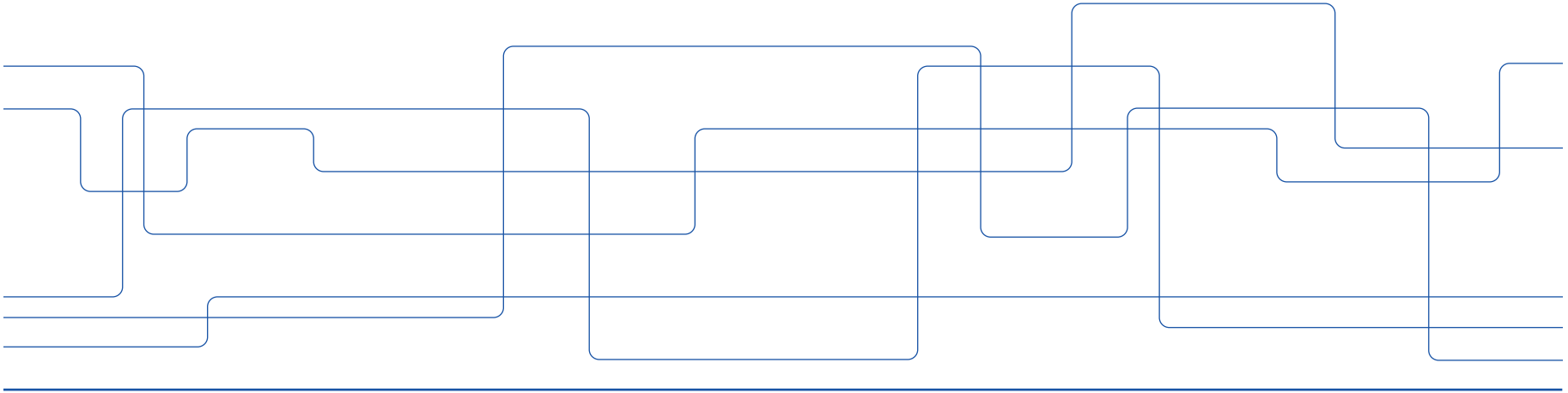
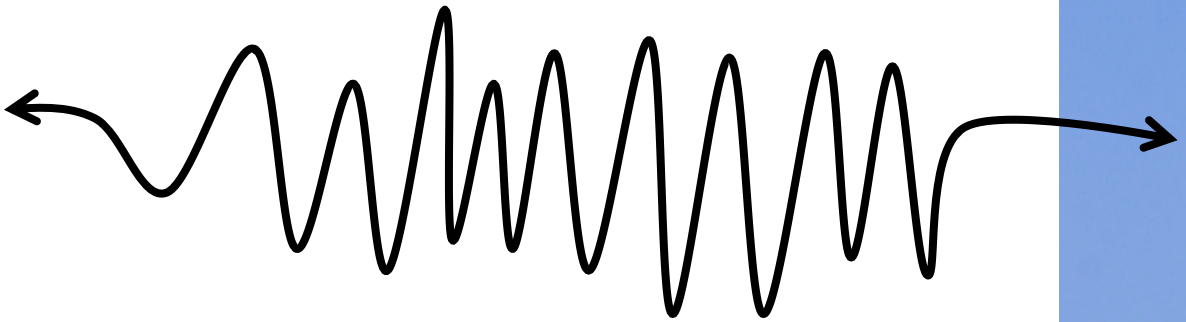
KTH ROYAL INSTITUTE
OF TECHNOLOGY

Introduction to Mobile Networks and Services



What is communication?

Information transfer



Classic technology

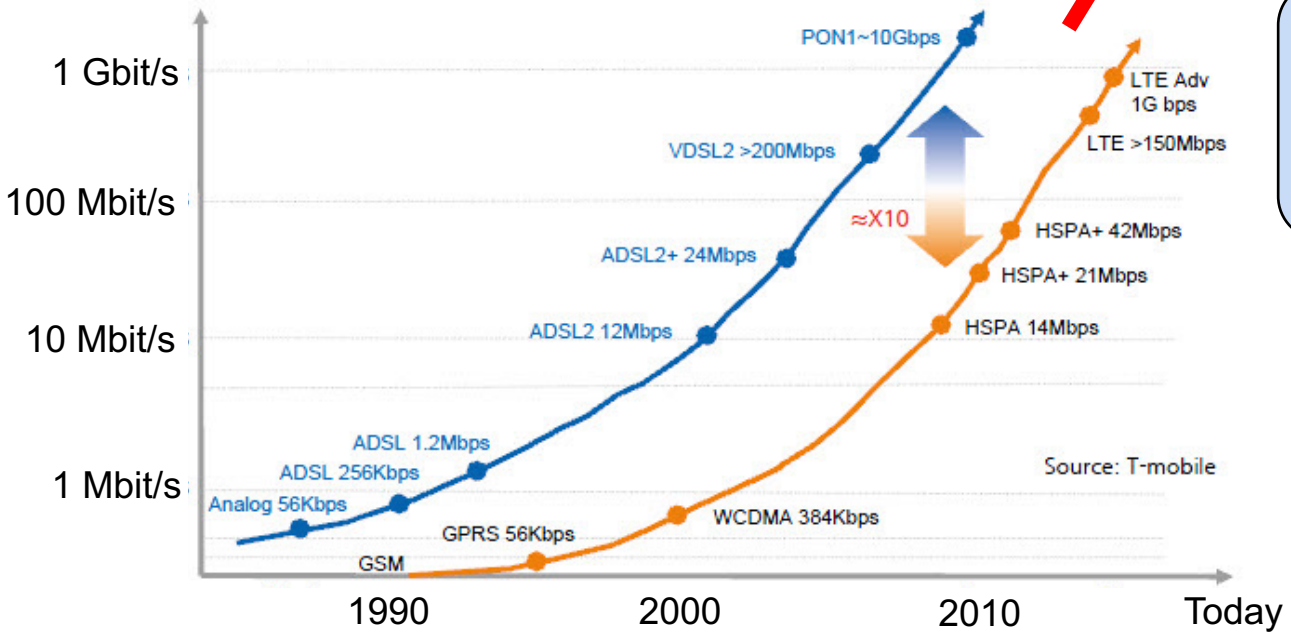
- Newspapers, books
- Telegraph
- Radio and TV broadcast

Modern technology

- CD, DVD, Blu-ray
- Optical fibres, network cables
- Wireless (4G/5G, WiFi)

Exponential increase in data speeds

New research challenges arise



Martin Cooper's law

The number of voice/data connections has doubled every 2.5 years (+32% per year)

Fast traffic growth

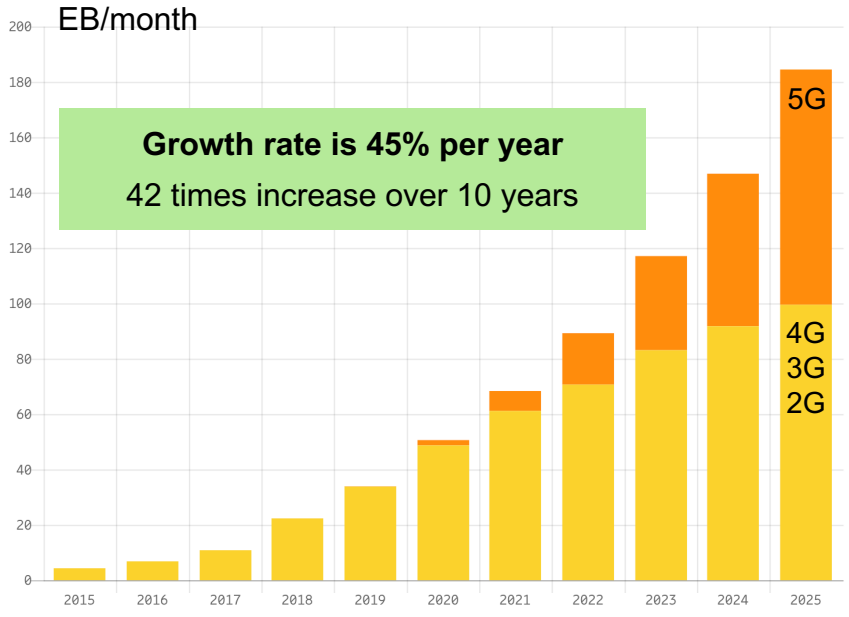
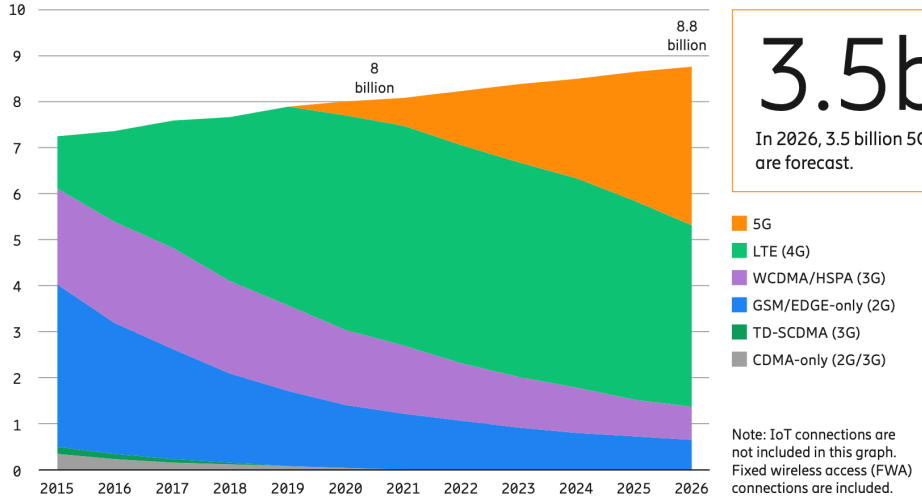


Figure 1: Mobile subscriptions by technology (billion)



3.5bn

In 2026, 3.5 billion 5G subscriptions are forecast.

Note: IoT connections are not included in this graph. Fixed wireless access (FWA) connections are included.

Number of subscriptions growth

- Traffic grows much faster

Source: Ericsson Mobility Report

Impact of wireless connectivity

- Shrinks the world
- Always connected
- Changes the way people communicate – Reach a person, social networking
- Converged global wireless network

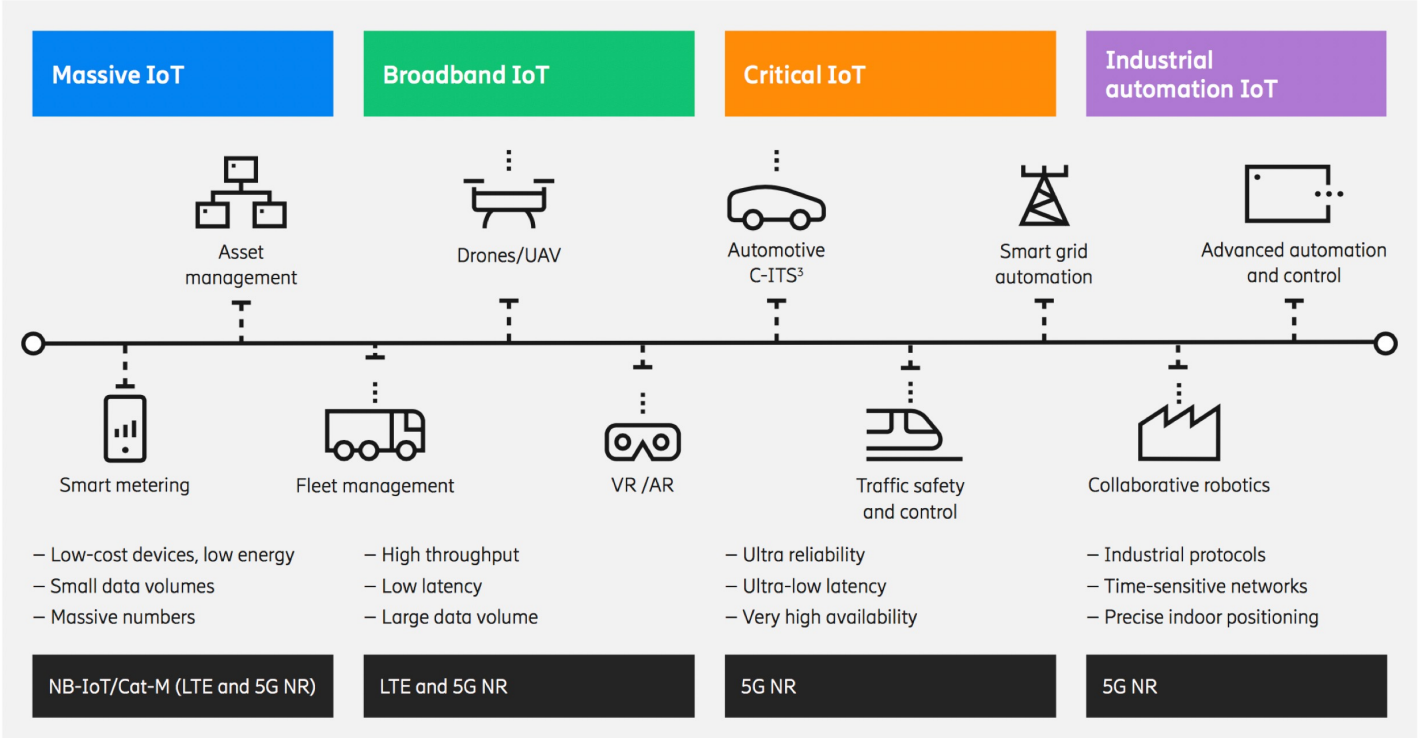
Now the enabler of digitalization of society

Smart cities, smart homes, Industry 4.0

Next consumer service: Augmented reality?

New use cases for Internet-of-Things (IoT)

Cellular IoT use case segments



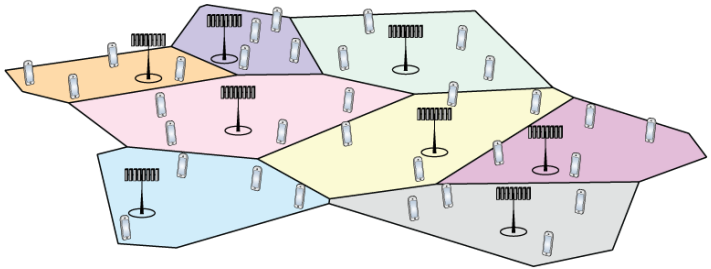
Source: Ericsson Mobility Report

A brief history of wireless communications

- Guglielmo Marconi invented the wireless telegraph in 1896
  - Communication by encoding alphanumeric characters in analog signal
  - Sent telegraphic signals across the Atlantic Ocean in 1901
- Communications satellites launched in 1960s
- Advances in wireless technology
  - FM radio, television from 1950s
  - Mobile telephone from 1980s; from analog to digital, mobile data
- Recent decades
  - Wireless networking, cellular technology
  - Mobile apps, Internet of Things

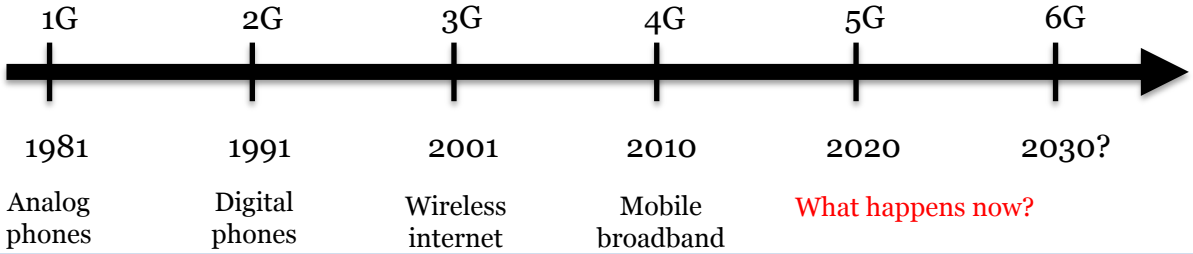
Cellular telephones and mobile networks

- Started as a replacement to the wired telephone
  - Bullington, K. (1953). “Frequency economy in mobile radio bands”.
  - Schulte, H. J. and W. A. Cornell (1960). “Multi-area mobile telephone system”.

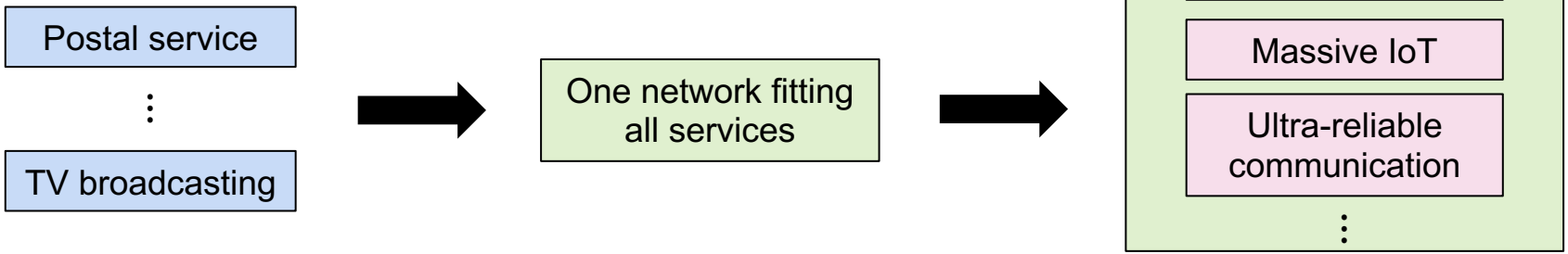


Many services

Voice calls, texting, social networking, mobile apps, mobile web, mobile commerce, video streaming



One network, many services

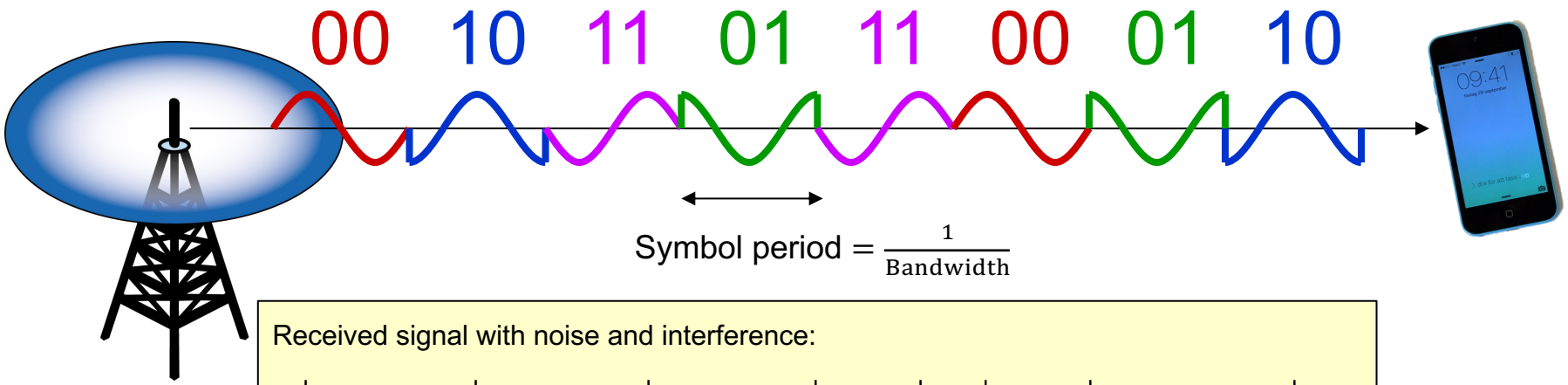


Past
One system per service

Present
One system for all service:
Wireless/wired connection to Internet, which delivers email, video, etc.

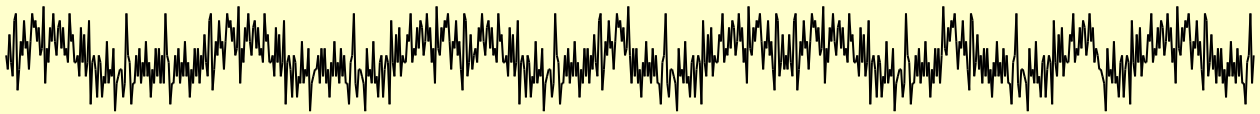
Future
Reconfiguration for different services:
Network slicing, software-defined

Physical Layer in a Nutshell



Symbol period $= \frac{1}{\text{Bandwidth}}$

Received signal with noise and interference:



How many bits can we transmit *reliably*?

Predicted by Shannon capacity

Achieved by modulation and coding

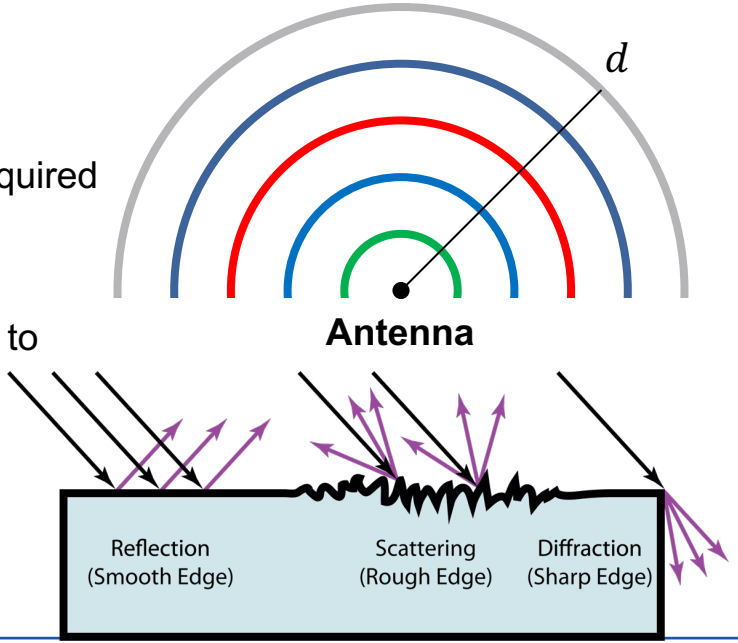
Communication algorithm

0010110111000110

Good and bad features of wireless communication

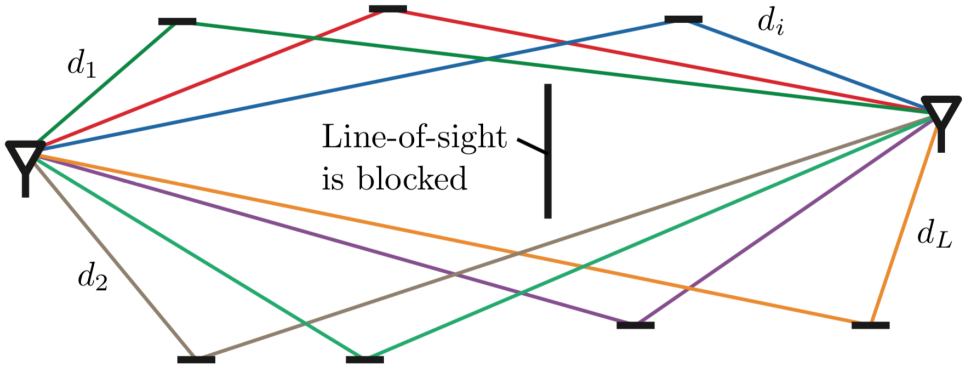
- Wireless is convenient, easy to deploy and less expensive, but not perfect
- Both political and technical limitations inhibit wireless technologies

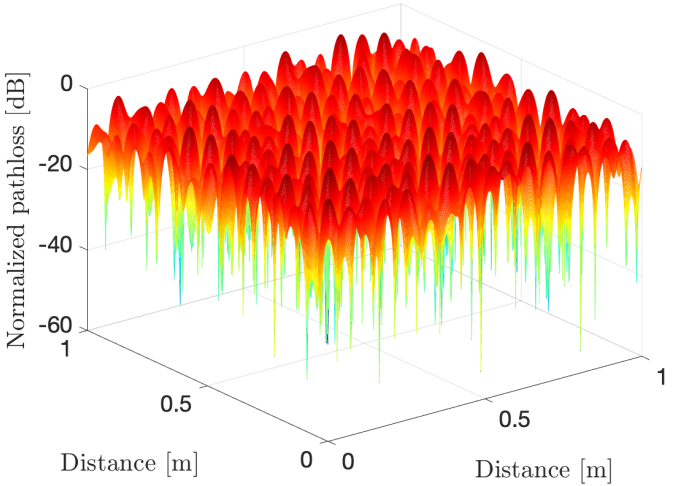
- Wireless channel
  - Line-of-sight is best but not required
    - > *Only attenuation with distance*
  - Non-line-of-sight possible due to
    - > *Transmission through objects*
    - > *Reflections off objects*
    - > *Scattering of signals*
    - > *Diffraction around edges of objects*



Fading, interference, and noise

- Multi-path fading
  - Signal copies interact: constructively and destructively
  - Changes over time and frequency



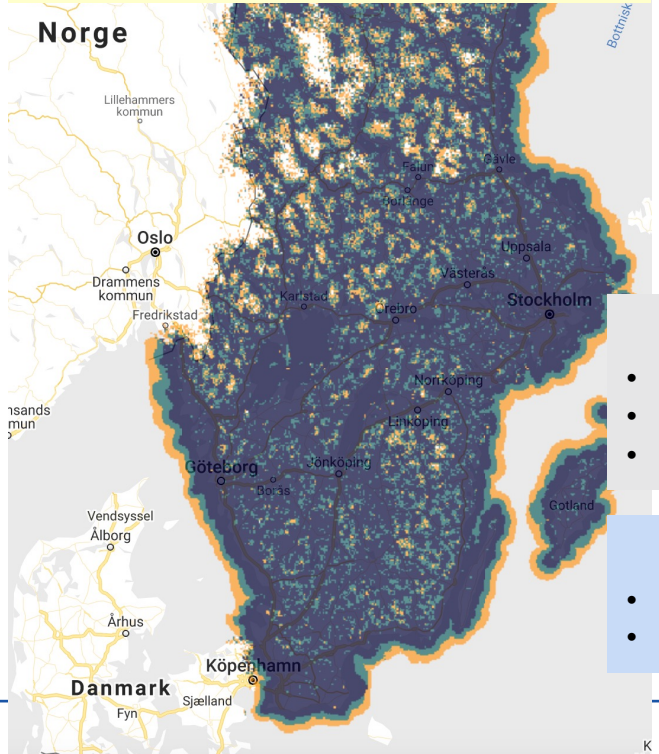


- Interference from other transmissions – co-existence
- Thermal noise

Basic metrics: Coverage and capacity

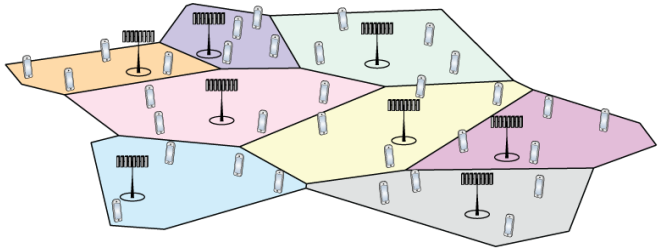
Geographical coverage

Locations where devices can connect



Traffic capacity

Capability to transfer data [bit/s/km^2]



Voice services

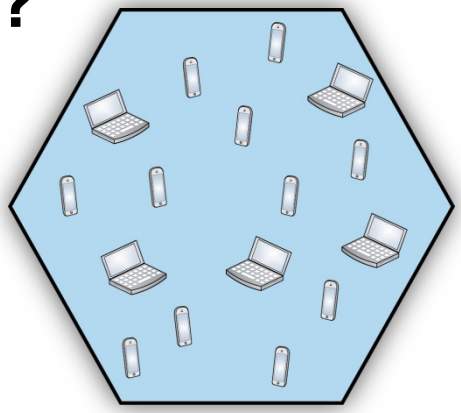
- Require 10-100 kbit/s, more is not better
- Service everywhere you have coverage
- If it doesn't work: Capacity-limited

Data services

- Higher data rates is better, up to ~100 Mbit/s
- More challenging to deliver!

How to increase the traffic capacity?

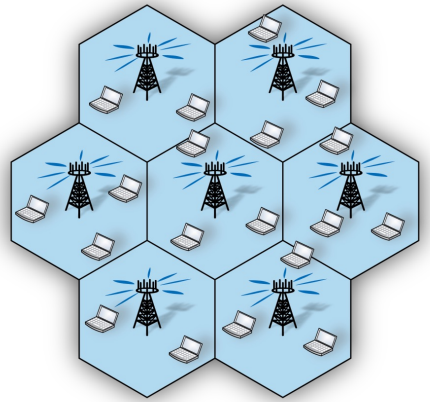
- Increasing data traffic [bit/s/km^2]
  - Handle 1 000 times more traffic per area (e.g., 1 km^2)



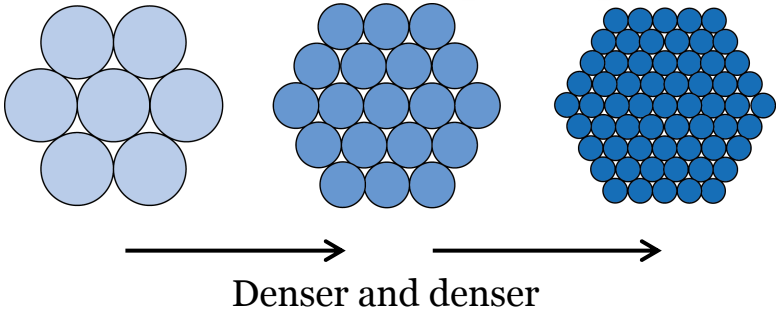
- Formula for data traffic in cellular network:

$$\underbrace{\text{Capacity}}_{\text{bit/s per km}^2} = \underbrace{\text{Cell density}}_{\text{cells/km}^2} \cdot \underbrace{\text{Spectral efficiency}}_{\text{bit/s/Hz/cell}} \cdot \underbrace{\text{Available spectrum}}_{\text{in Hz}}$$

Higher cell density [cells/km^2]



- Cellular networks
  - Coverage area divided into *cells*
  - One *access point* per cell – serves the users in the cell
- Denser deployment of access points
  - Shorter distance: stronger signal
- Challenge: Interference
  - Higher capacity if bit/s/cell maintained



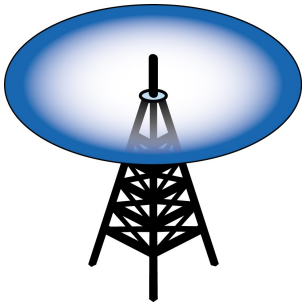
Higher spectral efficiency [bit/s/Hz]

- Spectral efficiency according to Shannon

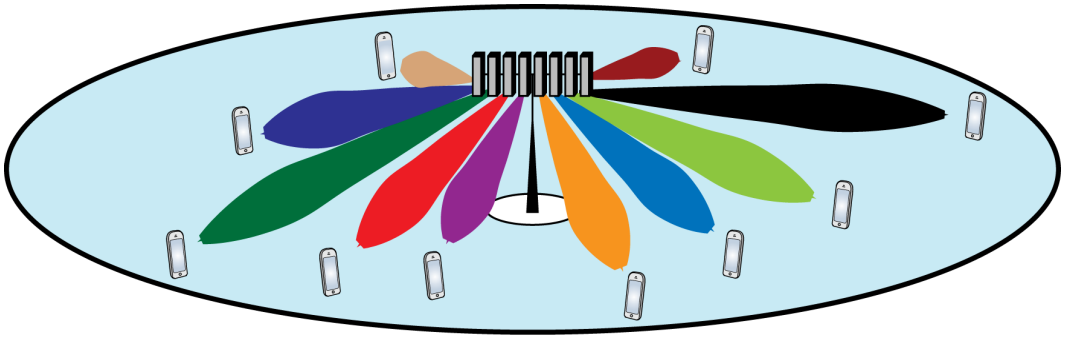
$$\log_2\left(1+\frac{\text{Signal power}}{\text{Interference+noise power}}\right) \text{ bit/s/Hz}$$

  - Expensive to increase: Exponential increase of power?

- Solution: Many simultaneous transmissions, *directed towards the users*



1 antenna



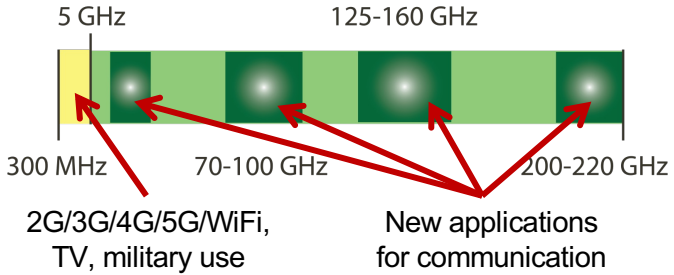
MIMO-technology: 100 antennas

MIMO = Multiple input, multiple output

More frequency spectrum [Hz]

- More spectrum
  - Reduced time per transmission
- Is there any unused spectrum?
- Much has already been allocated
  - More than 1 GHz to cellular, 500 MHz to WiFi (Sweden)
  - Many GHz of unused spectrum at mm-wave frequencies (30-300 GHz)
- Challenges:

Signal propagation very differently
Design of new hardware



Political challenges

- Between companies
  - Need common standards so products interoperate
    - *Leave some aspect*
  - Some areas have well agreed-upon standards
    - *Wi-Fi, 4G/5G*
    - *Not true for Internet-of-Things technologies*

- Spectrum regulations
  - Governments dictate how spectrum is used
    - *Many different types of services and users*
    - *Legacy technologies*
  - Some frequencies have restrictive bandwidths and power levels
    - *Others have much more bandwidth available, but worse propagation*
    - *Sensitive equipment must be protected*

Thank you for watching!