MOBILE SYSTEM-HT25
LECTURE 12:
CELLULAR WIRELESS NETWORKS

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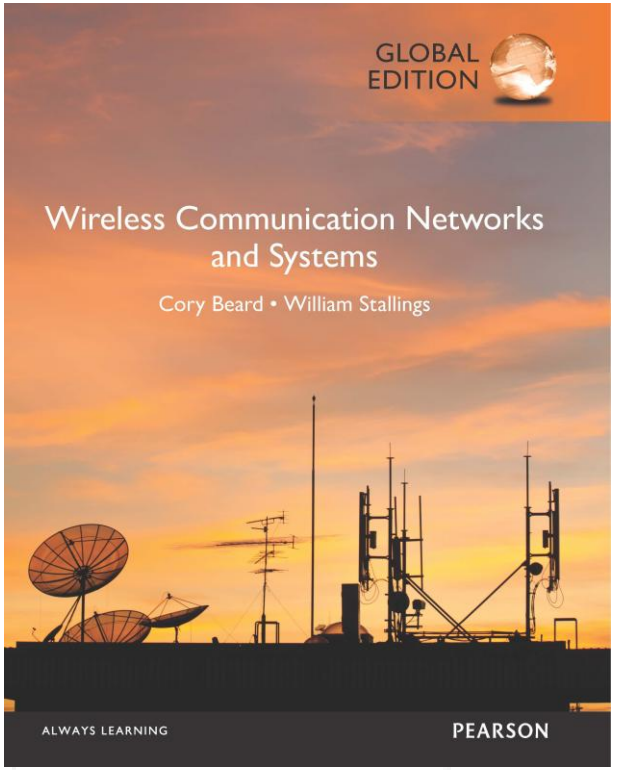
Most slides are primarily adapted from Beard & Stallings (2016), Wireless Communication Networks and Systems (Chapter 13)



Wireless Communication Networks and Systems

1st edition, Global edition

Cory Beard, William Stallings

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WHERE WE ARE IN THE COURSE

- Evolution of Wireless Communication, Transmission fundamentals, Analog and Digital Modulations (Lectures 2-4)
- The Wireless Channel (Lectures 5 and 6)
- Transmission Fundamentals (CTFT, DTFT) (Lecture 7)
- Orthogonal Frequency Division Multiplexing- OFDM (Lecture 8)
- Spread Spectrum (Lecture 10)
- Coding and Error Control (Lecture 11)
- Cellular Wireless Networks (Lecture 12)
- Short-Range Wireless Technologies & Applications of Wireless Technologies in IoT (Lecture 13)
- 5G, 6G och Vidare (Lecture 14)

OUTLINE

- Introduction to Cellular Networks
- Cellular Network Organization
  - Frequency Reuse (DT I)
  - Cellular System Terms
  - Hand-off (DT II)
  - Approaches to Cope with Increasing Capacity,
- 1G-4G (FDMA, TDMA, CDMA, **MIMO** (DT III))

INTRODUCTION TO CELLULAR NETWORKS

- Revolutionary development in data communications and telecommunications
- Foundation of mobile wireless
  - Basic cellphones, smartphones, tablets, wireless Internet, wireless applications
- Supports locations not easily served by wireless networks or WLANs
- Four generations of standards
  - 1G: Analog
  - 2G: Still used to carry voice
  - 3G: First with sufficient speeds for data networking, packets only
  - 4G: Truly broadband mobile data up to 1 Gbps

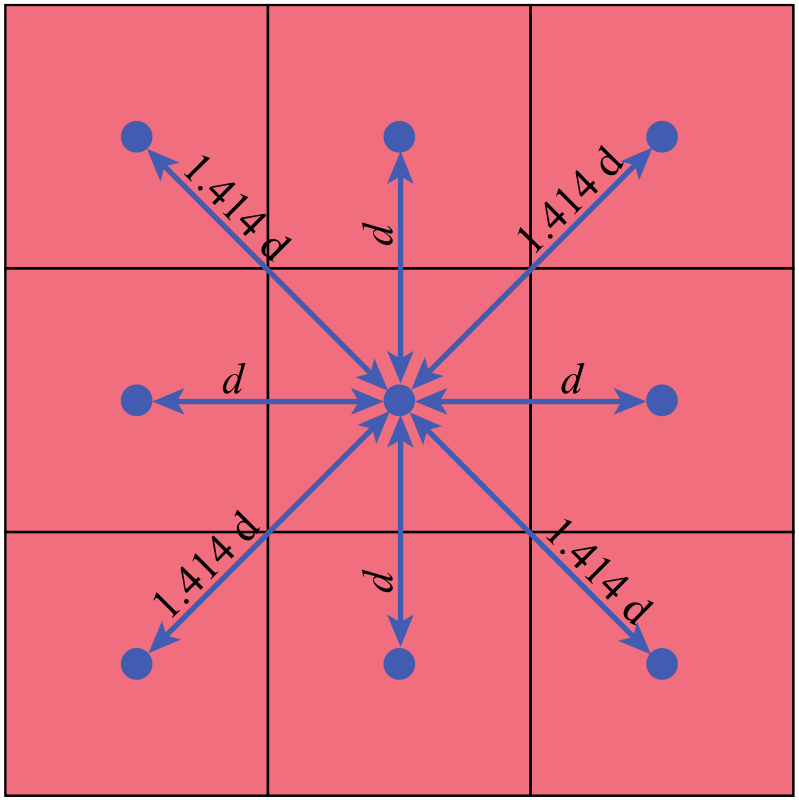
CELLULAR NETWORK ORGANIZATION

- Use multiple low-power transmitters (100 W or less)
- Areas divided into cells
  - Each served by base station consisting of an **antenna** to **sends/receives** radio signals to phones, radio equipment (**transmitter/receiver**) that generates and processes those signals, and a **control unit**.

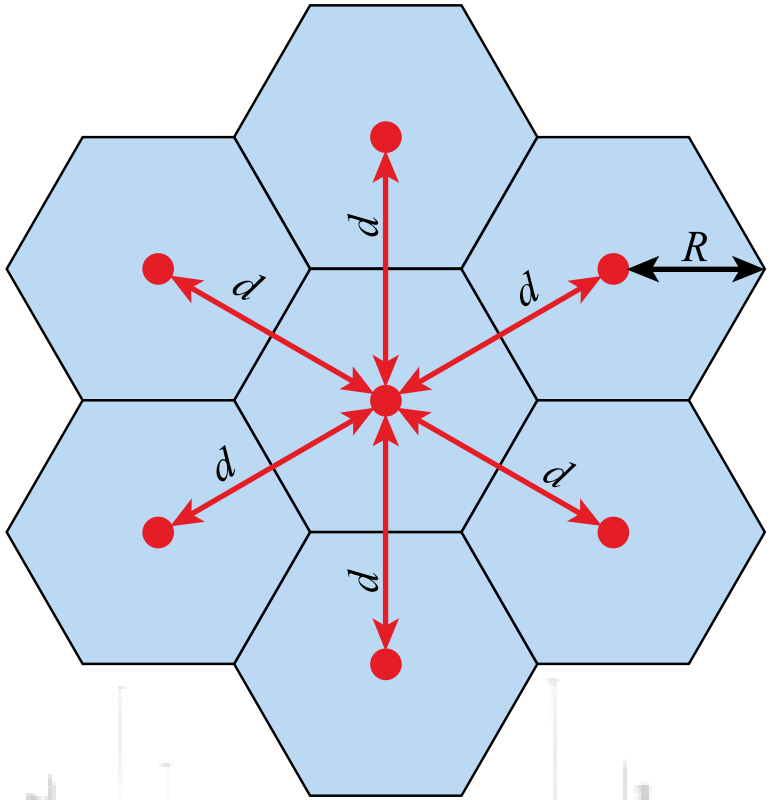
•**Receives radio signals** from your phone (voice or data)
•**Processes and forwards** them to the **core cellular network** (and then to the Internet, or another phone)
•**Receives data** from the network and **transmits it back** to your phone

  - Band of frequencies allocated
  - Cells set up such that antennas of all neighbors are equidistant (hexagonal pattern)

Frequency Reuse



(a) Square pattern



(b) Hexagonal pattern

13.1 CELLULAR GEOMETRIES

FREQUENCY REUSE

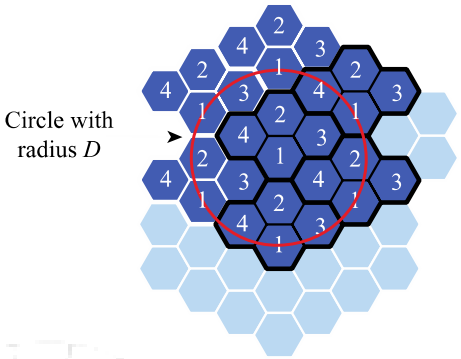
- Adjacent cells assigned different frequencies to avoid interference or crosstalk

Other cells that are far enough away to avoid interference

- Objective is to reuse frequency in nearby cells
  - 10 to 50 frequency channels assigned to each cell
  - Transmission power controlled to limit power at that frequency escaping to adjacent cells
  - The issue is to determine how many cells must intervene between two cells using the same frequency

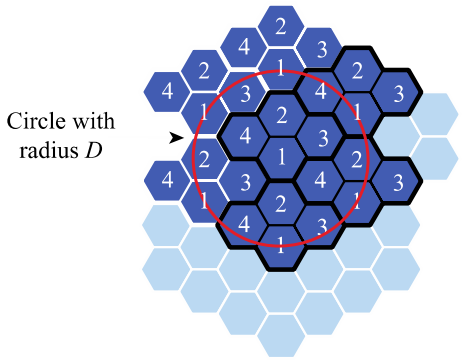
DISCUSSION TIME I

In frequency reuse, what happens if we make cluster size (N) smaller?

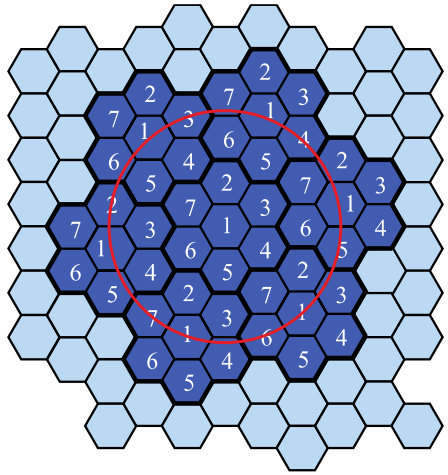


(a) Frequency reuse pattern for $N = 4$

1 Go to wooclap.com
2 Enter the event code in the top banner
Event code
EHQQCA

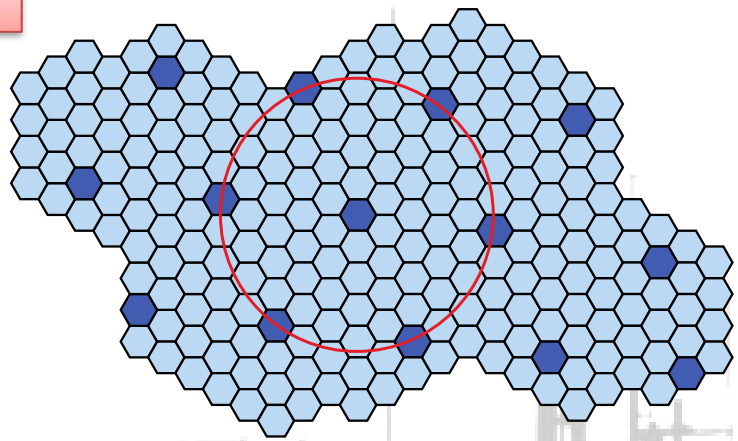


(a) Frequency reuse pattern for $N = 4$



(b) Frequency reuse pattern for $N = 7$

cluster size (N)



(c) Black cells indicate a frequency reuse for $N = 19$

13.2 FREQUENCY REUSE PATTERNS

CLASS DISCUSSION

In frequency reuse, what happens if we make cluster size (N) smaller?

We get more use out of the same spectrum, but the risk of signals interfering with each other increases.

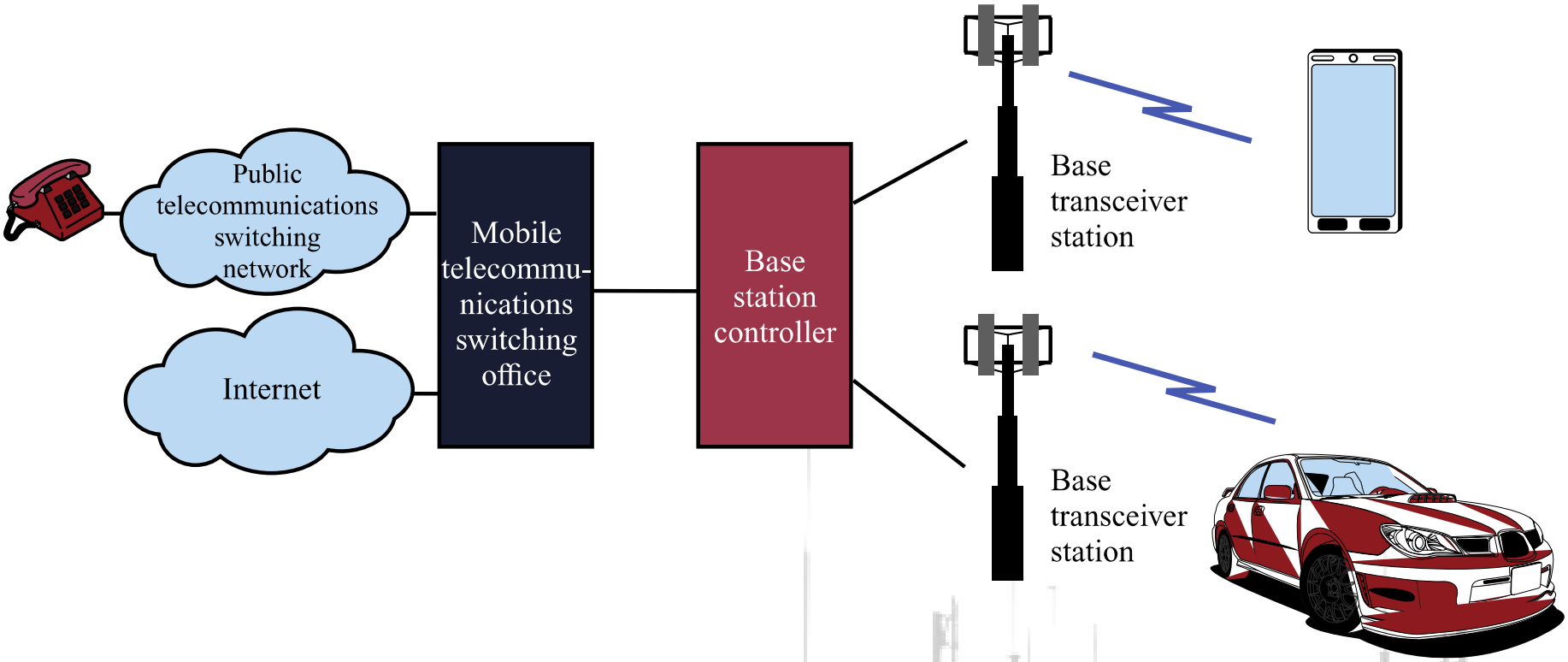
Smaller N = higher capacity but more interference

CELLULAR SYSTEMS TERMS

- Base Station (BS)
- Mobile telecommunications switching office (MTSO) – connects calls between mobile units

An **MTSO** is **part of** the **core cellular network**, responsible for:

- Mobility management
- Data and voice routing
- Security and subscriber databases
- National & global connectivity
- Home location register (HLR)
- Authentication servers (AUC)



13.5 OVERVIEW OF CELLULAR SYSTEM

CELLULAR SYSTEMS TERMS

- Two types of channels available between mobile unit and BS
  - **Control channels** – used to exchange information having to do with setting up and maintaining calls
  - **Traffic channels** – carry voice or data connection between users

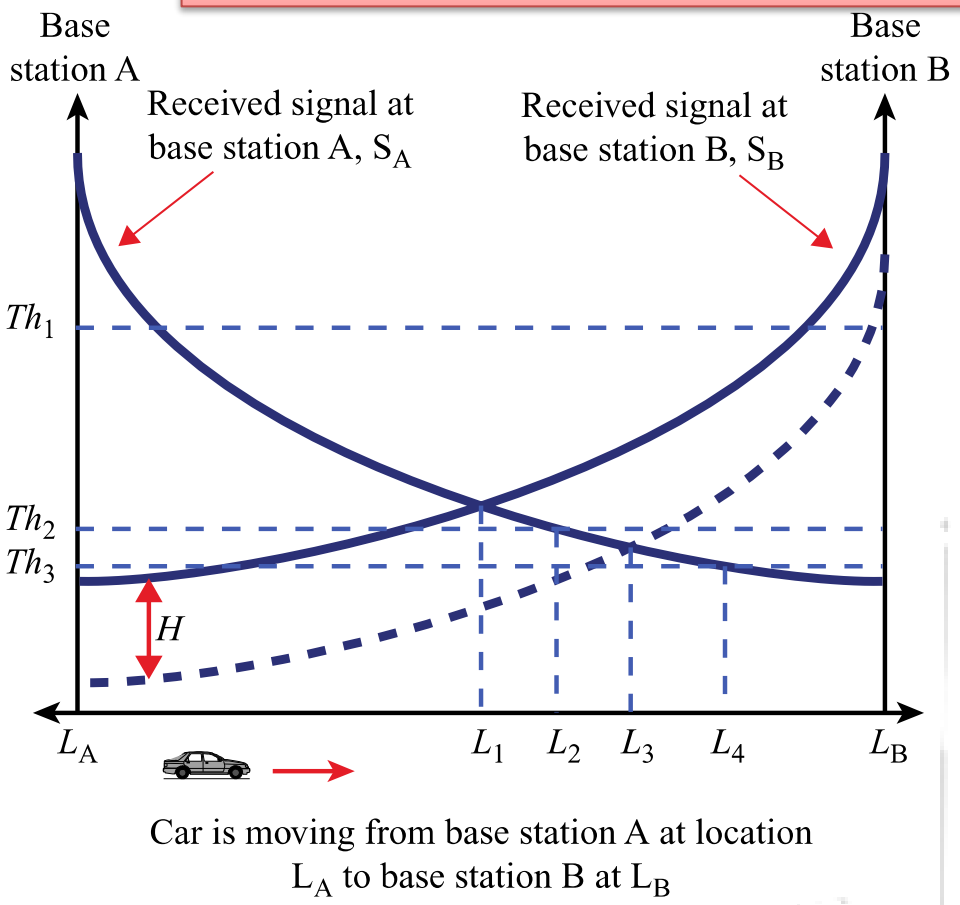
DISCUSSION II: WHY DO CALLS DROP?

Everyone has experienced a dropped call — especially when traveling.

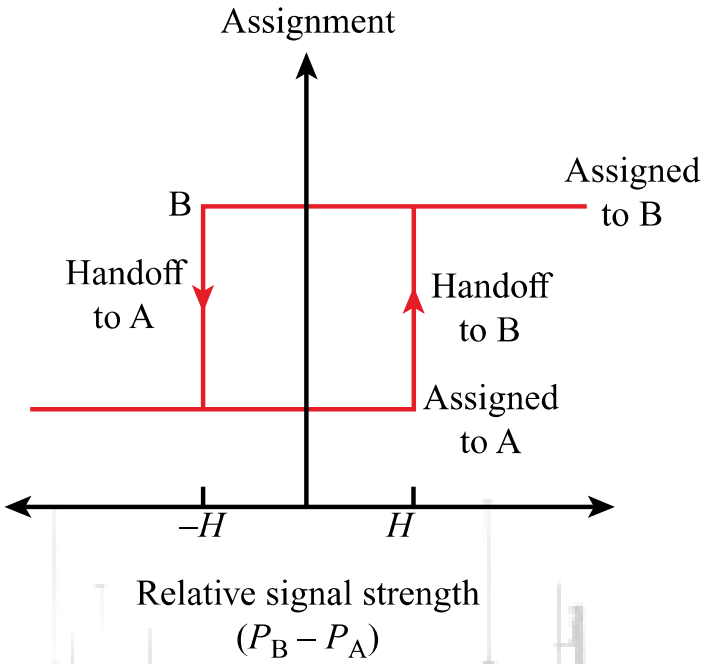
Consider cellular networks and discuss:

- Why do calls drop during movement or in certain areas?
- What are the key factors that affect whether a call stays connected?

Transferring responsibility of the connection from one cell to another



(a) Handoff decision as a function of handoff scheme



(b) Hysteresis mechanism

This prevents too many handoffs when the signal fluctuates around the boundary.

13.7 HANDOFF BETWEEN TWO CELLS

CLASS DISCUSSION

- **Handoff issues:** Calls drop when a phone moves from one cell to another and the new base station can't take over quickly enough.
- **Handoff delay / wrong timing:** The phone or network may detect the need to switch too late or too early, disrupting continuity.
    - **Fast movement (e.g., in vehicles):** Rapid handoffs increase the chance of timing errors.
- **Interference and congestion (**overloaded cells**):** When the target cell has no free channels or experiences strong interference, the call may be dropped.
- **Signal strength:** If the received signal falls below a threshold (due to obstacles, distance, or fading), the connection fails.

Modern systems use smarter handoff prediction and multiple connections (soft handoff in CDMA) to minimize drops.

APPROACHES TO COPE WITH INCREASING CAPACITY

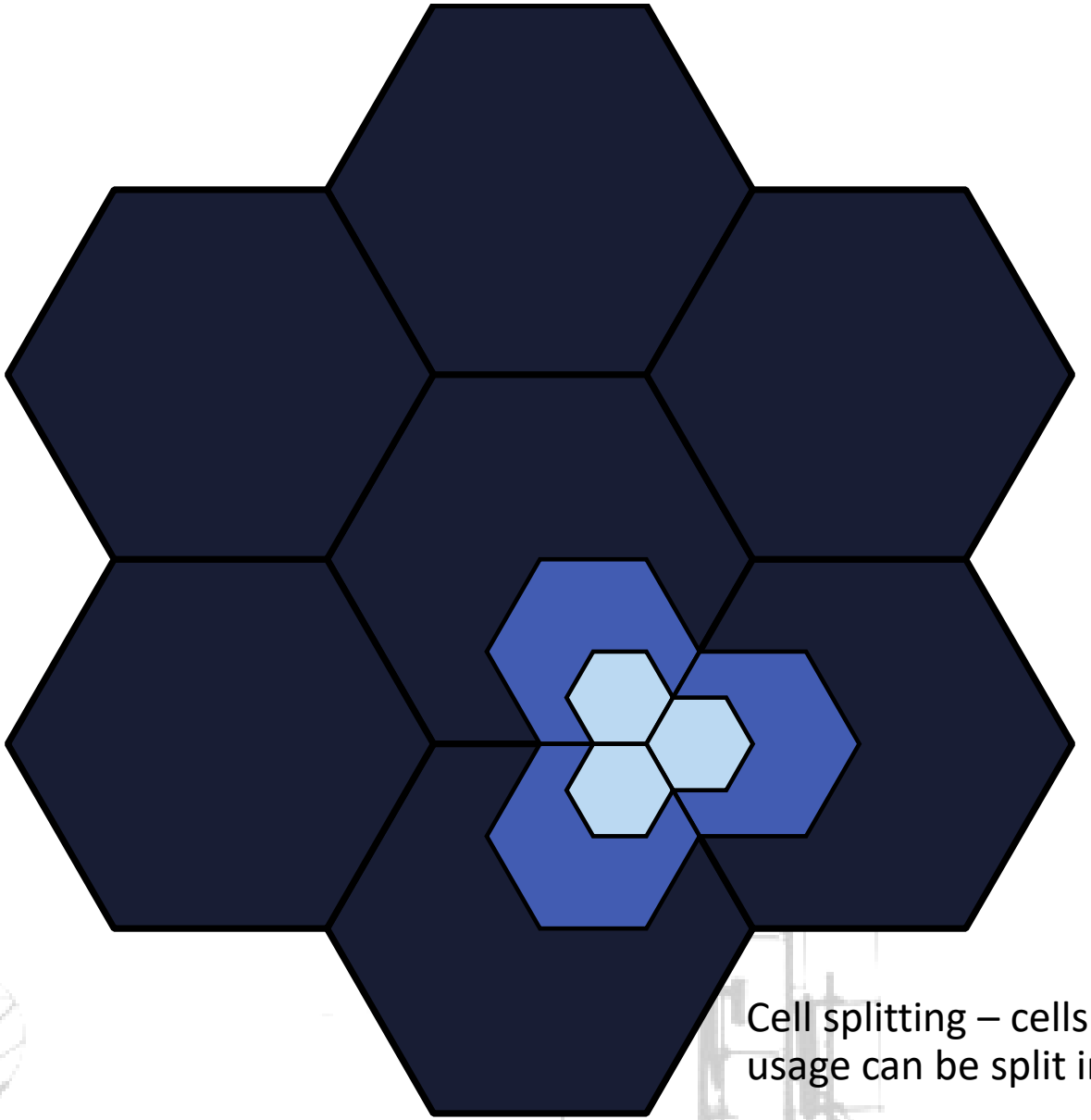
- Adding new channels

spectrum is limited and expensive.

- Frequency borrowing – frequencies are taken from adjacent cells by congested (overloaded) cells

- Cell splitting – cells in areas of high usage can be split into smaller cells

Each new cell gets a **new set** of frequency channels



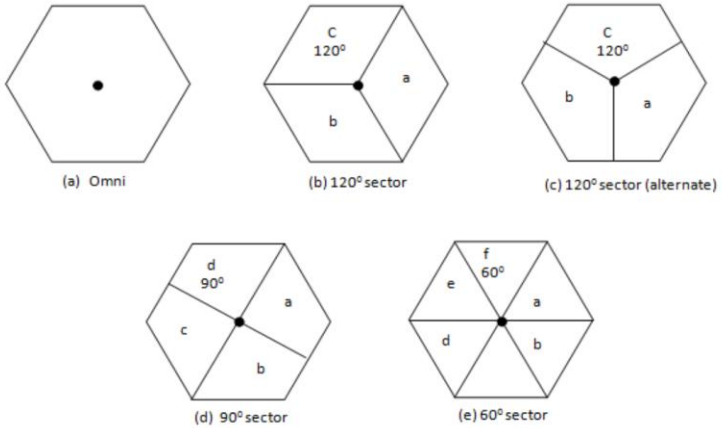
Cell splitting – cells in areas of high usage can be split into smaller cells

13.3 CELL SPLITTING

APPROACHES TO COPE WITH INCREASING CAPACITY

- Cell sectoring – cells are divided into a number of wedge-shaped sectors, each with their own set of channels

Sectoring reduces interference by making antennas directional. Lower interference → better signal → frequencies can be reused more → more users served.



Shehu, Nura Muhammad. "Coverage and capacity improvement in GSM network." *International Journal of Novel Research in Electrical and Mechanical Engineering* 2.3 (2015): 57-62.

APPROACHES TO COPE WITH INCREASING CAPACITY

- Interference coordination – tighter control of interference so frequencies can be reused closer to other base stations while reusing frequencies more aggressively.

- Network densification – more cells and frequency reuse
  - Microcells – antennas move to buildings, hills, and lamp posts
  - Femtocells – antennas to create small cells in buildings

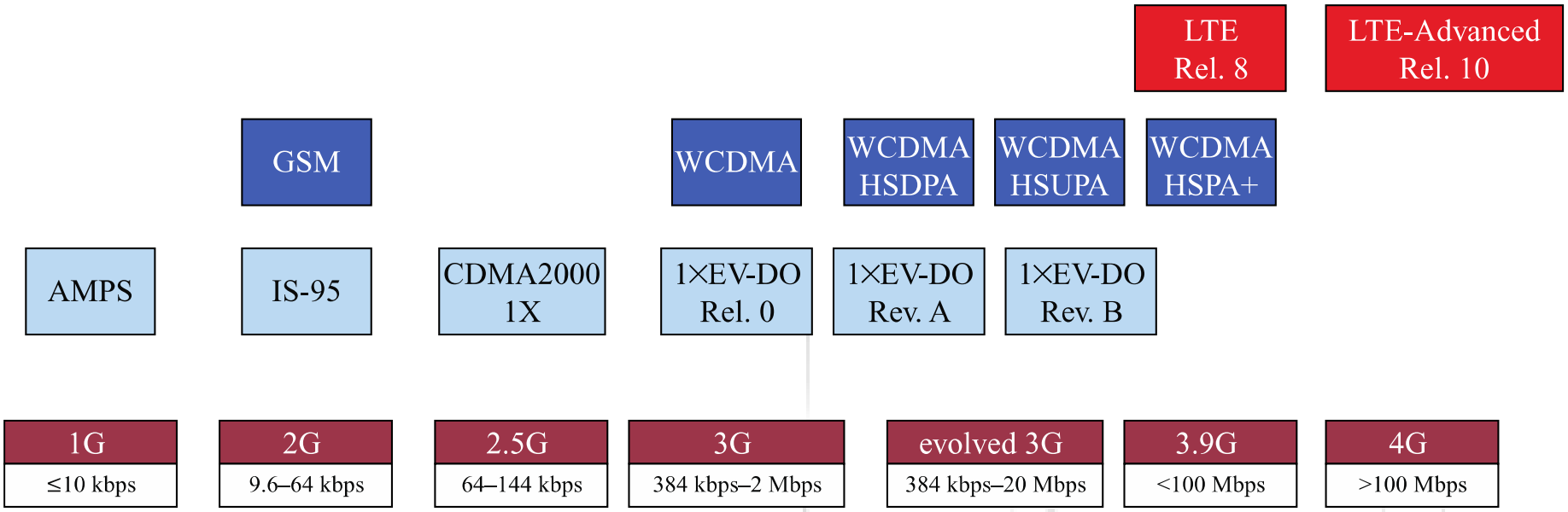
1G - 4G

FIRST-GENERATION ANALOG

- Advanced Mobile Phone Service (AMPS)
  - In North America, two 25-MHz bands allocated to AMPS
    - One for transmission from base to mobile unit (**downlink**)
    - One for transmission from mobile unit to base (**uplink**)
  - Each band split in two to encourage competition (FDMA)
  - Frequency reuse exploited

DIFFERENCES BETWEEN FIRST AND SECOND GENERATION SYSTEMS

- Digital traffic channels – first-generation systems are almost purely analog; second-generation systems are digital
  - Using **FDMA/TDMA** or **CDMA**
- Encryption – all second generation systems provide encryption to prevent eavesdropping
- Error detection and correction – second-generation digital traffic allows for detection and correction, giving clear voice reception
- Channel access – second-generation systems allow channels to be dynamically shared by a number of users



13.13 EVOLUTION OF CELLULAR WIRELESS SYSTEMS

ADVANTAGES OF CDMA FOR CELLULAR SYSTEMS

- Multipath resistance – chipping codes used for CDMA exhibit low cross correlation and low autocorrelation
- Privacy – privacy is inherent since spread spectrum is obtained by use of noise-like signals
- Graceful degradation – system only gradually degrades as more users access the system
- Frequency diversity – frequency-dependent transmission impairments have less effect on signal

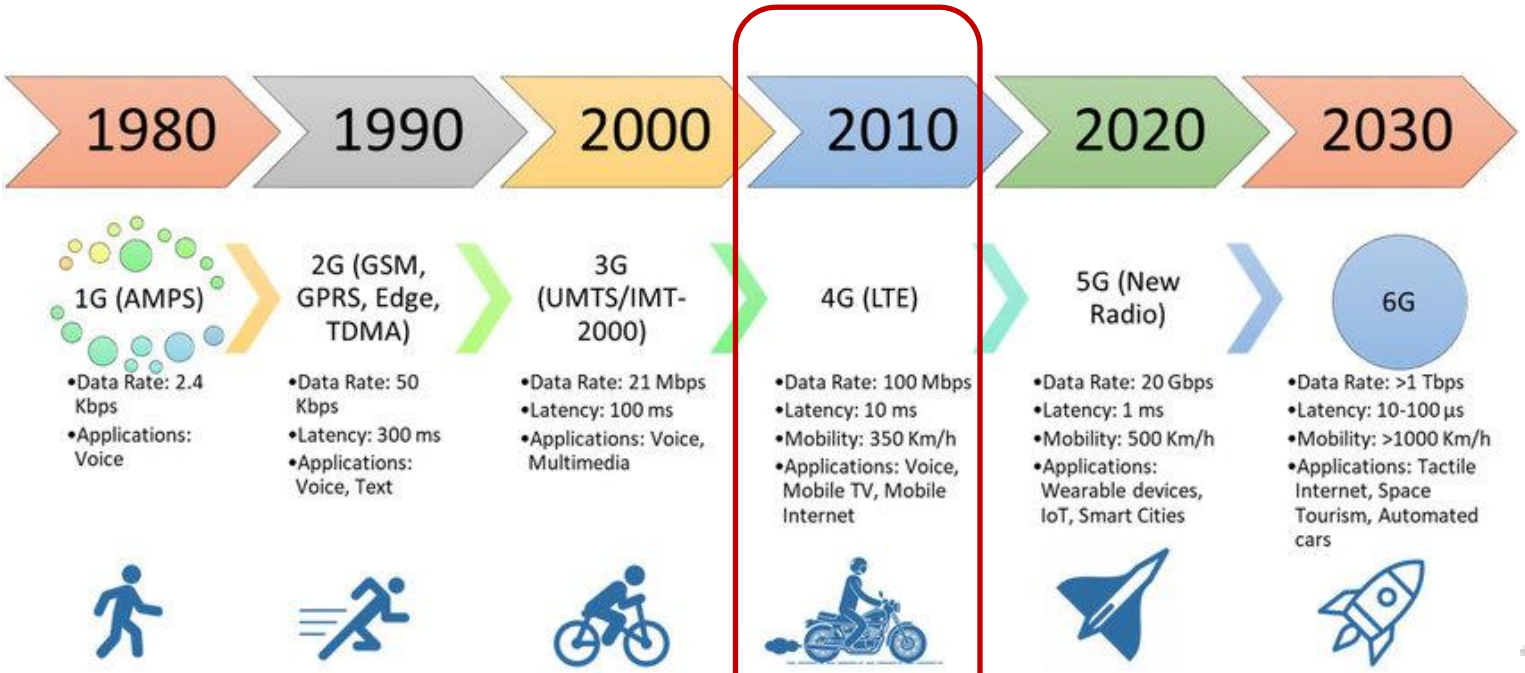
MOST IMPORTANT DRAWBACK OF CDMA CELLULAR

- Self-jamming – arriving transmissions from multiple users not aligned on chip boundaries unless users are perfectly synchronized

MOBILE WIRELESS CDMA DESIGN CONSIDERATIONS

- RAKE receiver – when multiple versions of a signal arrive more than one chip interval apart, RAKE receiver attempts to recover signals from multiple paths and combine them
  - See Chapter 9
- Soft Handoff – mobile station **temporarily connected to more than one base station** simultaneously
  - Requires that the mobile acquire a new cell before it relinquishes the old
  - More complex than hard handoff used in FDMA and TDMA schemes

4G

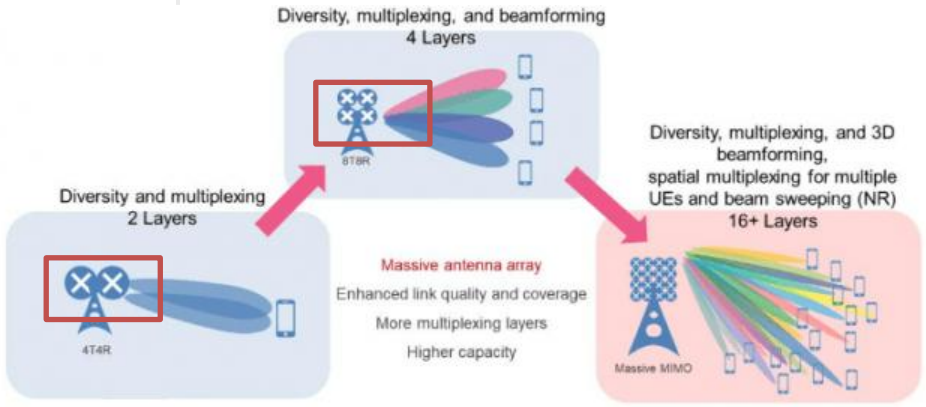


https://www.researchgate.net/figure/Wireless-Communication-Evolution_fig1_353039842

MIMO **Massive MIMO**

MIMO (MULTIPLE INPUT MULTIPLE OUTPUT)

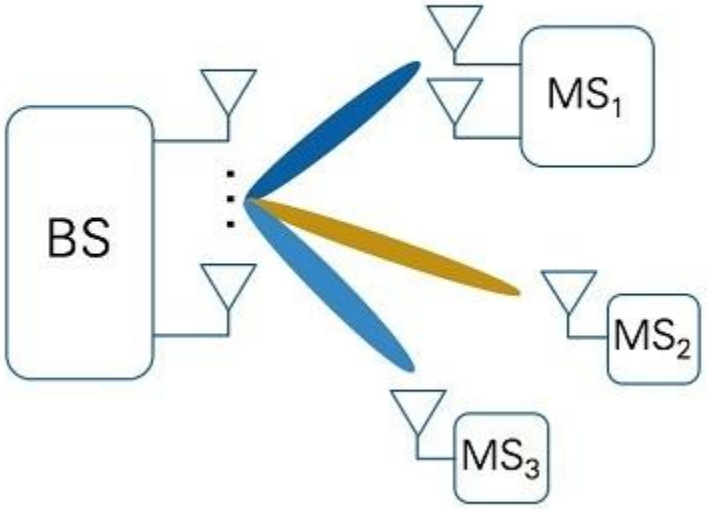
- MIMO is a wireless communication technology that uses multiple antennas at both the transmitter and receiver to improve data transmission speed and reliability.
- Introduced in 4G LTE



https://www.5gworldpro.com/blog/2022/04/17/evolution-from-mimo-to-massive-mimo/

DISCUSSION TIME III

How does MIMO improve wireless communication performance?



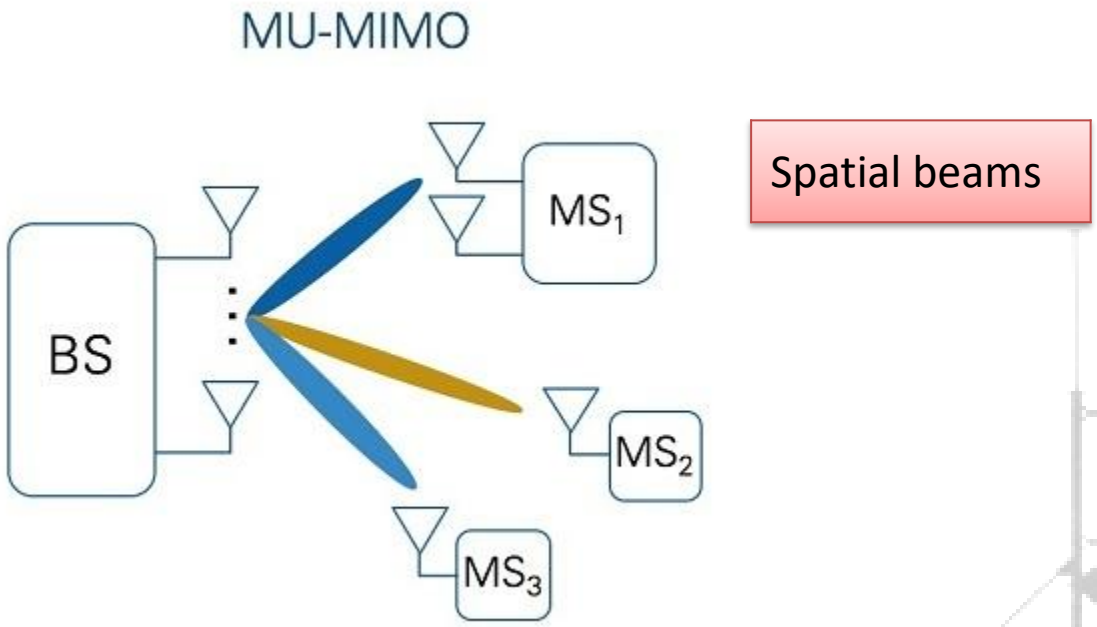
MULTIPLE INPUT MULTIPLE OUTPUT (MIMO) ANTENNAS

- Use MIMO antennas for
  - Beamforming – Signals can be focused **in a specific direction** for stronger coverage and less interference.
  - Diversity –Multiple antennas receive slightly different versions of the same signal
  - Multiple streams – parallel data streams
  - Multi-user MIMO – The base station can direct **different beams to different users** at the same time, increasing total network capacity

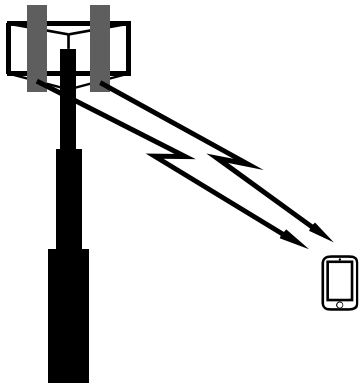
Increases throughput, signal quality, spectral efficiency, diversity, …

MULTI-USER MIMO

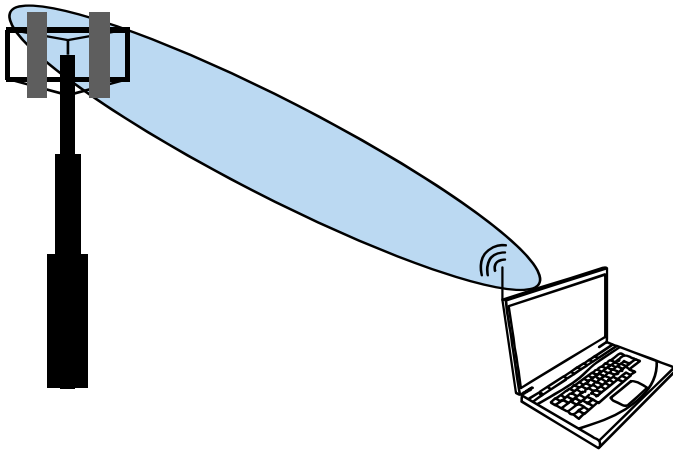
- Users may share the **same frequency and same time**
- Separated by **spatial beams**
- Base station uses **multiple antennas** to create different directional beams for each user



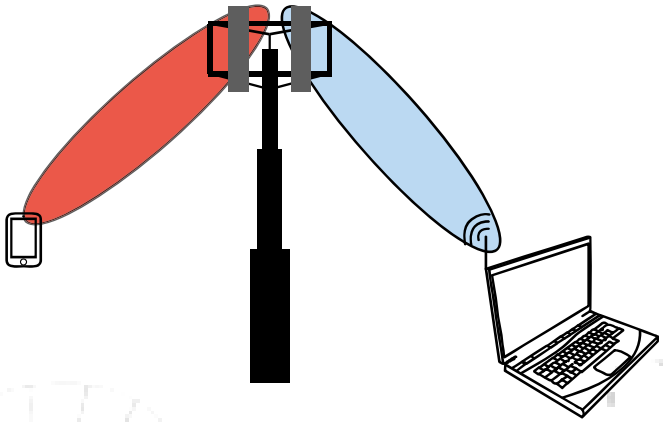
https://www.everythingrf.com/community/what-is-mu-mimo



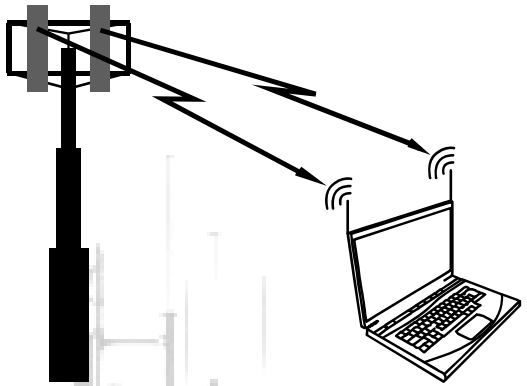
Diversity for improved
system performance



Beam-forming for improved coverage
(less cells to cover a given area)



Spatial division multiple access
("MU-MIMO") for improved capacity
(more user per cell)



Multi layer transmission
("SU-MIMO") for higher data rates
in a given bandwidth

6.18 FOUR USES OF MIMO

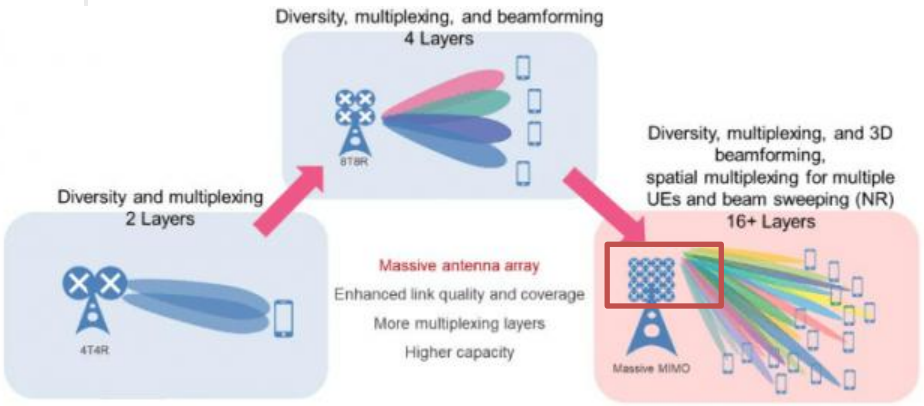
MULTIPLE INPUT MULTIPLE OUTPUT (MIMO) ANTENNAS

- Modern systems
  - 4 × 4 (4 transmitter and 4 receiver antennas)
  - 8 × 8
  - Two dimensional arrays of 64 antennas
  - Future: Massive MIMO with many more antennas

MASSIVE MIMO

Massive MIMO extends the concept of MIMO by using **dozens or even hundreds of antennas** at the base station to serve many users **simultaneously and more efficiently**.

- A key enabling technology in **5G**
- Uses **advanced beamforming** to focus energy toward specific users/devices
- Greatly enhances:
  - **Capacity**
  - **Coverage**
  - **Energy efficiency**



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QUESTIONS?