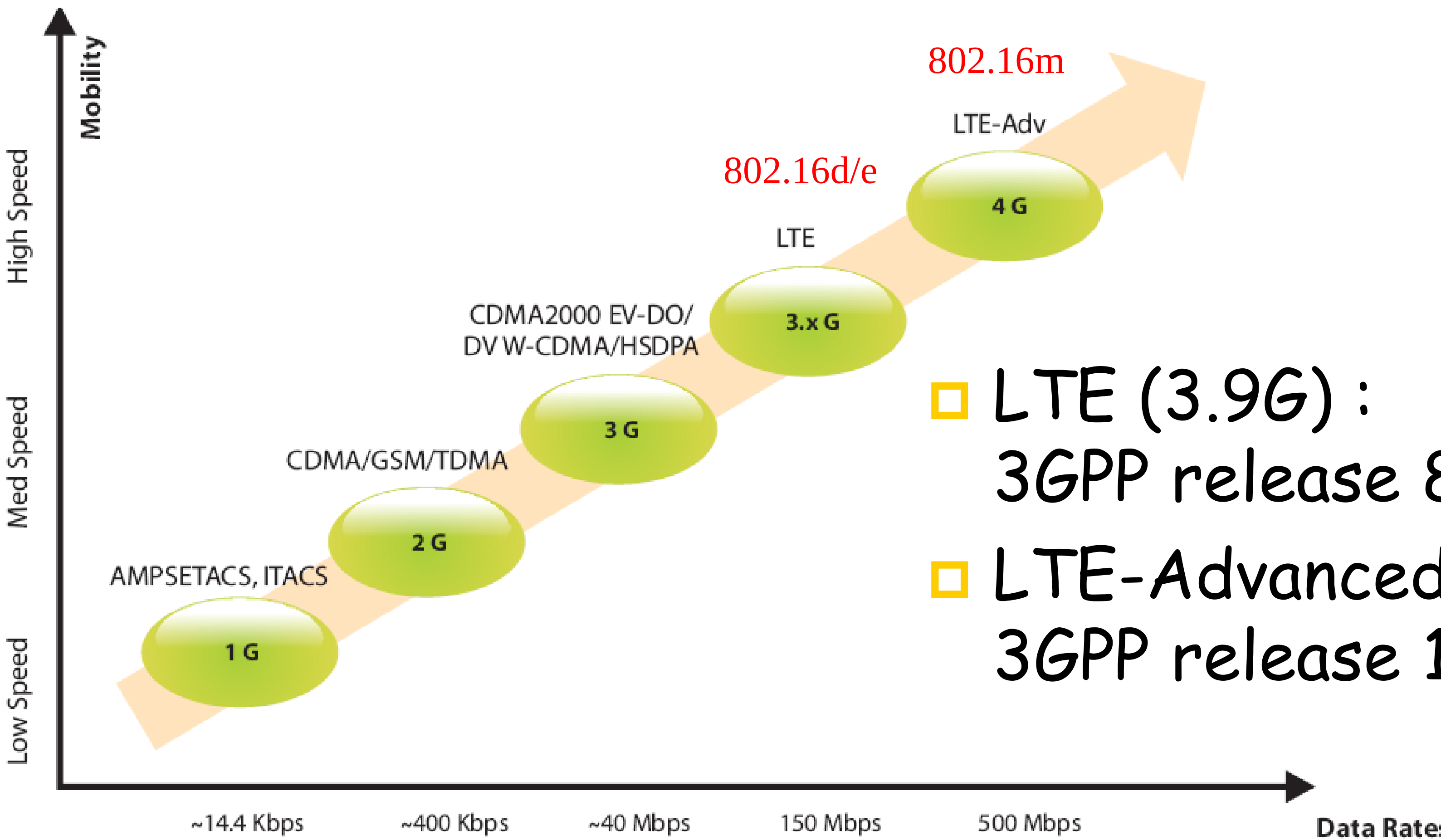
Part 1 Outline

- Visions and Requirements for 5G

Overview of Mobile Communications Standards

Overview of Mobile Communications Standards

- Evolution of Radio Access Technologies



- LTE (3.9G) : 3GPP release 8~9
- LTE-Advanced : 3GPP release 10+

Explosive Growth of Data Capacity Demands

- An explosive growth in demand for data capacity
  - Organic traffic growth
    - More intelligent mobile devices
      - increase in screen size, image resolution and battery life of mobile devices,
    - Improvement of network infrastructures, peak data rate
  - User-generated content and social networking
  - Machine-type connected devices (Internet of Things)
    - The number of devices could reach the tens or even hundreds of billions by the time 5G comes to fruition

Source: R. Q., Hu, and Y. Qian, Heterogeneous Cellular Networks, John Wiley & Sons, Ltd, 2013, Chapter 1, Section 1.1.2

Explosive Growth of Data Capacity Demands

- In just a decade, the amount of IP data handled by wireless networks will have increased by well over a factor of 100:
  - From under 3 EB in 2010 to over 190 EB by 2018, on pace to exceed 500 EB by 2020
- An incremental approach will not come close to meeting the demands that networks will face by 2020

- Source: Cisco, "Visual networking index," white paper at Cisco.com, Feb. 2014.

Explosive Growth of Data Capacity Demands

- How does 5G meet such a explosive growth data?

- Before answering this question, it is necessary to first identify the requirements and corresponding challenges for a 5G system
  - Visions and Requirements for 5G
  - Challenges and Key Enabling Emerging Technologies for 5G

Visions and Requirements for 5G

- 1) Data Rate
  - The need to support the mobile data traffic explosion is unquestionably the main driver behind 5G
- 2) Latency
- 3) Energy and Cost

Visions and Requirements for 5G

- 1) Data Rate: can be measured in several different ways
  - Aggregate data rate
  - Edge rate, or 5% rate
  - Peak rate

Visions and Requirements for 5G

- Aggregate data rate:
  - Total amount of data the network can serve, characterized in units of bits/s/area.
- Edge rate, or 5% rate:
  - The worst data rate that a user can reasonably expect to receive when in range of the network, and so is an important metric and has a concrete engineering meaning
- Peak rate:
  - The best-case data rate that a user can hope to achieve assuming:
    - The whole bandwidth being allocated to a single user
    - With the highest modulation and coding scheme, and
    - The maximum number of antennas supported

Visions and Requirements for 5G

- Aggregate data rate:
  - The general consensus is that this quantity will need to increase by roughly 1000x from 4G to 5G.
- Edge rate, or 5% rate:
  - Goals for the 5G edge rate range from 100 Mbps (easily enough to support high-definition streaming) to as much as 1 Gbps.
  - Meeting 100 Mbps for 95% of users will be extraordinarily challenging, even with major technological advances.
  - This requires about a 100x advance since current 4G systems have a typical 5% rate of about 1 Mbps, although the precise number varies quite widely depending on the load, cell size, and other factors.

Visions and Requirements for 5G

- Data Rate: measured in several different ways
  - Peak rate:
    - The peak rate is a marketing number, devoid of much meaning to engineers, but in any case it will likely be in the range of tens of Gbps.

Key Performance Requirement Targets for LTE Release 8

		Absolute requirement	Release 6 (for comparison)	Comments
Downlink	Peak transmission rate	> 100 Mbps	14.4 Mbps	LTE in 20 MHz FDD, 2 × 2 spatial multiplexing. Reference: HSDPA in 5 MHz FDD, single antenna transmission
	Peak spectral efficiency	> 5 bps/Hz	3 bps/Hz	
	Average cell spectral efficiency	> 1.6–2.1 bps/Hz/cell	0.53 bps/Hz/cell	LTE: 2 × 2 spatial multiplexing, Interference Rejection Combining (IRC) receiver [3]. Reference: HSDPA, Rake receiver [4], 2 receive antennas
	Cell edge spectral efficiency	> 0.04–0.06 bps/Hz/user	0.02 bps/Hz/user	As above, 10 users assumed per cell
	Broadcast spectral efficiency	> 1 bps/Hz	N/A	Dedicated carrier for broadcast mode
Uplink	Peak transmission rate	> 50 Mbps	11 Mbps	LTE in 20 MHz FDD, single antenna transmission. Reference: HSUPA in 5 MHz FDD, single antenna transmission
	Peak spectral efficiency	> 2.5 bps/Hz	2 bps/Hz	
	Average cell spectral efficiency	> 0.66–1.0 bps/Hz/cell	0.33 bps/Hz/cell	LTE: single antenna transmission, IRC receiver [3]. Reference: HSUPA, Rake receiver [4], 2 receive antennas
	Cell edge spectral efficiency	> 0.02–0.03 bps/Hz/user	0.01 bps/Hz/user	As above, 10 users assumed per cell
System	User plane latency (two way radio delay)	< 10 ms		LTE target approximately one fifth of Reference.
	Connection set-up latency	< 100 ms		Idle state → active state
	Operating bandwidth	1.4–20 MHz	5 MHz	(initial requirement started at 1.25 MHz)
	VoIP capacity	NGMN preferred target expressed in [2] is > 60 sessions/MHz/cell		

Visions and Requirements for 5G

- 1) Data Rate
- 2) Latency
  - In terms of both connection establishment and transmission latency
  - 5G will need to be able to support a roundtrip latency of about 1 ms, an order of magnitude faster than 4G (which is on the order of about 15 ms)
- 3) Energy and Cost

Visions and Requirements for 5G

- 1) Data Rate
- 2) Latency
- 3) Energy and Cost
  - As we move to 5G, costs and energy consumption will, ideally, decrease, but at least they should not increase on a per-link basis
  - Since the per-link data rates being offered will be increasing by about 100x, this means that the Joules per bit and cost per bit will need to fall by at least 100x

Key Technologies to Get to 1000X Data Rate

- The complementary functions of the regulatory authorities and the standardization organizations can be summarized broadly by the following relationship:

$$\text{Aggregated data rate} = \underbrace{\text{bandwidth}}_{\substack{\text{regulation and licences} \\ \text{(ITU-R, regional regulators)}}} \times \underbrace{\text{spectral efficiency}}_{\substack{\text{technology} \\ \text{and standards}}}$$

- Bandwidth
- Spectral efficiency
- What would be the third factor?

Key Technologies to Get to 1000X Data Rate

- a) Increased bandwidth
- b) Increased spectral efficiency
- c) ??

Increased Bandwidth

- Adding more spectrum
  - Adding more frequency bands, both licensed and unlicensed, for mobile internet applications.
  - Primarily by moving towards and into mmWave spectrum
  - Also, making better use of WiFi's unlicensed spectrum in the 5 GHz band

Solution for Overall Network Efficiency

- More flexible spectrum utilization
  - Spectrum sharing, dynamic spectrum access and cognitive radio with opportunistic network access
    - spectrum sharing (e.g. TV bands),

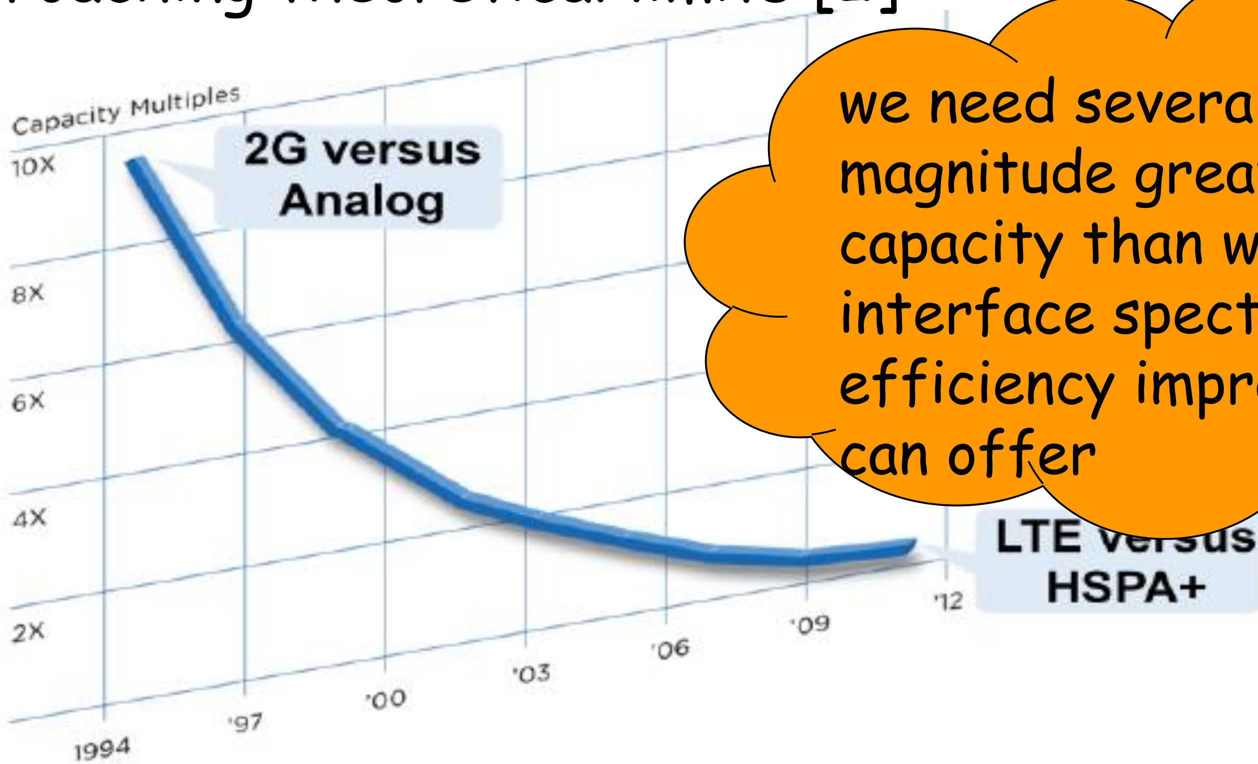
Source: R. Q., Hu, and Y. Qian, Heterogeneous Cellular Networks, John Wiley & Sons, Ltd, 2013, Chapter 1, Section 1.1.2

Spectral Efficiency

- Primarily through advances in Turbo/LDPC/MIMO/OFDM, to support more bits/s/Hz per node
- In-band Full duplexing

Spectral Efficiency

After decades of relentless air interface innovations, improvements in spectral efficiency is practically approaching theoretical limits [2]



we need several orders of magnitude greater system capacity than what the air interface spectral efficiency improvement can offer

Source: Qualcomm Incorporated, "LTE Advanced: Heterogeneous Networks", February 2010

Key Technologies to Get to 1000X Data Rate

- The complementary functions of the regulatory authorities and the standardization organizations can be summarized broadly by the following relationship:

$$\text{Aggregated data rate} = \underbrace{\text{bandwidth}}_{\substack{\text{regulation and licences} \\ \text{(ITU-R, regional regulators)}}} \times \underbrace{\text{spectral efficiency}}_{\substack{\text{technology} \\ \text{and standards}}}$$

- Bandwidth
- Spectral efficiency
- What would be the third factor?
  - ***Area Spectral Efficiency***

Area Spectral Efficiency

- From Spectral Efficiency to Area Spectral Efficiency (Overall Network Efficiency)
  - It becomes essential that the future focus of wireless technology shifts from further increasing the spectral efficiency of the radio link to improving the overall network efficiency through extreme densification and offloading via heterogeneous network architecture
  - Is Physical Layer Dead?
- **Road Ahead:**
  - From link optimization to overall network optimization

Key Technologies to Get to 1000X Data Rate

- a) Increased bandwidth

- b) Increased spectral efficiency

- c) Extreme densification and offloading
  - To improve the area spectral efficiency.
  - Put differently, more active nodes per unit area and Hz
  - Heterogeneous Networks (Macro/Pico/Femto cells)

Solution for Overall Network Efficiency

- Data Offloading
  - Offloading the traffic from macro base stations to the alternative small-cell networks, essentially forming a basic heterogeneous network
  - There is no single answer to the mobile data offloading question.
  - These options are complementary, and all of them will continue to develop to meet the ever increasing capacity demands.

Solution for Overall Network Efficiency

- Options for offloading strategy,
  - Macrocell network and small-cell network of the same air interface technology: In-band small-cell networks (Femto-cell- networks)
  - Between networks of different air interface technologies :Out-band small cell networks (cellular WiFi networks)
  - Between mobile operator core network and public internet

Source: [1], Chapter 1, Section 1.1.2

Extreme Densification and Offloading

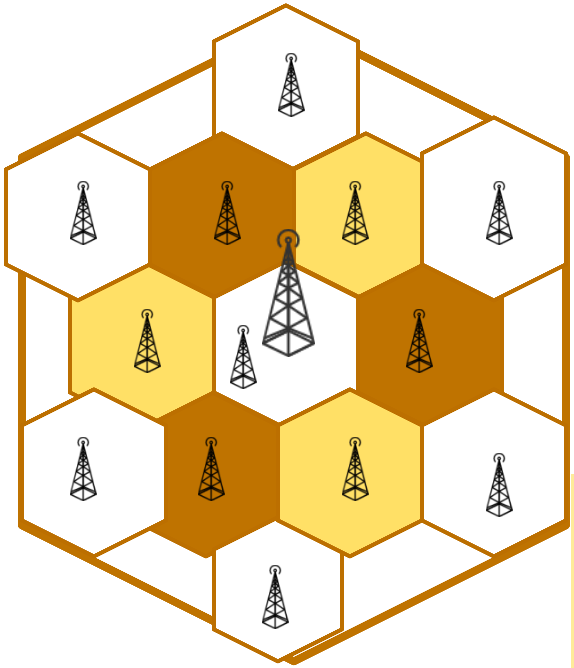
The wireless capacity has doubled every 30 months since *"The wireless capacity has doubled every 30 months over the last 104 years"*

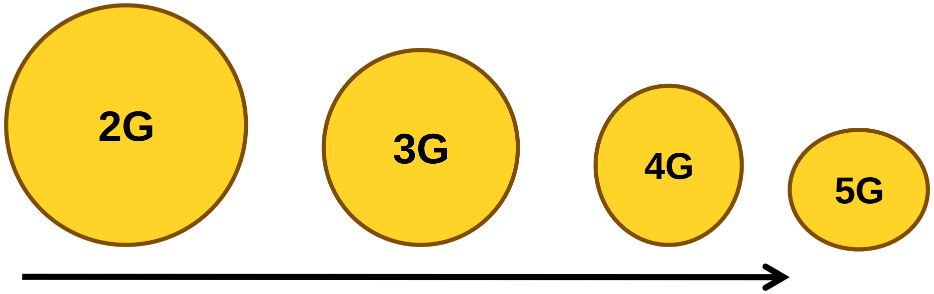
-Martin Cooper of Arraycomm

- This translates into an approximately million-fold capacity increase since 1957 (to 2007).
  - 25x improvement from wider spectrum
  - 5x improvement by dividing the spectrum into smaller slices
  - 5x improvement by designing better modulation schemes
  - 1600x gain through reduced cell sizes and transmit distance.

- The main problem of current cellular network
  - The expensive deployment cost of network infrastructure (60,000$/year/marcrocell)
  - Low signal strength received from an outdoor BS inside a building

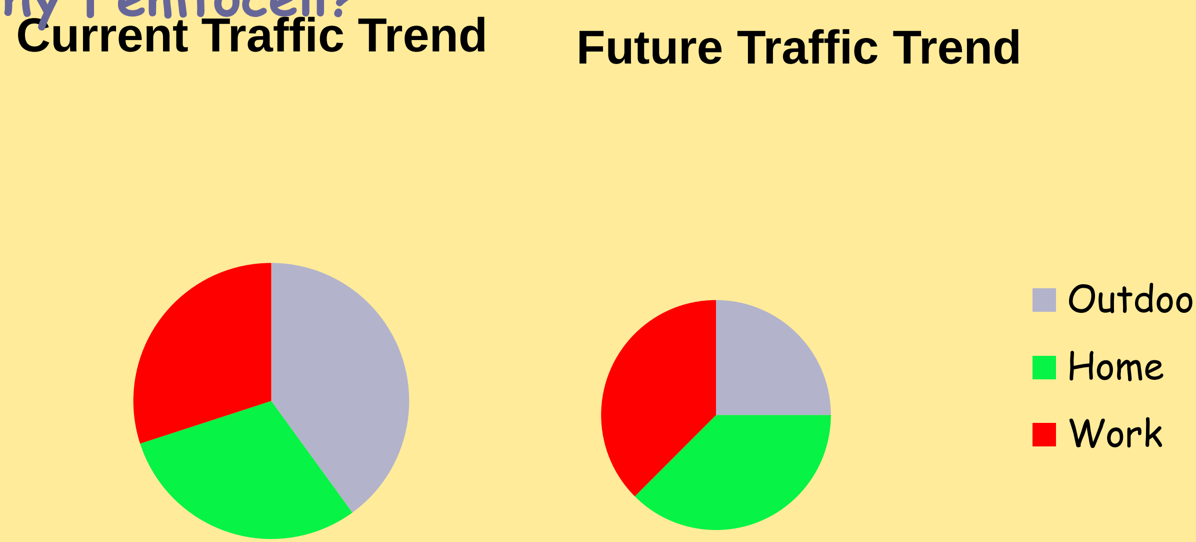
Extreme Densification and Offloading





As throughput demand and usage increases, cell size decreases

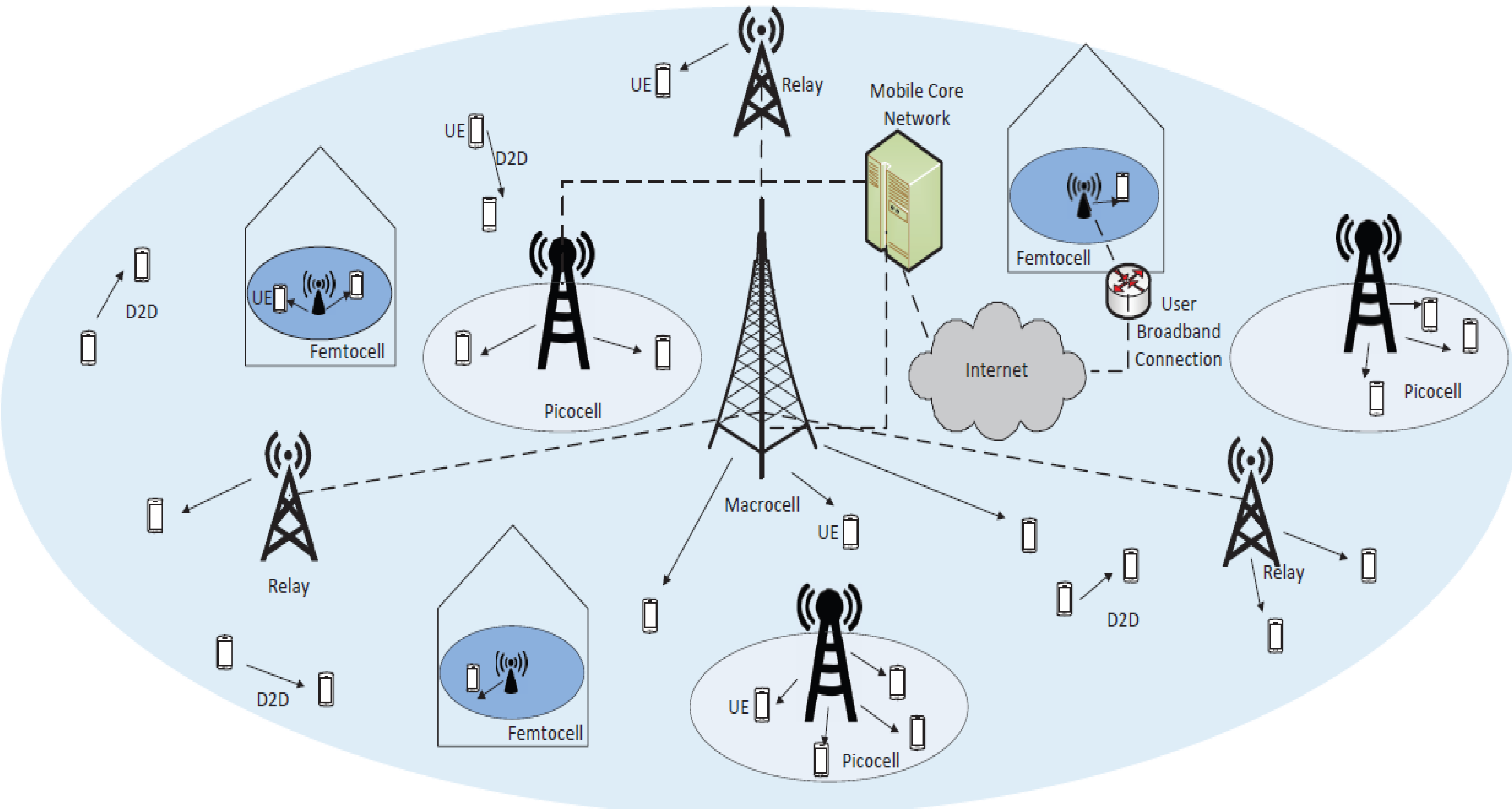
Why Femtocell?



Macro Base Stations

Femto Stations

5G Heterogeneous Networks



Need for Femtocells

- Macrocell cannot provide good signal strength for indoor coverage
- Higher data rate- Femtocells can enable higher capacity
- Reduce the power on the macrocells

"Femtocells are low-power wireless access points that operate in licensed spectrum to connect standard mobile devices to a mobile operator's network using residential DSL or cable broadband connections"

Benefits of Femtocells

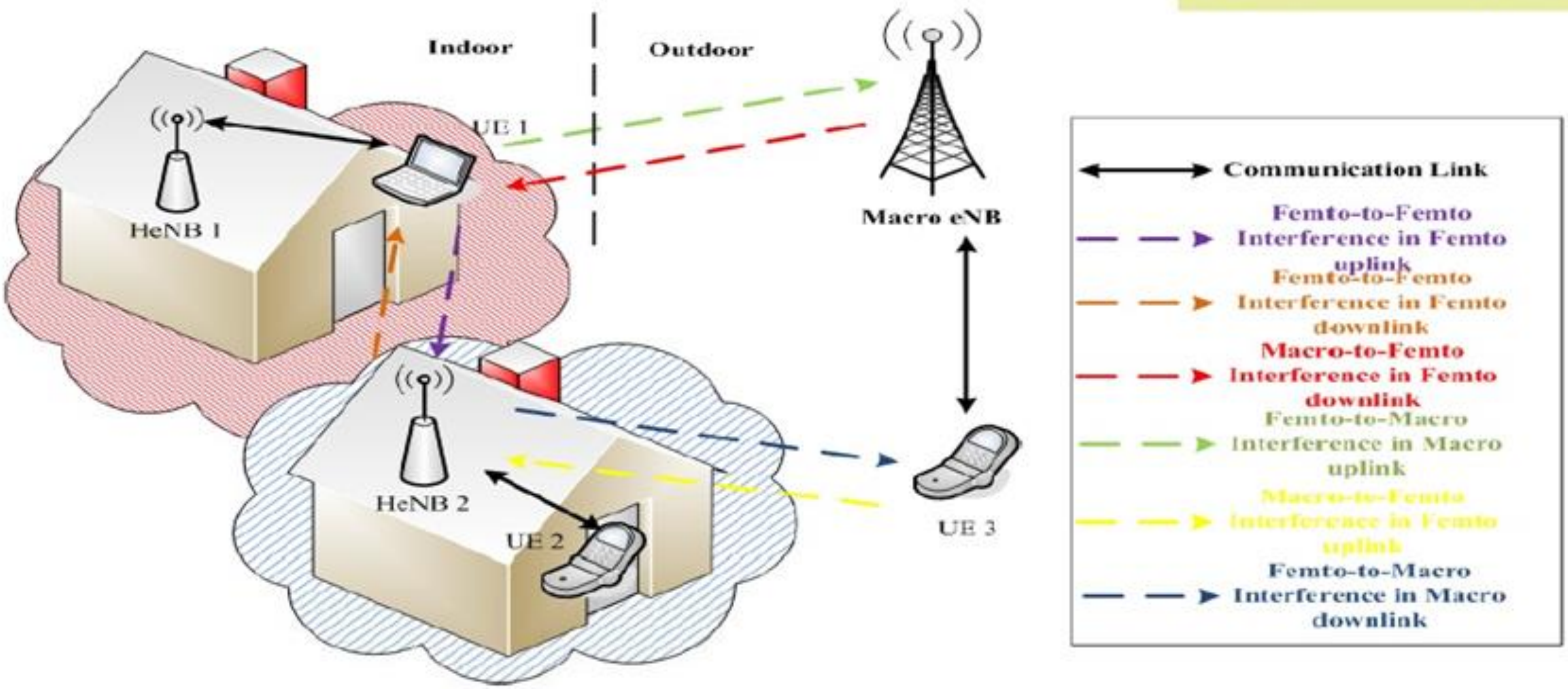
- Better coverage and capacity
  - Due to short transmit-receive distance
    - • Lower transmit power
    - • Prolong handset life
    - • Higher SINR
    - • Higher spectral efficiency
- Improved macro reliability
  - BS can provide better reception for mobile users
    - Traffic originating indoors can be absorbed into femtocell networks over IP backbone
- Cost Benefit
  - 60,000$/year/marcrocell vs. 200$/year/femtocell
- Reduced subscriber turnover
  - Enhanced home coverage will reduce motivation for users to switch carriers

Benefits of Femtocells

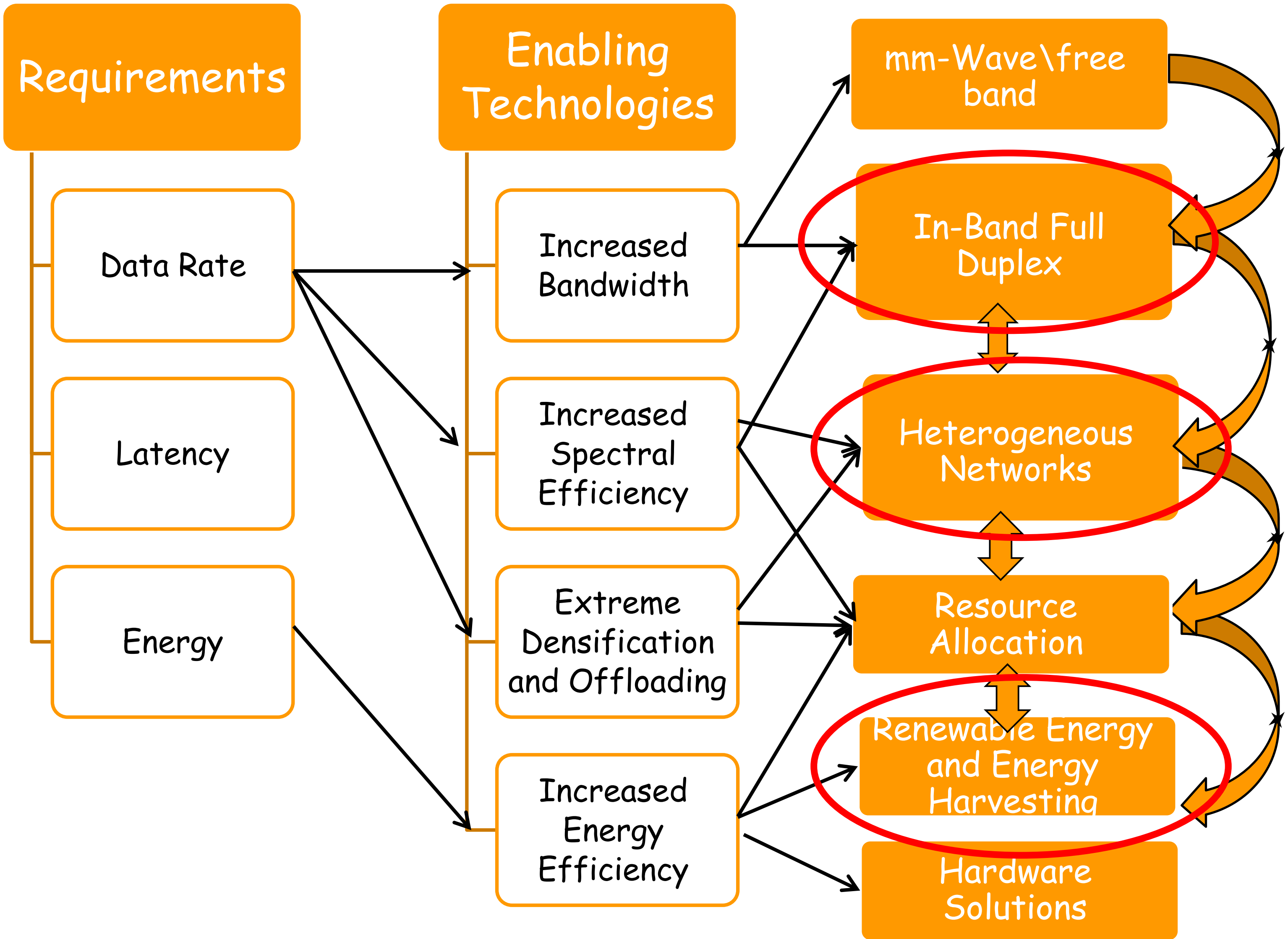
- Capacity benefits of femtocell
  - Reduced distance between sender and receiver leads to higher signal strength (capacity improvement
  - Lowered transmit power decrease the interference for neighboring cells (capacity improvement)
  - Femto-AP can devote a larger portion of resource for fewer users (frequency efficiency)

Technical Challenges: Interference Management

- Power control is required in Femto-AP to avoid interference for outdoor users
  - Marcocell-to-Femtocell Interference
  - Femtocell-to-Femtocell Interference
  - Femtocell-to-Marcocell Interference



Summary


Requirements
Enabling Technologies
mm-Wave\free band
Data Rate
Increased Bandwidth
In-Band Full Duplex
Latency
Increased Spectral Efficiency
Heterogeneous Networks
Energy
Extreme Densification and Offloading
Resource Allocation
Renewable Energy and Energy Harvesting
Increased Energy Efficiency
Hardware Solutions

Lecture 2 Outline

- Overview of Heterogeneous Wireless Networks
  - Motivations for Heterogeneous Networks
  - Available Solutions for Overall Network Efficiency
  - Definitions of Heterogeneous Networks
  - Heterogeneous Networks Challenges

Definitions of Heterogeneous Networks

- A heterogeneous network is a network containing network nodes with different characteristics such as transmission power and RF coverage area (different cell-sizes)
- Heterogeneous networks consisting of layers of networks operating at different frequency bands
- Dynamic Spectrum Access (cognitive radio networks) are expected to become part of the global heterogeneous networks

Source: [1], Chapter 1, Section 1.2

Definitions of Heterogeneous Networks

- Heterogeneous Networks
  - Connecting to Wireless Networks different in
    - Cell sizes (macro/micro/pico/femto)
    - Radio Access Technology (Carrier Frequency and MAC)
    - Spectrum Access

Source: [1], Chapter 1, Section 1.1.1