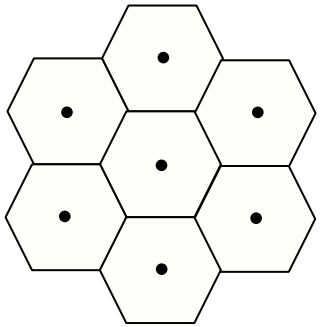
Lecture 24 Overview

- Last Lecture
  - Wireless LAN
  - Bluetooth
- This Lecture
  - Cellular Networks
  - MIMO
  - Source: chapters 16.2, 19.3
- Next Lecture
  - Advanced Networking Topics

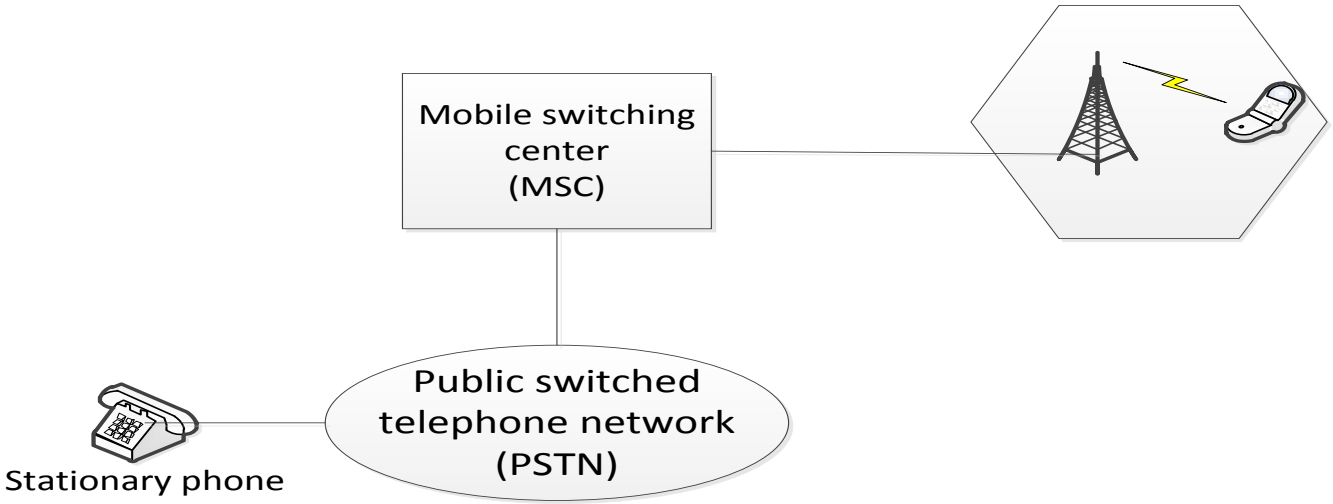
Cellular Technology

- Basic concepts
  - Base Station (BS)
  - Cell
  - Mobile Station (MS)



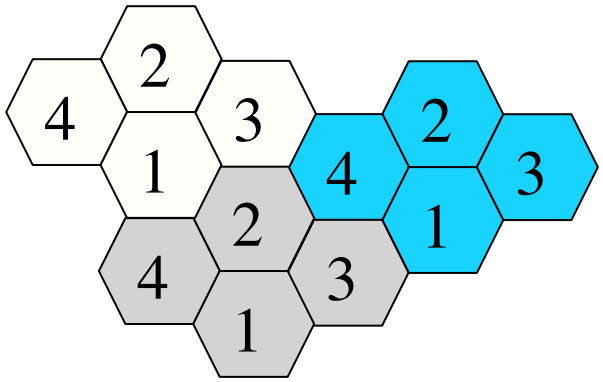
Hexagonal pattern

- Cellular System



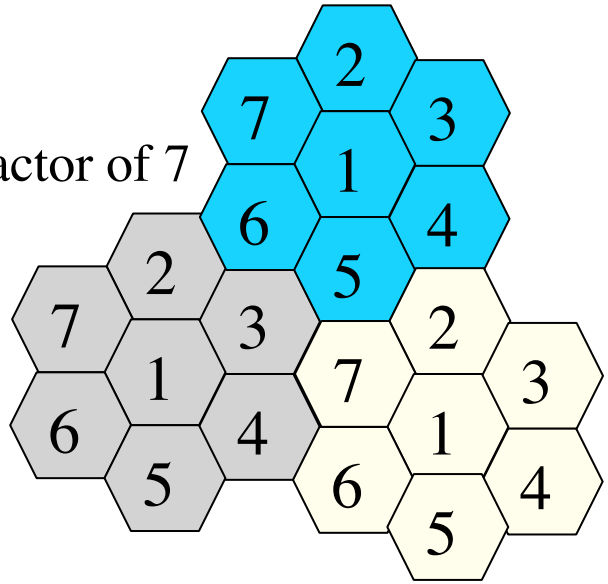
Frequency-Reuse Principle

- Neighbouring cells cannot use the same set of frequencies for communication
- The set of frequencies available is limited
- Frequencies need to be reused
- A frequency reuse pattern is a configuration of N cells where N is the **reuse factor**



Reuse factor of 4

Reuse factor of 7



Handoff

- During a conversation, a mobile station moves from one cell to another. The MSC monitors the signal strength every few seconds. If the signal strength diminishes below a threshold, the MSC seeks a new base station that can better accommodate the communication.
  - **Hard handoff:** A mobile station can communicate with only one base station. During handoff the communication link to the previous base station must be first broken before connecting to the new one.
  - **Soft handoff:** A mobile station can communicate with two base station at the same time. During handoff a mobile station may continue communicating with the new base station before breaking off from the old one.

Roaming

- In principle, a mobile station can have access to communication or can be reached where there is coverage.
- A service provider usually has limited coverage
- Neighboring service providers can provide extended coverage through a roaming contract
  - Example, the charge for delivery of letters between two countries can be divided upon agreement by the two countries.
- Traditional roaming is defined as the ability for a cellular customer to automatically make and receive calls, send and receive data, or access other services, including home data services, when traveling outside the geographical coverage of the home network, by means of using a visited network.

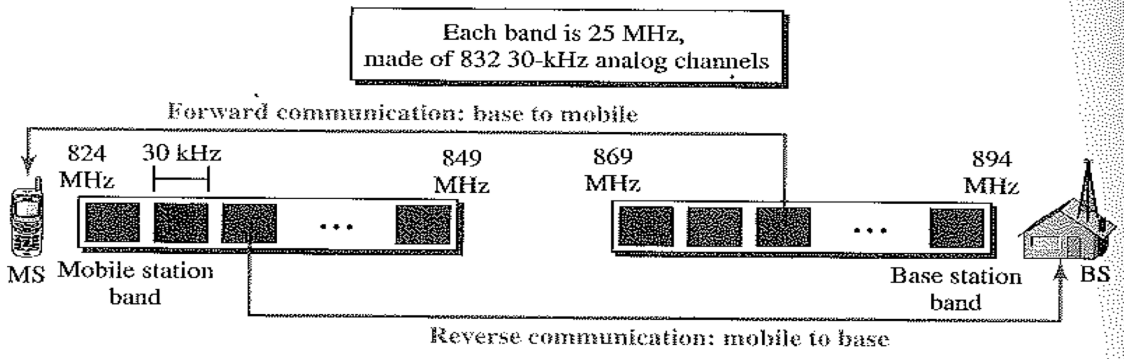
History of Cellular Networks

- Cellular networks is now in its fourth and fifth generations
  - First generation (AMPS)
  - Second generation (D-AMPS, GSM, CDMA)
  - Third generation (UMTS, CDMA2000)
  - Fourth generation (mobile WiMAX, LTE)
  - Fifth generation (Massive MIMO, mmWave MIMO, Small Cell)

First Generation

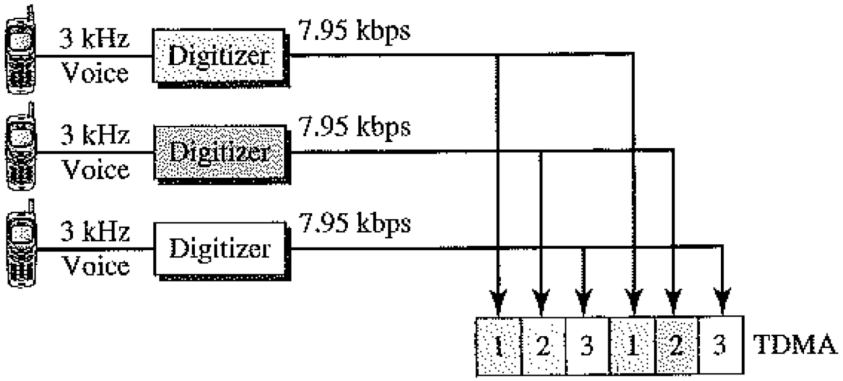
- Designed for voice communication using analog signals
- Advanced Mobile Phone System (AMPS)
  - Uses FDMA
  - Two separate analog channels
- Cellular bands for AMPS

Figure 16.3 *Cellular bands for AMPS*



Second Generation

- Designed for digital voice communication
  - D-AMPS: Digital AMPS
    - Use TDMA and FDMA



  - GSM: Global System for Mobile Communication
    - Similar to D-AMPS
    - European standard
  - CDMA: Code Division Multiple Access

CDMA

- Code-division multiple access
  - Only one channel occupies the entire bandwidth
  - All station can send simultaneously
- Analogy

  In a large room with many peoples

  -- two people can talk in English if nobody else understand English

  -- two people can talk in Chinese if they are the only ones who understand Chinese

  -- so on

CDMA (cont.)

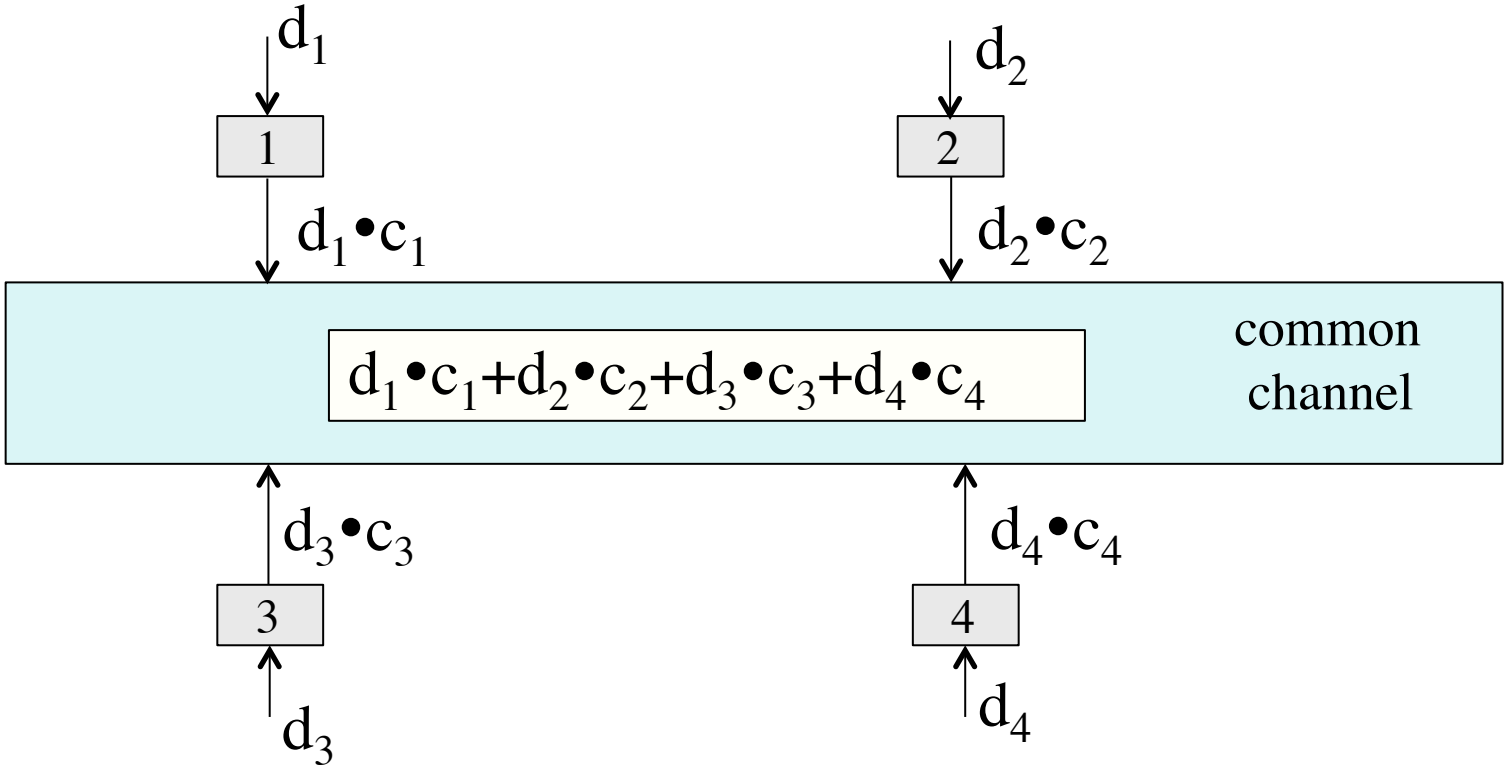
- Each station is assigned a code
- Two properties on the assigned codes
  - If we multiply each code by another, we get 0
  - If we multiply each code by itself, the value we get is equal to the number of stations
- Example

c_1	c_2	c_3	c_4
[+1 +1 +1 +1]	[+1 -1 +1 -1]	[+1 +1 -1 -1]	[+1 -1 -1 +1]

- $C_1 \bullet C_2$ [+1 +1 +1 +1]•[+1 -1 +1 -1]=1-1+1-1=0
- $C_1 \bullet C_1$ [+1 +1 +1 +1]•[+1 +1 +1 +1]= 1+1+1+1 = 4
- $2 \bullet C_1$ 2•[+1 +1 +1 +1] = [+2 +2 +2 +2]

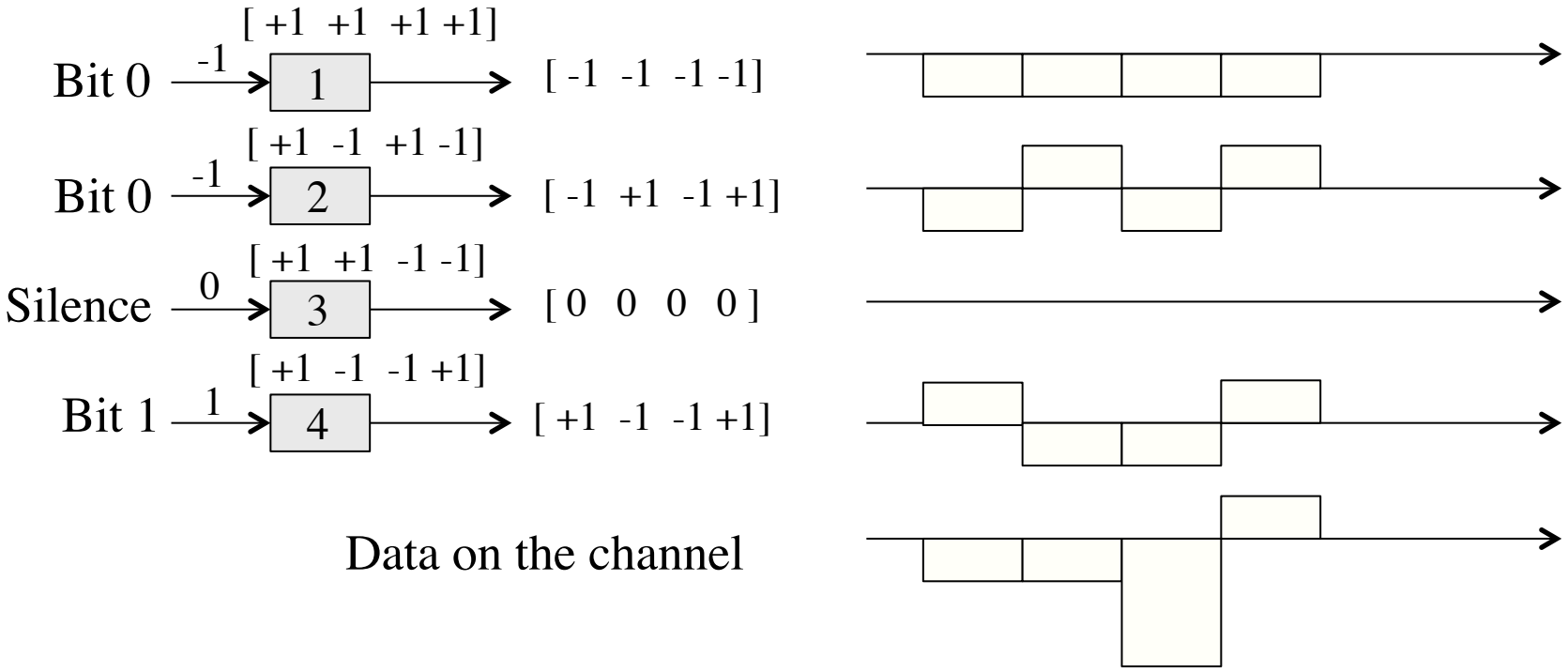
CDMA (cont.)

- Basic Idea



CDMA (cont.)

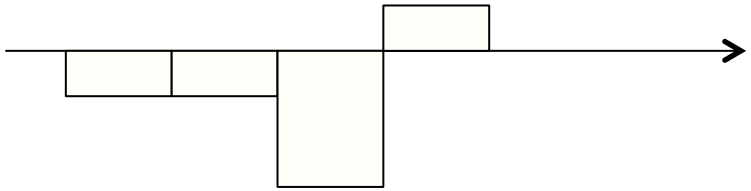
- Data representation
  - Data bit 0 -----> -1
  - Data bit 1 -----> 1
  - Silence -----> 0
- Encoding



CDMA (cont.)

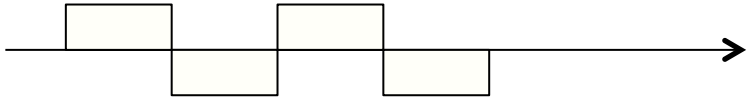
- Decoding

Data on the channel

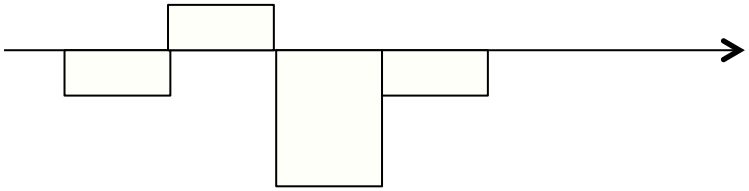


Station 2's code

[+1 -1 +1 -1]



Inter product result



Summing the values

-1+1-3-1 = - 4

-4/4 = -1 -> Bit 0

Third Generation

- A combination of technologies that provide a variety of services.
- Fulfill the Internet Mobile communication 2000 (IMT-2000)
  - Voice quality comparable to that of the public telephone network
  - 144kbps for access in a moving car, 384 kbps for access as the pedestrians, 2Mpbs for the stationary user
  - Support for packet switch and circuit-switch data services
  - Bandwidth of 2Mhz
  - Interface to the Internet
- Major Technologies
  - Universal Mobile Telecommunications System (UMTS)– 3GPP in 2001
  - CDMA2000– 3GPP2 in 2002

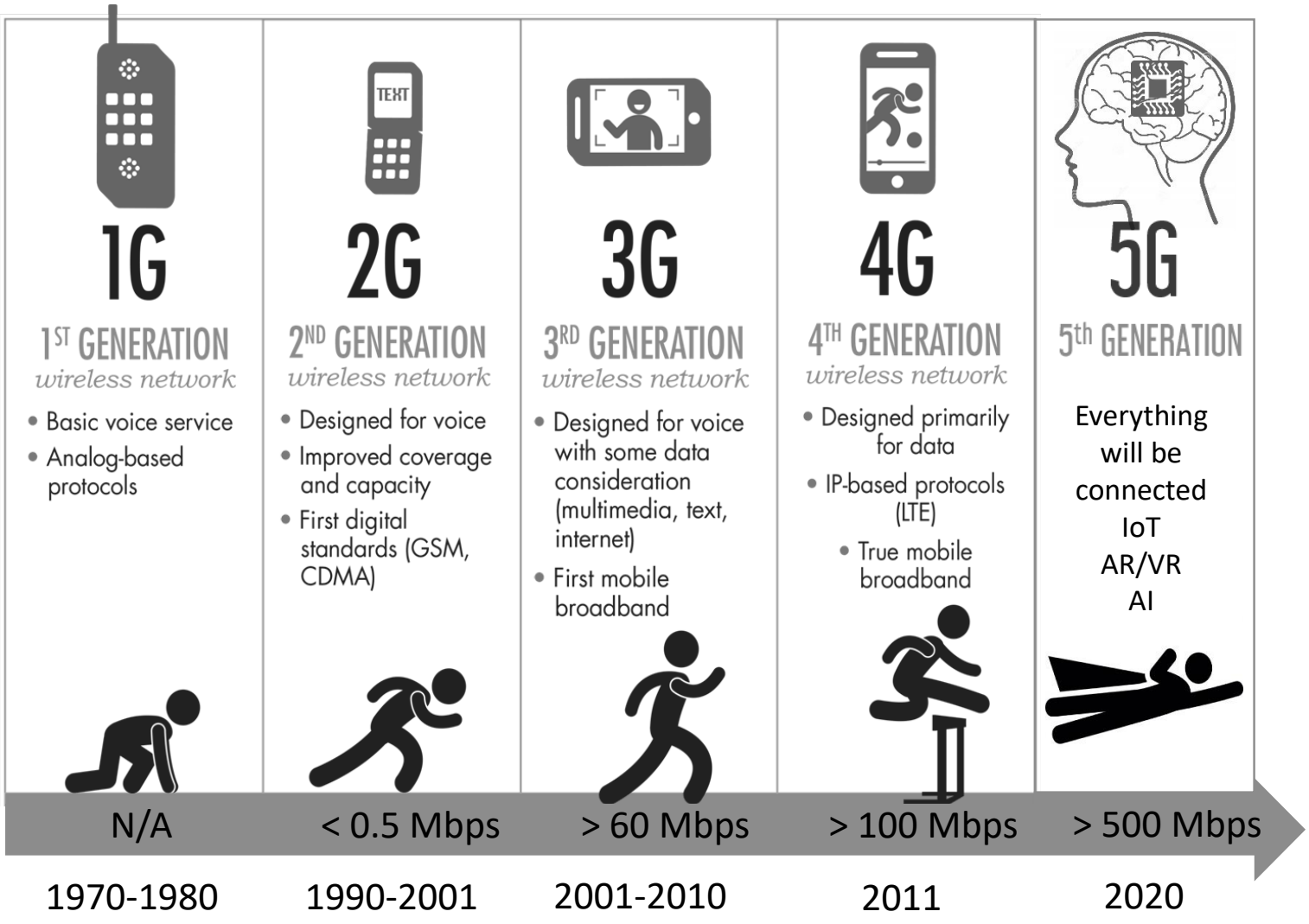
Fourth Generation

- Provide a comprehensive and secure all-IP based mobile broadband solution to laptop, smartphones and other mobile devices
- International Mobile Telecommunications Advanced(IMT-Advanced)
- 100 Mbit/s for high mobility communication, 1Gbit/s for low mobility communication
- Major Technologies
  - Mobile Worldwide Interoperability for Microwave Access (Mobile WiMAX) –2006
  - Long term evolution (LTE) -- 2009

Fifth Generation

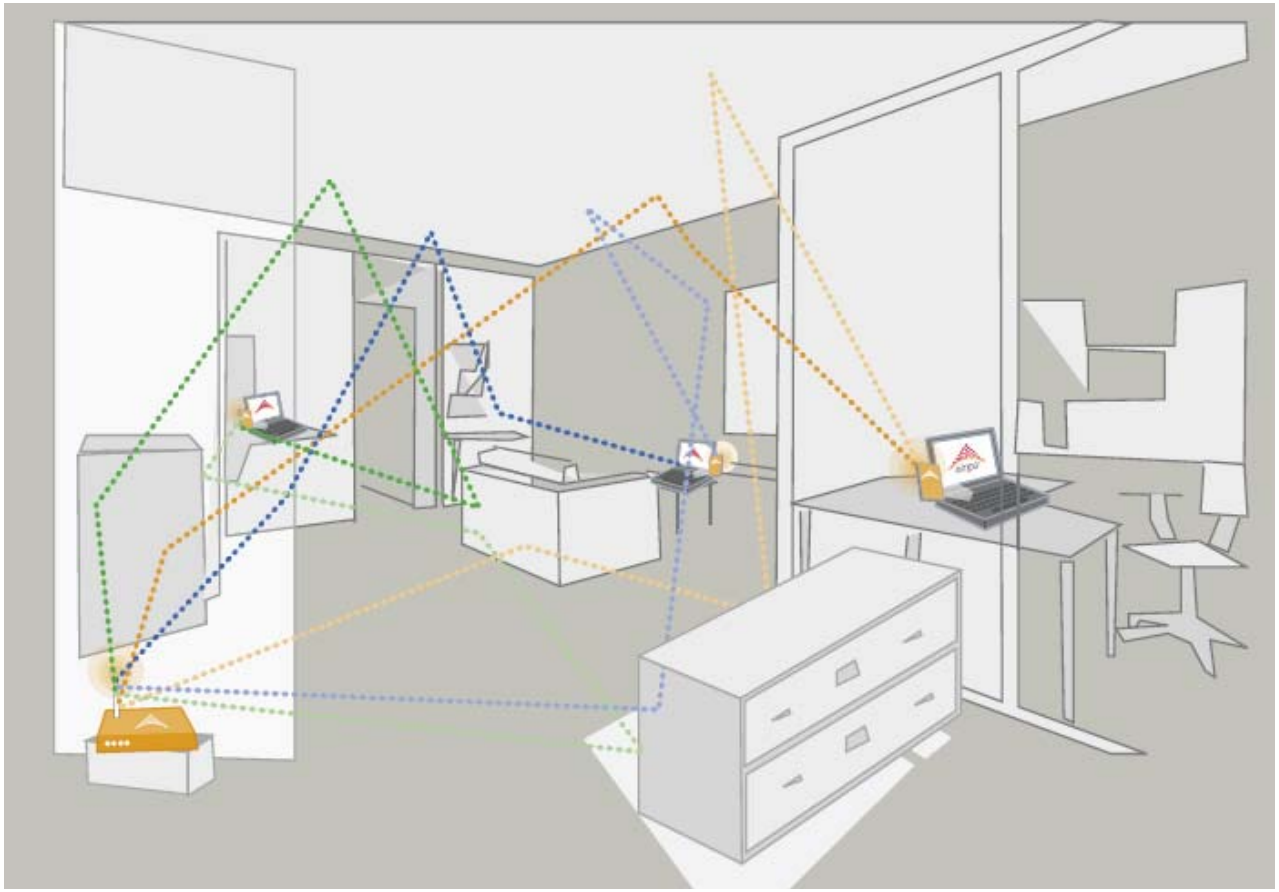
- Aim at higher capacity than current 4G, allowing a higher density of mobile broadband users
  - 100 megabits per second for metropolitan areas
  - 1 Gb per second simultaneously to office users
  - better implementation of the Internet of Things
  - Significantly reduced latency
- Major technologies
  - Massive MIMO
  - Millimeter Wave MIMO
  - Small Cell
  - …

Summary of different generations



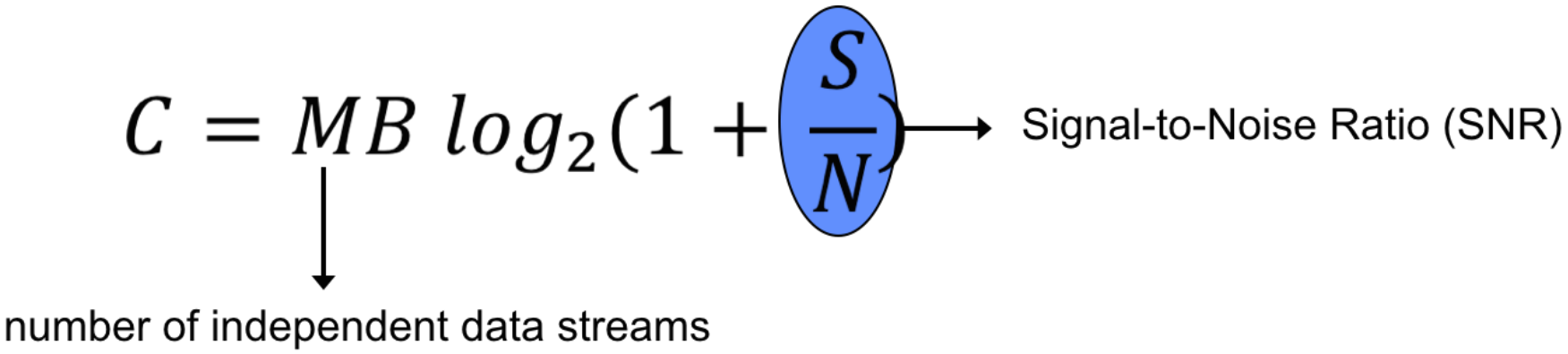
Multipath Propagation

- Wireless signal can be propagated in multiple paths due to scattering on different obstacles



Channel Capacity

- Shannon – Hartley Theorem

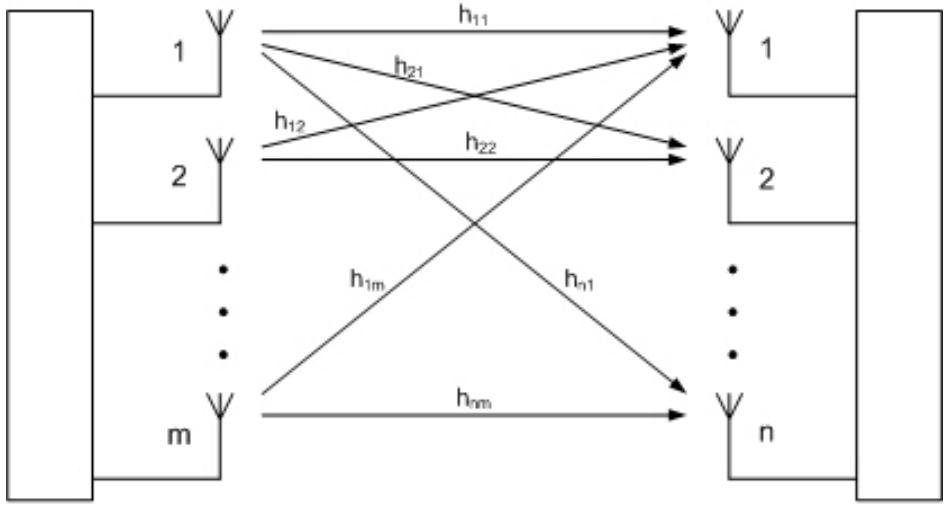


MIMO

- Conventional Radio System

SISO

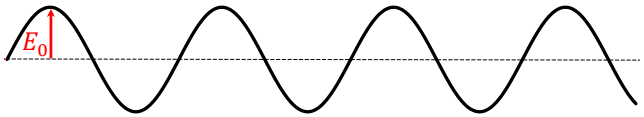
- Multiple Input, Multiple Output (MIMO)
  - Take the advantage of multipath propagation



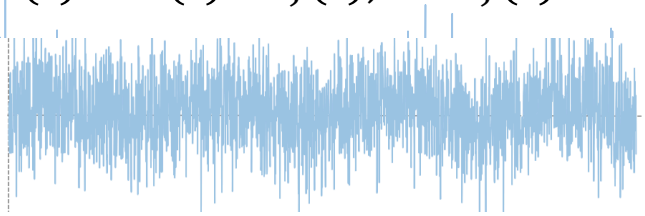
How MIMO works

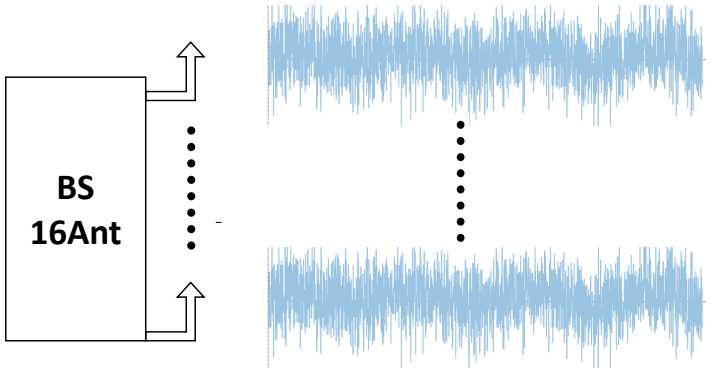
- **Spatial diversity** to make communication robust
  - The same information is sent via multiple paths
  - Receiver reconstruct the information based on multiple copies of the received signals.

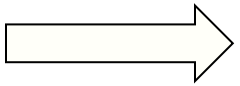
$s(t)$

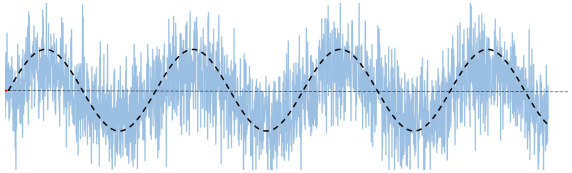


$s'(t) = s(t) + \xi(t), \qquad \xi(t) \sim N(0, \sigma)$





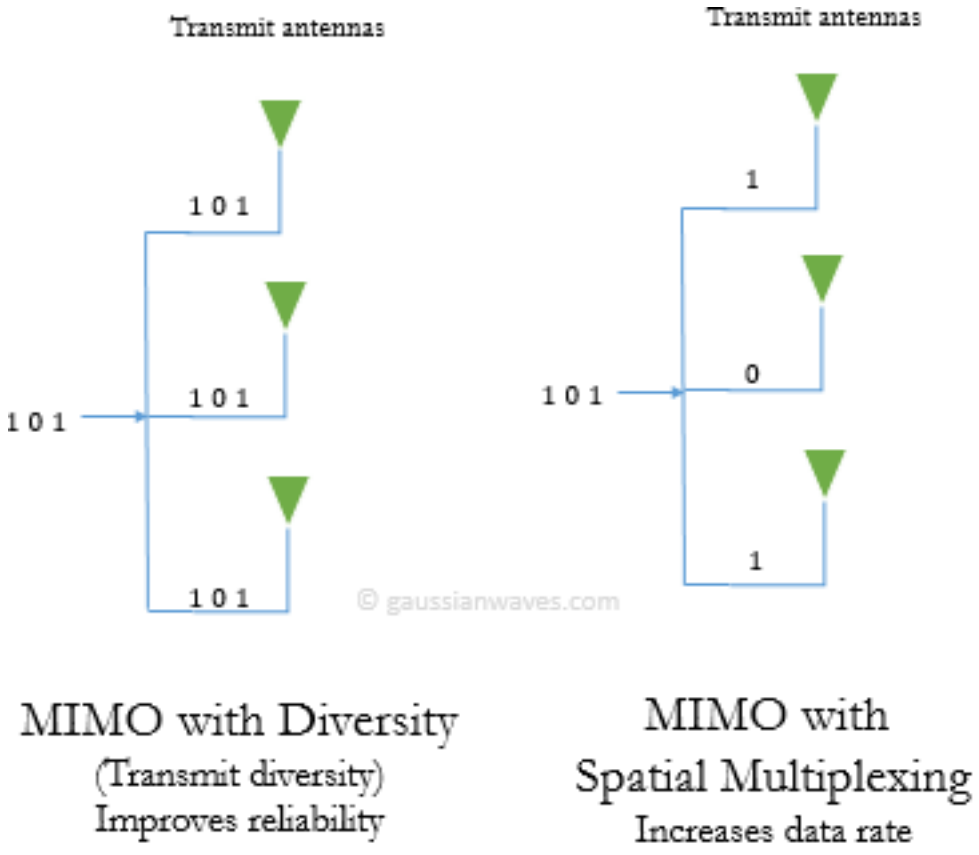




$s'_{16}(t) = s(t) + \zeta_{16}(t), \qquad \zeta_{16}(t) \sim N\left(0, \frac{\sigma}{4}\right)$

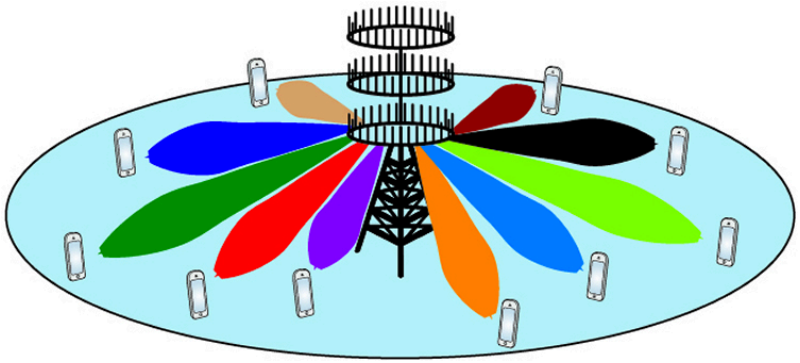
How MIMO works

- **spatial multiplexing** to increase data rate
  - Each channel carries independent information.



Massive MIMO

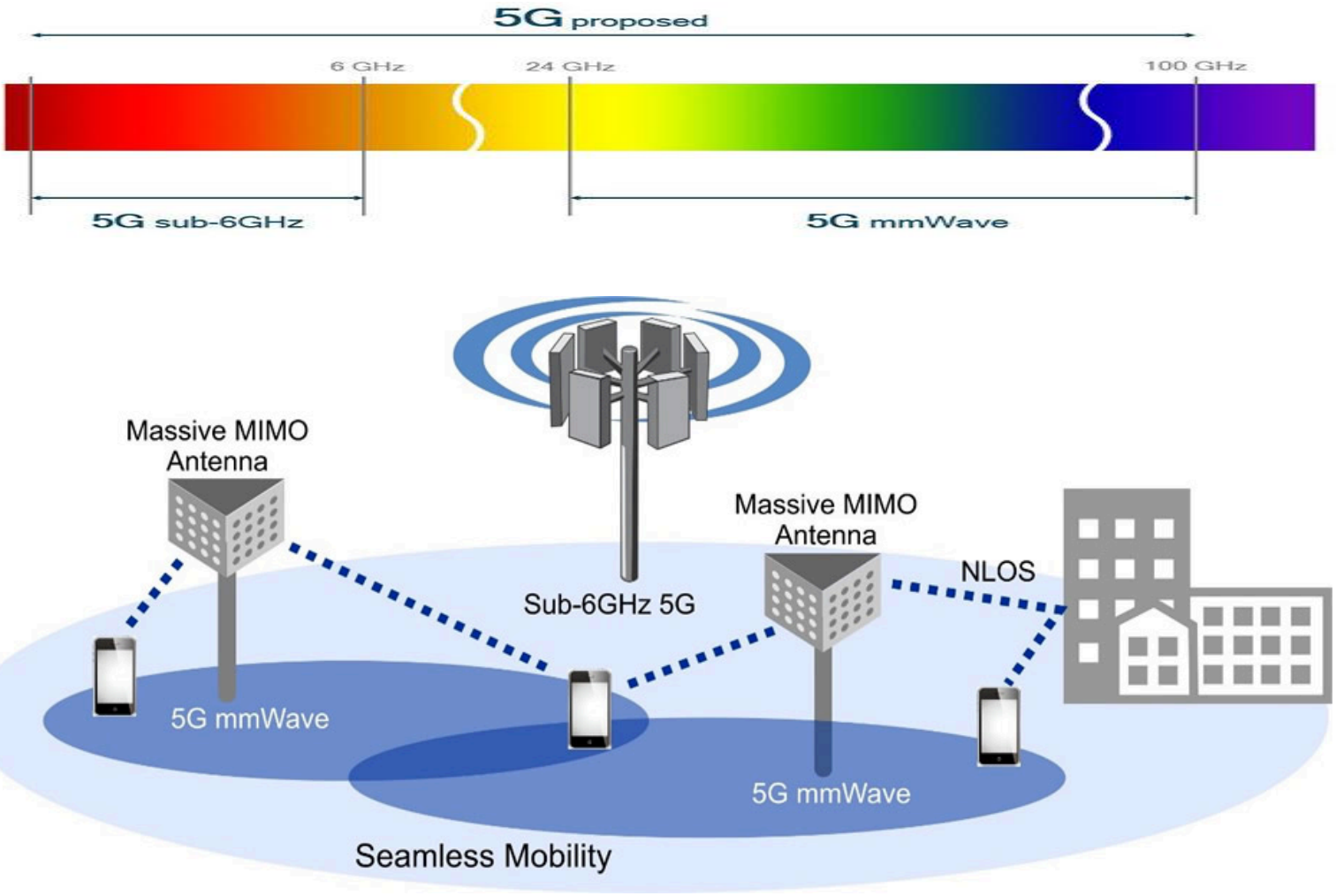
- **Massive -> very large**



beamforming

Massive MIMO testbed
@LUND University

Millimeter-Wave MIMO



Summary

- Cellular Networks
  - Handoff
  - Roaming
  - Different generations
- MIMO