

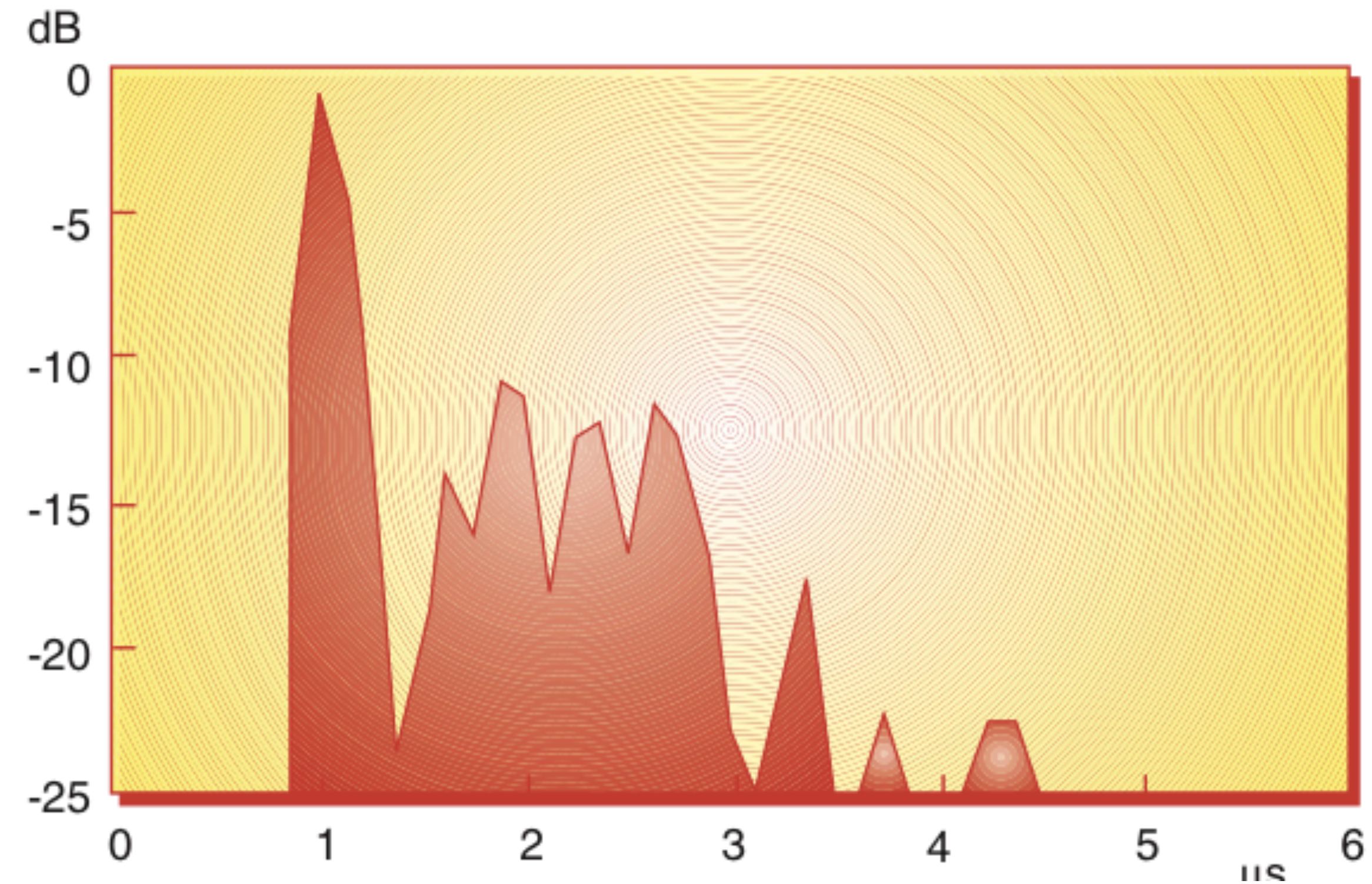
TEK5110: L3 Propagation

## Propagation Characteristics

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# TEK5110 - Before we start

- Questions to L2 - radio characteristics?
- Paper selection, state of the art based on your interest
  - preparation, evaluation
  - when to present
- Group work (later)
- Questions for Exam: [http://its-wiki.no/wiki/TEK5110/List\\_of\\_Questions](http://its-wiki.no/wiki/TEK5110/List_of_Questions) (to be completed)
  - Compendium:

# Learning outcomes

- ➔ Antennas
  - Gain and directivity
- ➔ Multipath propagation
  - Non Line of Sight (NLOS) communications
  - Multipath
- ➔ Propagation Models
  - Outdoor, impulse response
  - Indoor

## ⌘ B-Antennas and Propagation

### **Free Space Propagation**

[Antennas, Gain, Radiation Pattern](#)

[Multipath Propagation, Reflection, Diffraction](#)

[Attenuation, Scattering](#)

[Interference and Fading \(Rayleigh, Rician, ...\)](#)

[Mobile Communication dependencies](#)

### **C-Propagation models**

[Environments \(indoor, outdoor to indoor, vehicular\)](#)

[Outdoor \(Lee, Okumura, Hata, COST231 models\)](#)

[Indoor \(One-slope, multiwall, linear attenuation\)](#)

<http://its-wiki.no/wiki/>

[Building Mobile and Wireless Networks Compendium](#)

Keywords: [Antennas](#), [Hertz Dipol](#), [Antenna Gain](#)

## ⌘ B2-Antenna Basics [\[edit\]](#)

The gain is the radiation intensity of an antenna into the main direction as compared to an isotropic antenna (omnidirectional). For a perfect antenna without any losses, the gain  $G$  will be identical to the directivity  $D$ .

$$D = D_{\text{main}} / D_{\text{isotropic}}$$

$$D_{\text{rad}} = \frac{4\pi F_{\text{max}}(\theta, \varphi)}{\int_0^{2\pi} \int_0^\pi F(\theta, \varphi) \sin(\theta) d\theta d\varphi}$$

## ⌘ Antenna pattern [\[edit\]](#)

If the antenna pattern is known, then the gain can be easily calculated.

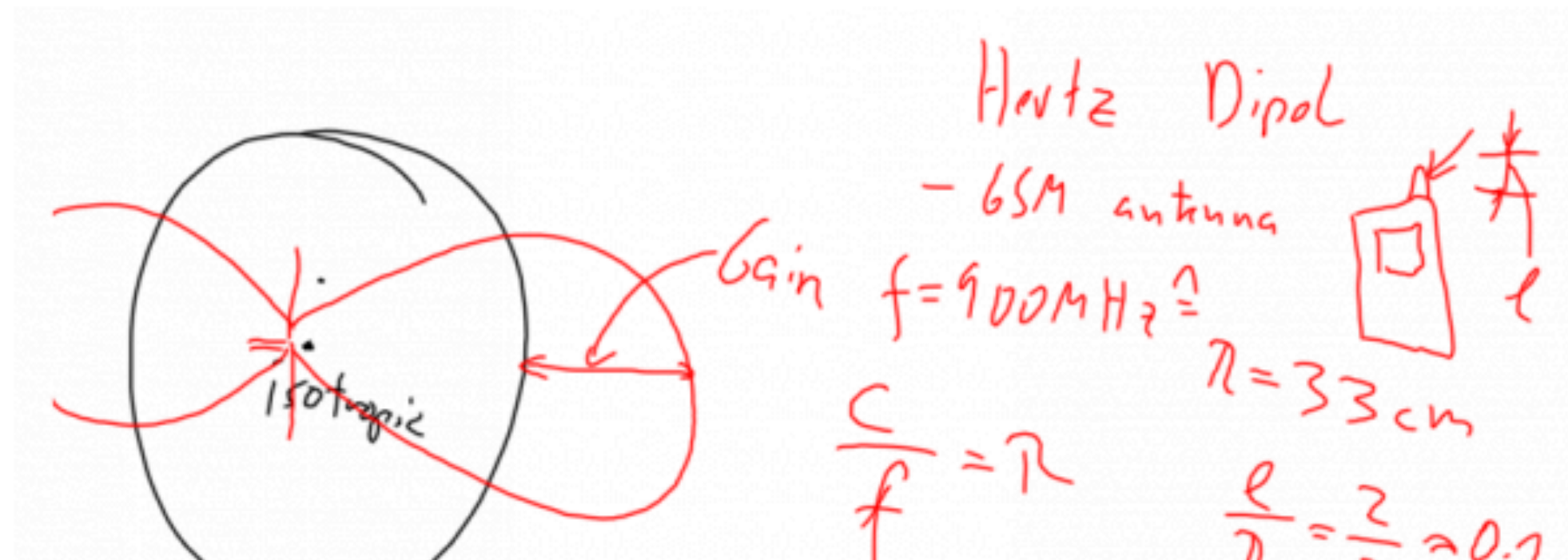
- Isotropic antenna = point source:  $G_s = 0\text{dB}$
- Hertz Dipol = Short dipol:  $G_s = 1,5 = 1,76\text{dB}$
- $\lambda/2$ -Dipol:  $G_s \approx 1,64 = 2,15\text{dB}$
- draw electrical field of dipole
- Aperture antennas:  $A_{\text{eff}} = e_{\text{ap}} A_{\text{phys}}$ , with  $e_{\text{ap}} = 0.65 \dots 0.75 (0.85)$ , leads to gain of  $G_s = A_{\text{eff}} \frac{4\pi}{\lambda^2}$
- examples of reflector antennas (effective aperture)

For more info, see intro course: <http://www.cv.nrao.edu/course/astr534/AntennaTheory.html>

## ⌘ Example: [\[edit\]](#)

Gain calculation for a  $\lambda/2$ -antenna calculate the gain of a  $\lambda/2$  antenna, given that the electrical field can be described as:

$$E(\vartheta) = -j \frac{\pi l}{c\lambda} \sin(\vartheta) I_0 \frac{e^{-j\omega t}}{r}$$



## Building .... Networks

### History, Now and Future

[History](#)

[Pioneers: Maxwell, Hertz,...](#)

[1G, 2G,... 5G networks](#)

[Frequencies and Standards](#)

[Future Challenges](#)

### A-Basics of Communication

[Electromagnetic Signals](#)

[Radio Communication Principles](#)

[Digital communication: Signal/Noise Ratio](#)

[Signal strength and Capacity: Shannon](#)

### B-Antennas and Propagation

[Free Space Propagation](#)

[Antennas, Gain, Radiation Pattern](#)

[Multipath Propagation, Reflection, Diffraction](#)

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### C-Propagation models

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[Indoor \(One-slope, multiwall, linear attenuation\)](#)

### D-System Comparison

[Proximity: RFID, NFC](#)



# Free space propagation

## → Questions/Tasks:

- Propagation equation in dB
- provide examples for  $f = 10$  MHz, 1 GHz, 100 GHz

Power received in an area in a distance  $R$  from transmitter:

- area of a sphere is  $A_s = 4 * \pi * R^2$
- power transmitted from isotropic antenna is  $P_t$
- antenna area of receiver is  $A_r = \lambda^2 / 4\pi$
- power received in  $A_r = P_r$

$$P_r = P_t * A_r / A_s = P_r = P_t * A_r / (4 * \pi * R^2)$$

thus

$$\left( \frac{\lambda}{4\pi r} \right)^2$$

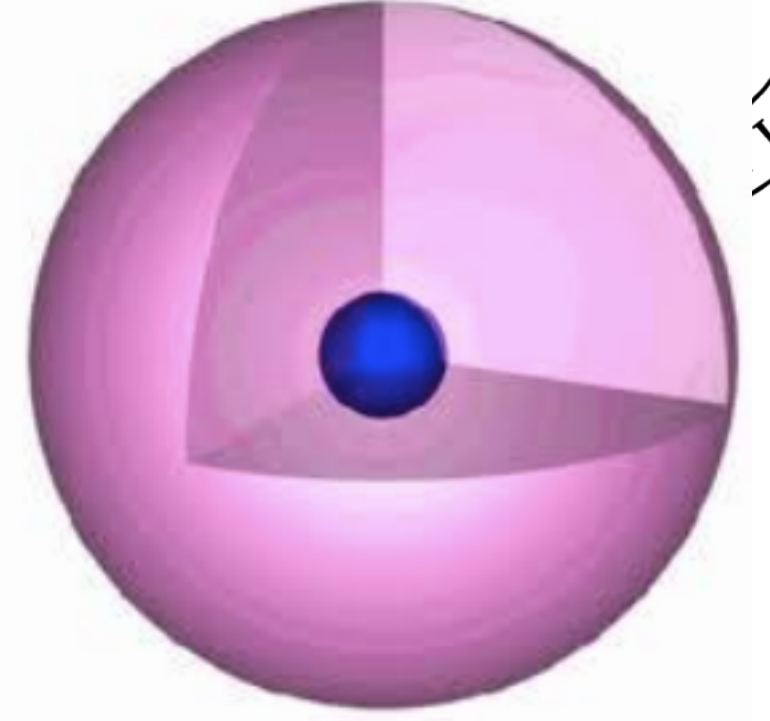
- 0 dBm =  $10^{(0/10)} = 1$  mW
- 10 dBm =  $10^{(10/10)} = 10$  mW

$$\text{Free space attenuation } L = 92,4 + 20 \log(d[\text{km}]) + 20 \log(f[\text{GHz}])$$

see (<http://www.antenna-theory.com/basics/friis.php>)

# B2-Antenna Basics

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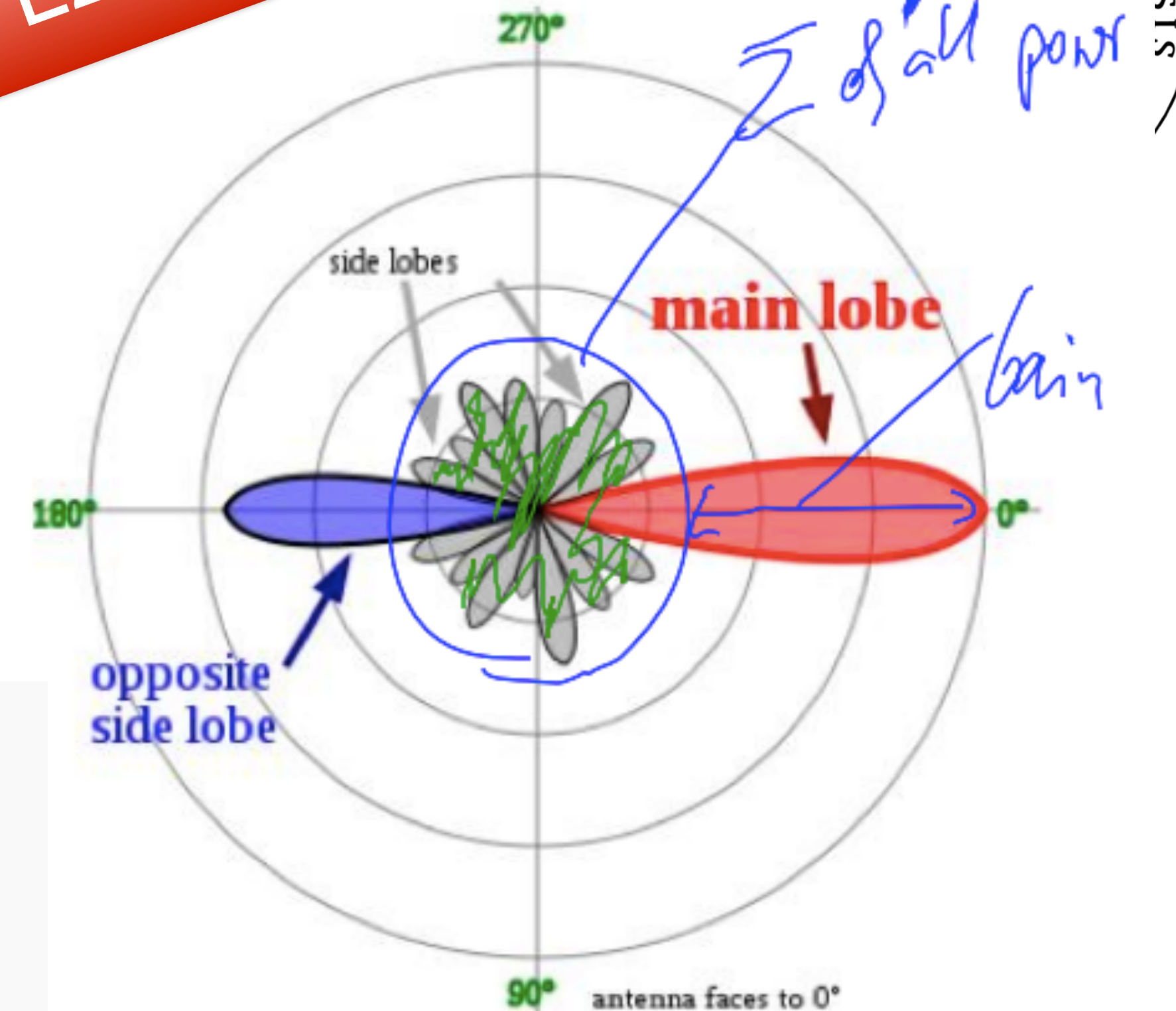
# Antenna pattern

L2



→ If the antenna pattern is known, then the gain can be easily calculated.

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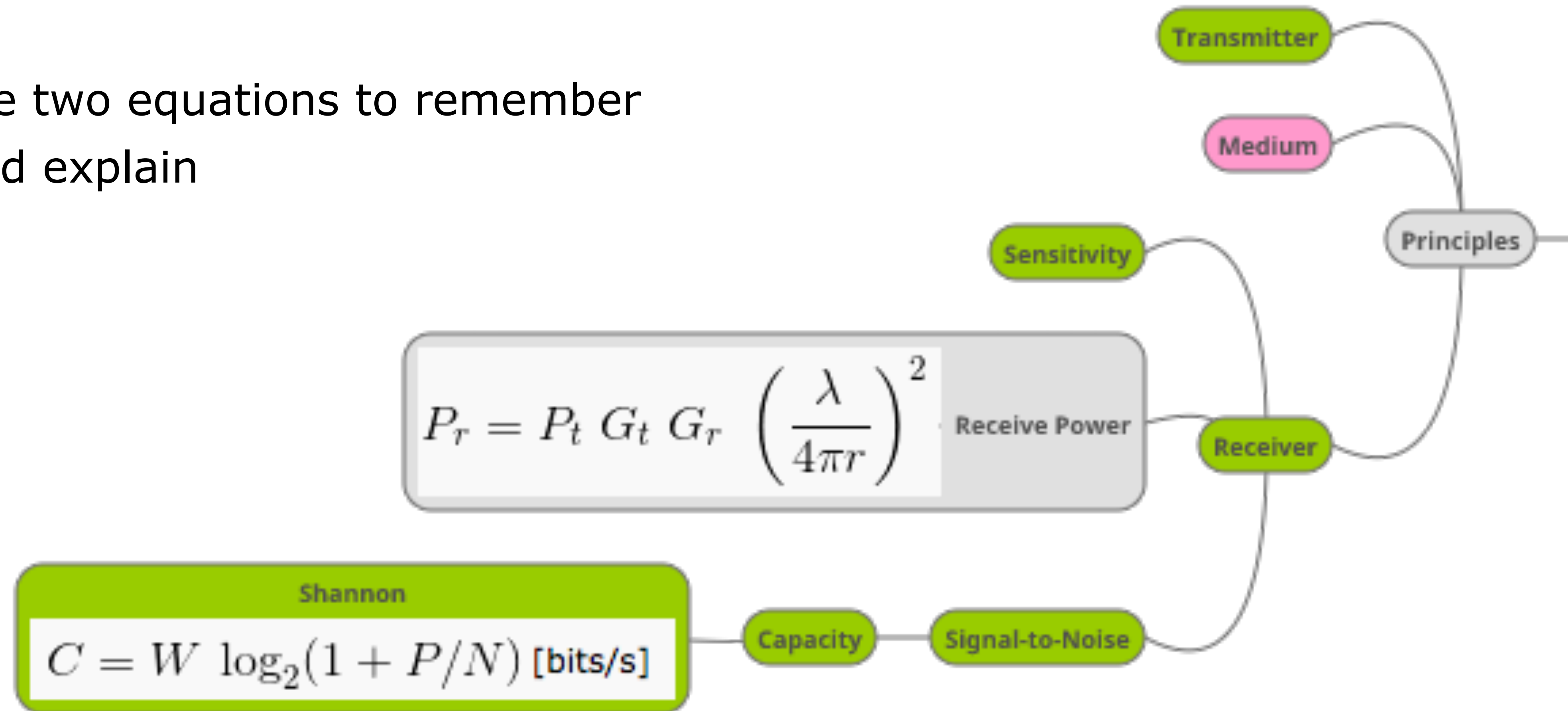
• [Media:Antennas\\_for\\_communications\\_Haavard.pdf](#) (by Håvard Austad)

# Antenna Questions

- Q: draw typical antenna pattern (Hertz Dipol,  $\lambda/2$ , reflector antenna)
- Q: what is the diagram of a lambda antenna?
- What else affects propagation?

# Receiver characteristics

- the two equations to remember
- and explain



online mindmap was removed by google

# Signal to Noise, Shannon

- in-band vs out-of-band noise
- interference vs noise
- Shannon theorem (1948)
  - almost 30 years after Hartley  $C \sim W$

$$C = W \log_2(1 + P/N) \text{ [bit/s]}$$

- interference free environment:  $P/N = \frac{P}{N_0 W}$
- with Interference

$$N_0 W + N_{\text{interference}}$$

$$\text{SNR} = \frac{P_{\text{signal}}}{P_{\text{noise}}}$$

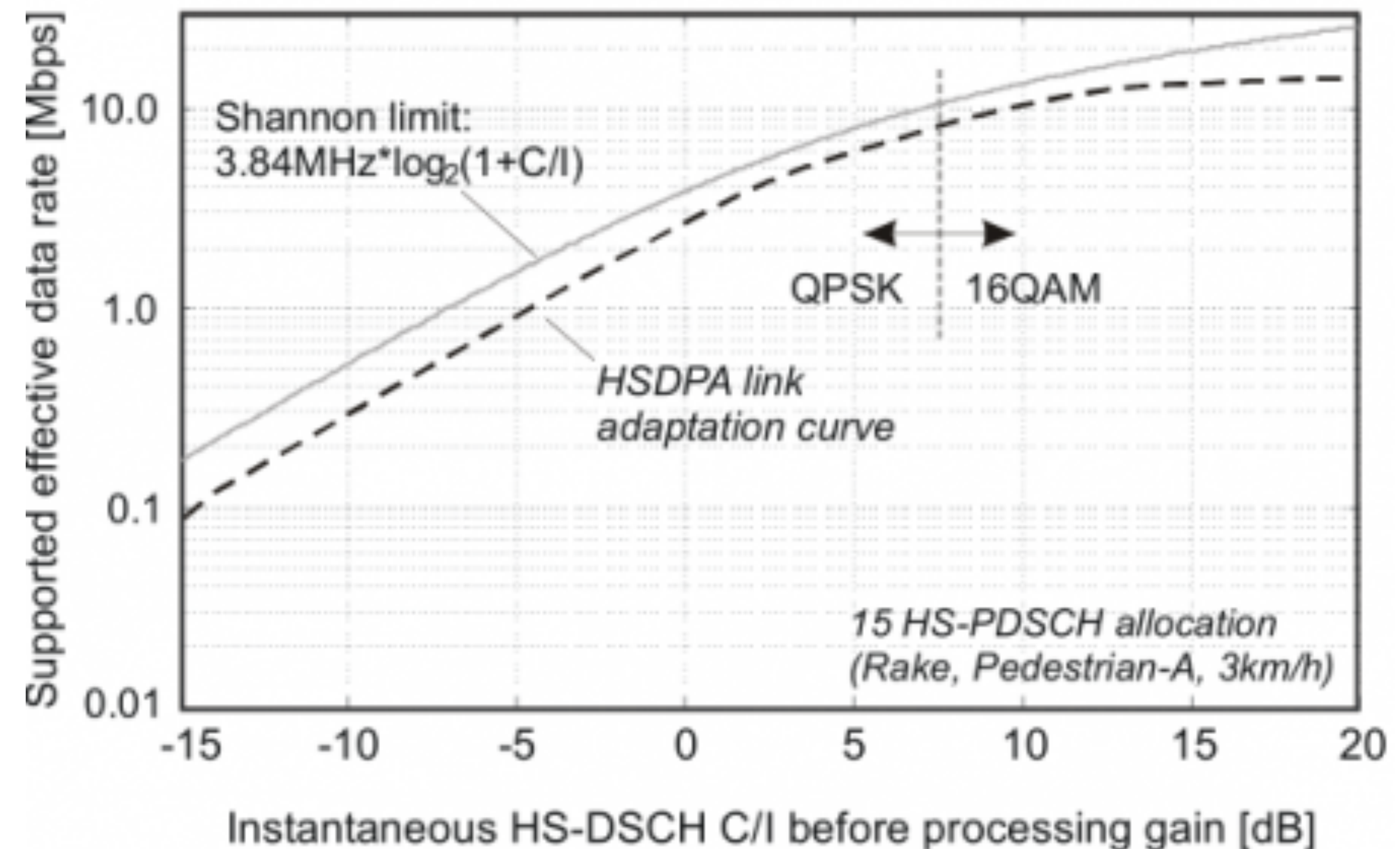
$$\text{SNR(dB)} = 10 \log_{10} \left( \frac{P_{\text{signal}}}{P_{\text{noise}}} \right),$$

# Shannon - Exercises

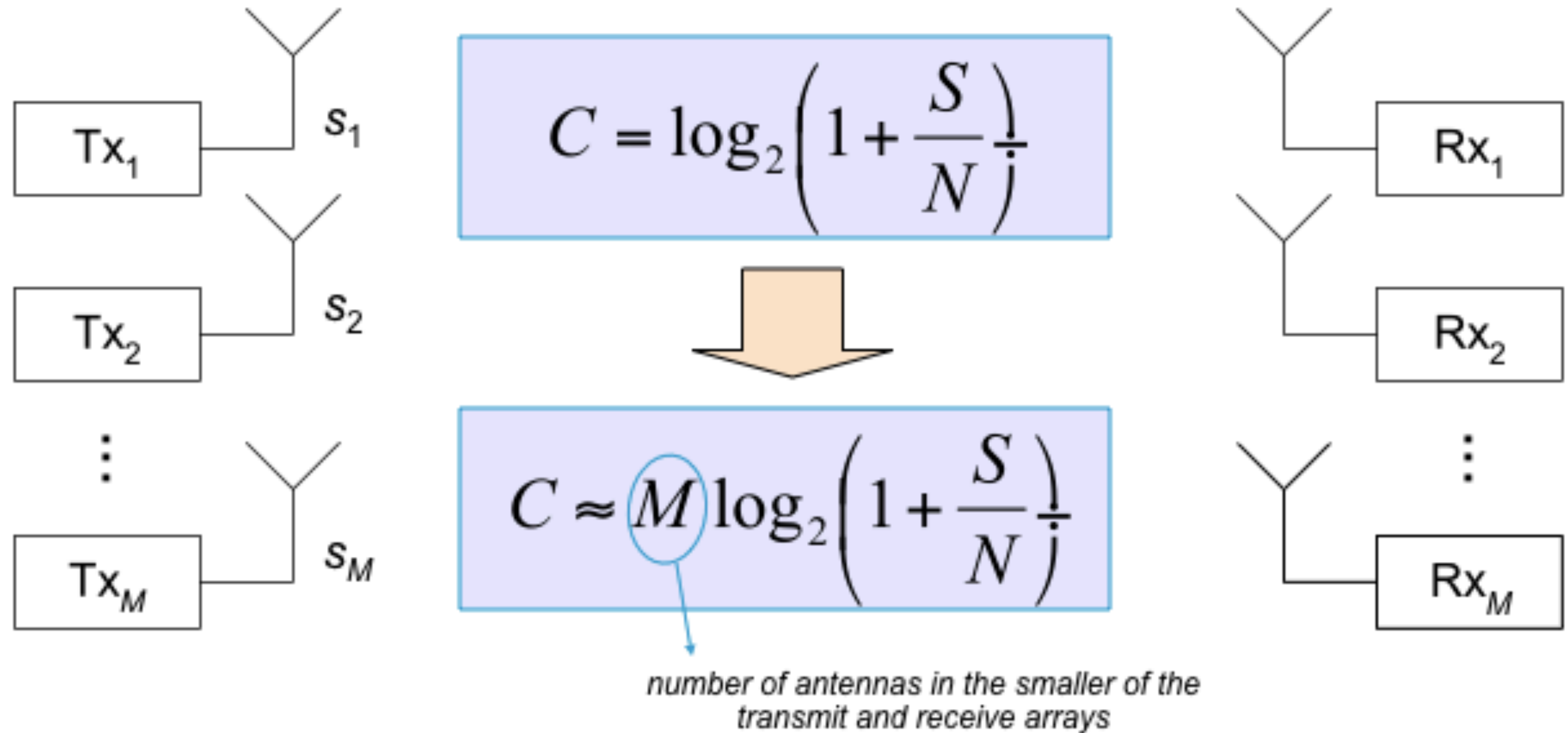
- calculate capacity for  $W = 200 \text{ kHz}$ ,  $3.8 \text{ MHz}$ ,  $26 \text{ MHz}$ , (all cases  $P/N = 0 \text{ dB}$ ,  $10 \text{ dB}$ ,  $20 \text{ dB}$ )
- If the SNR is  $20 \text{ dB}$ , and the bandwidth available is  $4 \text{ kHz}$ , what is the capacity of the channel?
- If it is required to transmit at  $50 \text{ kbit/s}$ , and a bandwidth of  $1 \text{ MHz}$  is used, what is the minimum S/N required for the transmission?

# Cell capacity

- UMTS has already good spectrum efficiency with respect to Shannon.
- Modulation schemes like QPSK and 16-QAM are applied to achieve higher bandwidth.
- Higher modulation schemes need a higher signal to noise ratio, **Why?**



# Multiple-Input, Multiple-Output (MIMO)



□ source: Reinaldo Valenzuela, Lucent Technology □

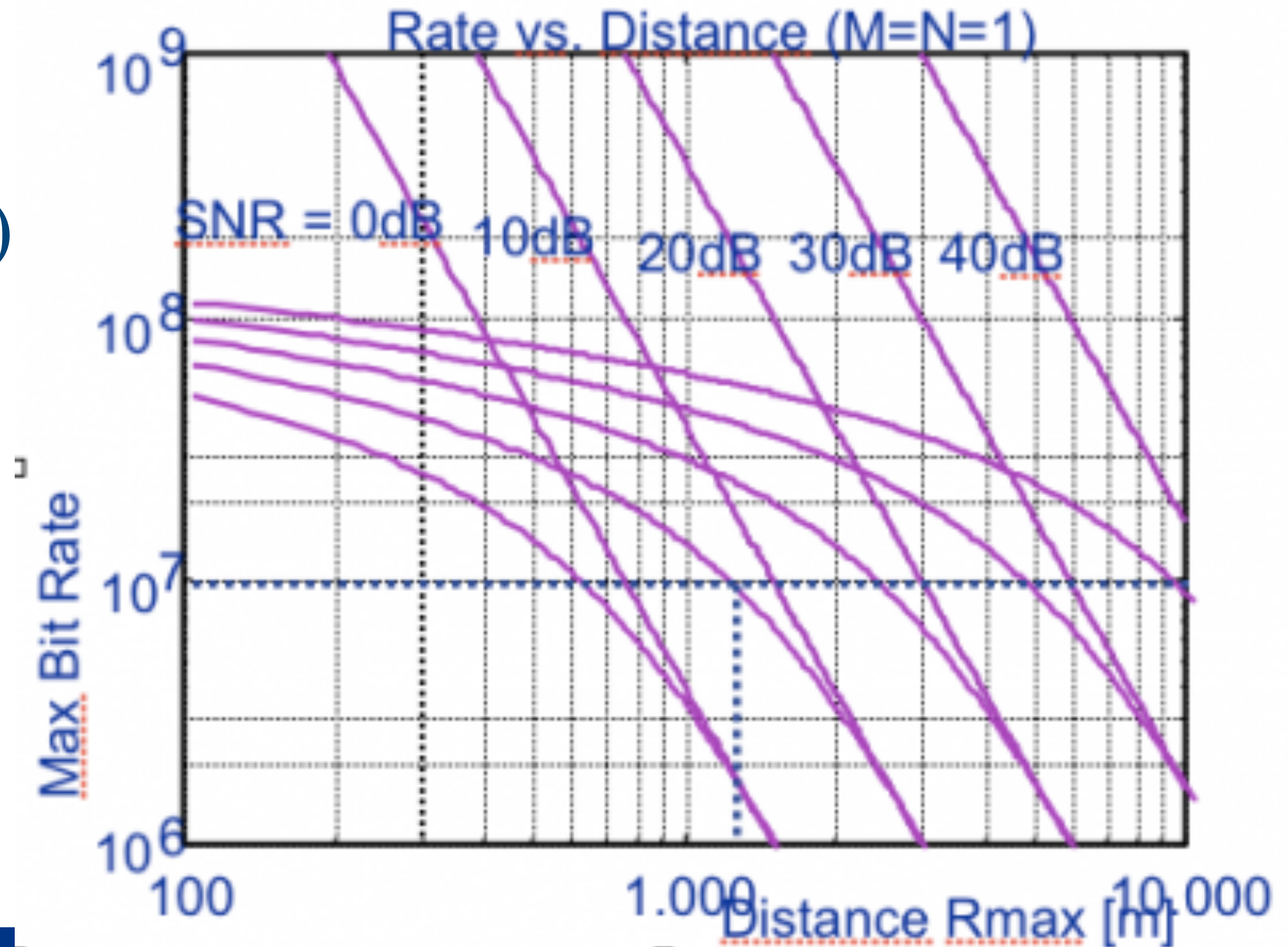
# MIMO laptop



# Range versus SNR

→ max range

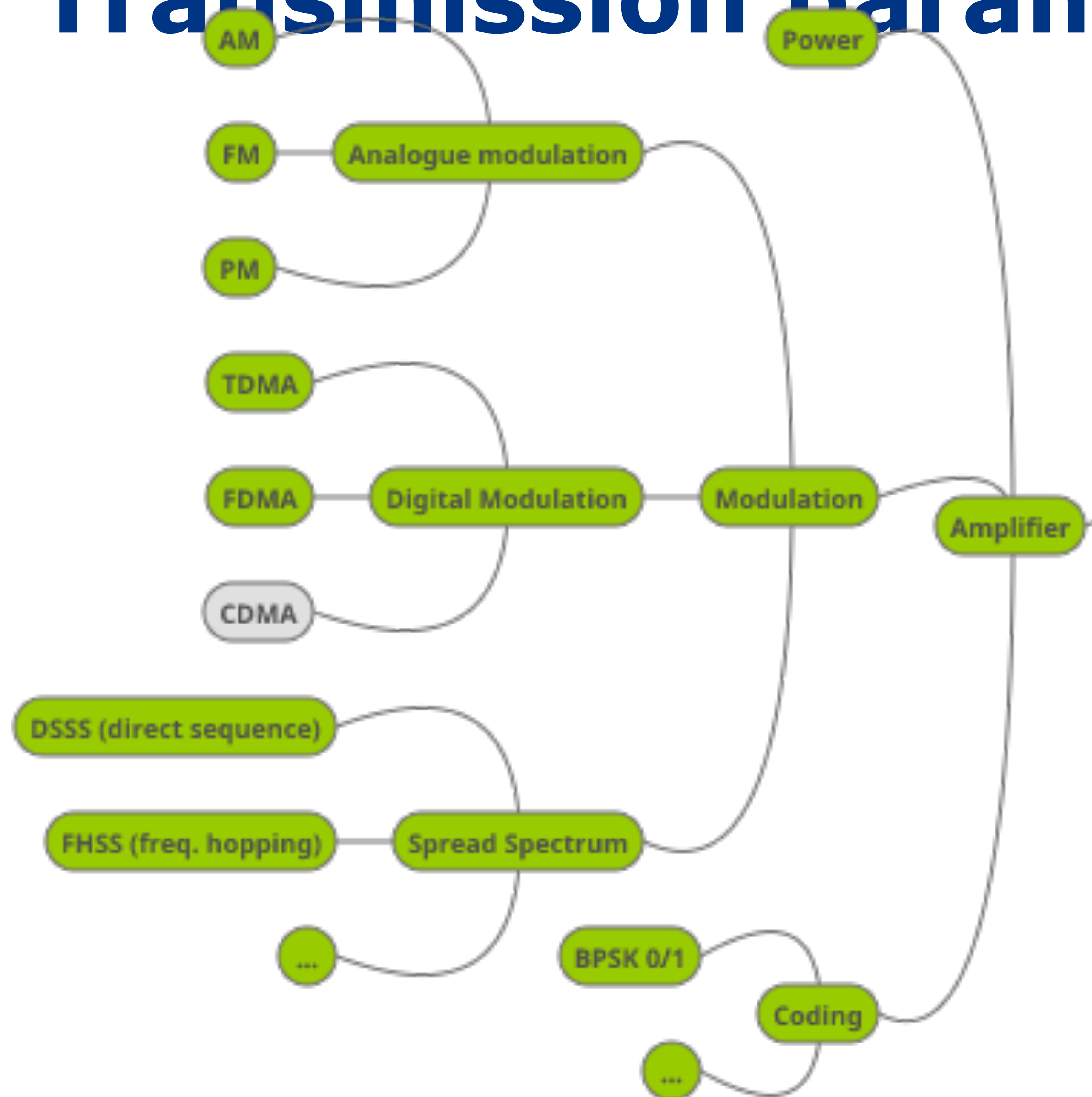
$$R_{\max} = \log_2(1 + \text{SNR})$$



Real system

| SNR | Range   | Capacity                      |
|-----|---------|-------------------------------|
| 0   | 600m    | 10 Mbit/s                     |
| 30  | 300m    | 60 Mbit/s                     |
| 10  | 3 km(?) | 1 Mbit/s (UMTS cell capacity) |

# Transmission parameters



- Isotropic antenna = point source:  $G_s = 0\text{dB}$
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# Scattering, Reflection, Diffraction

## → Reflection

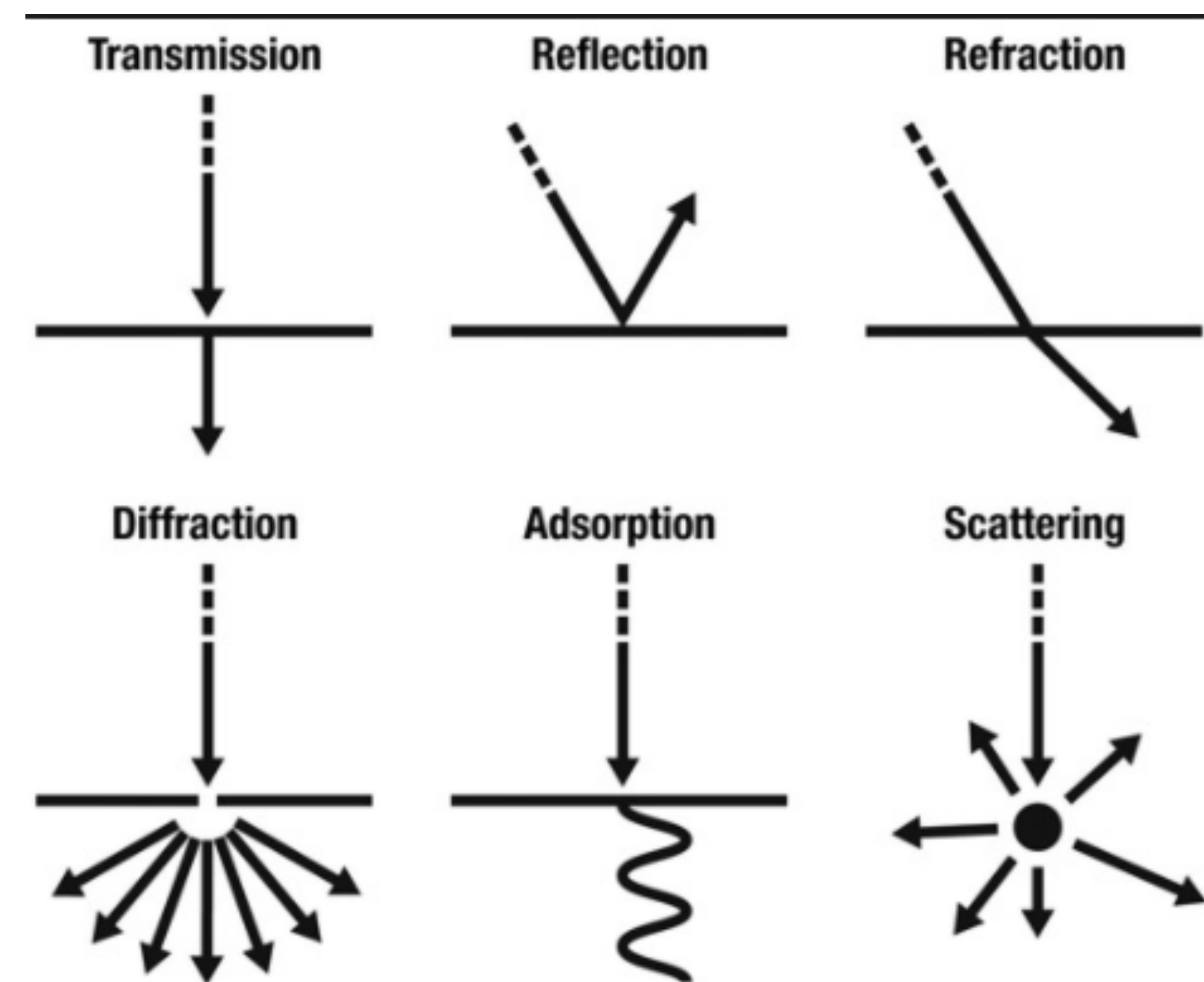
- wave hits smooth surface
- dimension  $\gg \lambda$
- typical: buildings, walls, water
- "ideal" reflection: mirror

## → Diffraction

- dimension  $\sim \lambda$ , or
- edges (roof top)
- bending wave

## → Scattering

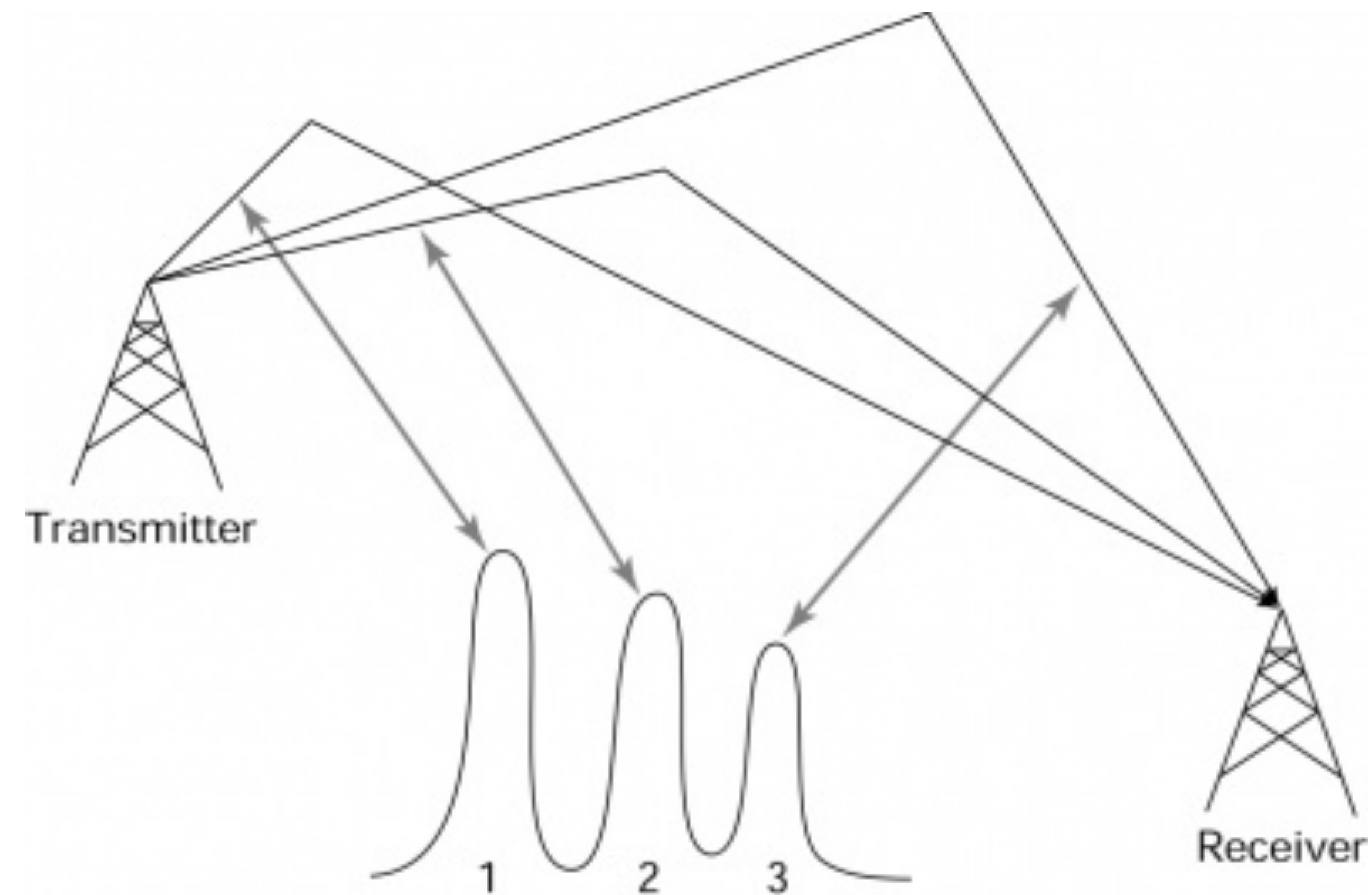
- dimension  $\ll \lambda$
- spread out energy



source: <https://physicsweekly.weebly.com/reflection-refraction-and-diffraction.html>

# Multipath propagation

- ➔ Mobile phone: no direct link between Tx and Rx
- ➔ communication “around the corner” or “over the hill” is called **NLOS** (non line-of-sight)
- ➔ typical reduction: 20-30 dB (Q: in power?)
- ➔ Effects:
  - rapid change in signal strength (Q: why?)
  - time dispersion (delays)
  - fading (small-scale)



# Physics - ideal reflection

→  $E_{tan} = 0$  on an ideal reflector

$$|r| = 1, \phi_r = 180\text{deg}$$

# Attenuation

→ wave attenuation, travelling through lossy material

→ EU project Hydra:

$$L = 92,4 + 20\log(d[\text{km}]) + 20\log(f[\text{GHz}]) + \sum n_i \alpha_i$$

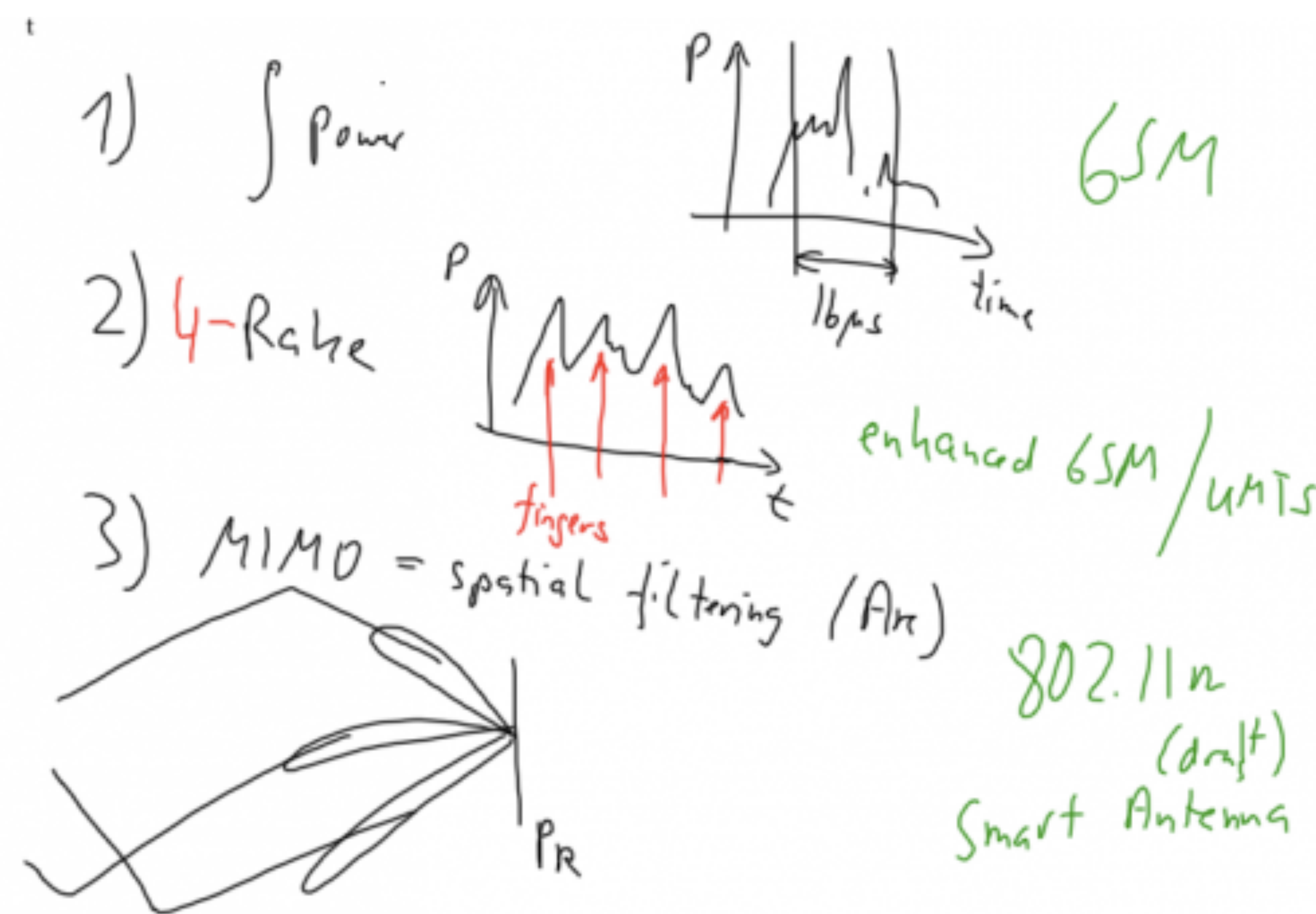
→ Q: Relation between fading margin and receiver sensitivity?

2.4 GHz attenuation, source: Hydra Deliverable D5.4

| Obstacle                      | Attenuation $\alpha_i$ [dB] |
|-------------------------------|-----------------------------|
| Brick wall with window        | 2                           |
| Brick wall next to metal door | 3                           |
| Cinder Block wall             | 4                           |
| Office wall                   | 6                           |
| Metal door in office wall     | 6                           |
| Metall door in brick wall     | 12.4                        |
| Floor                         | 30                          |

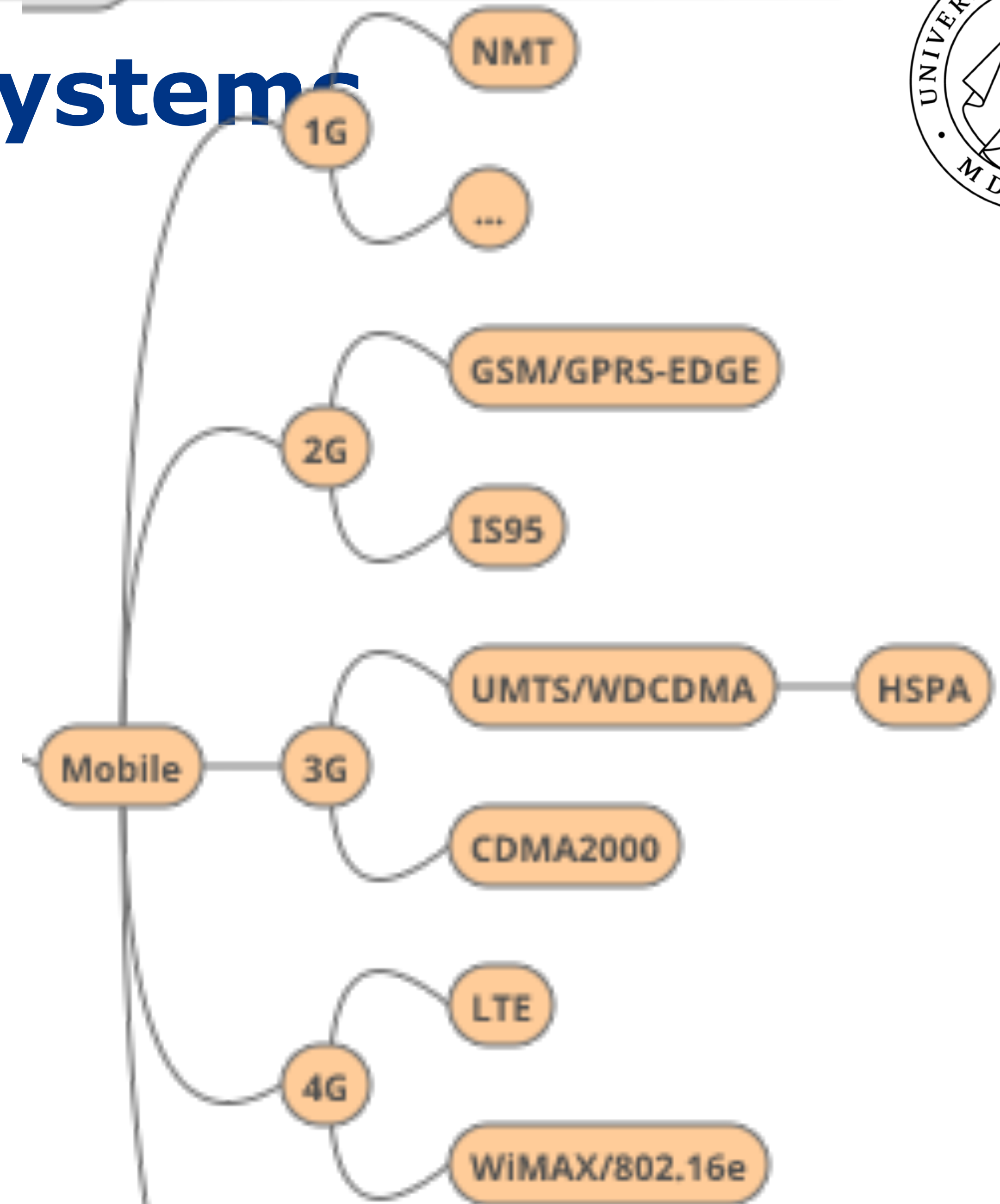
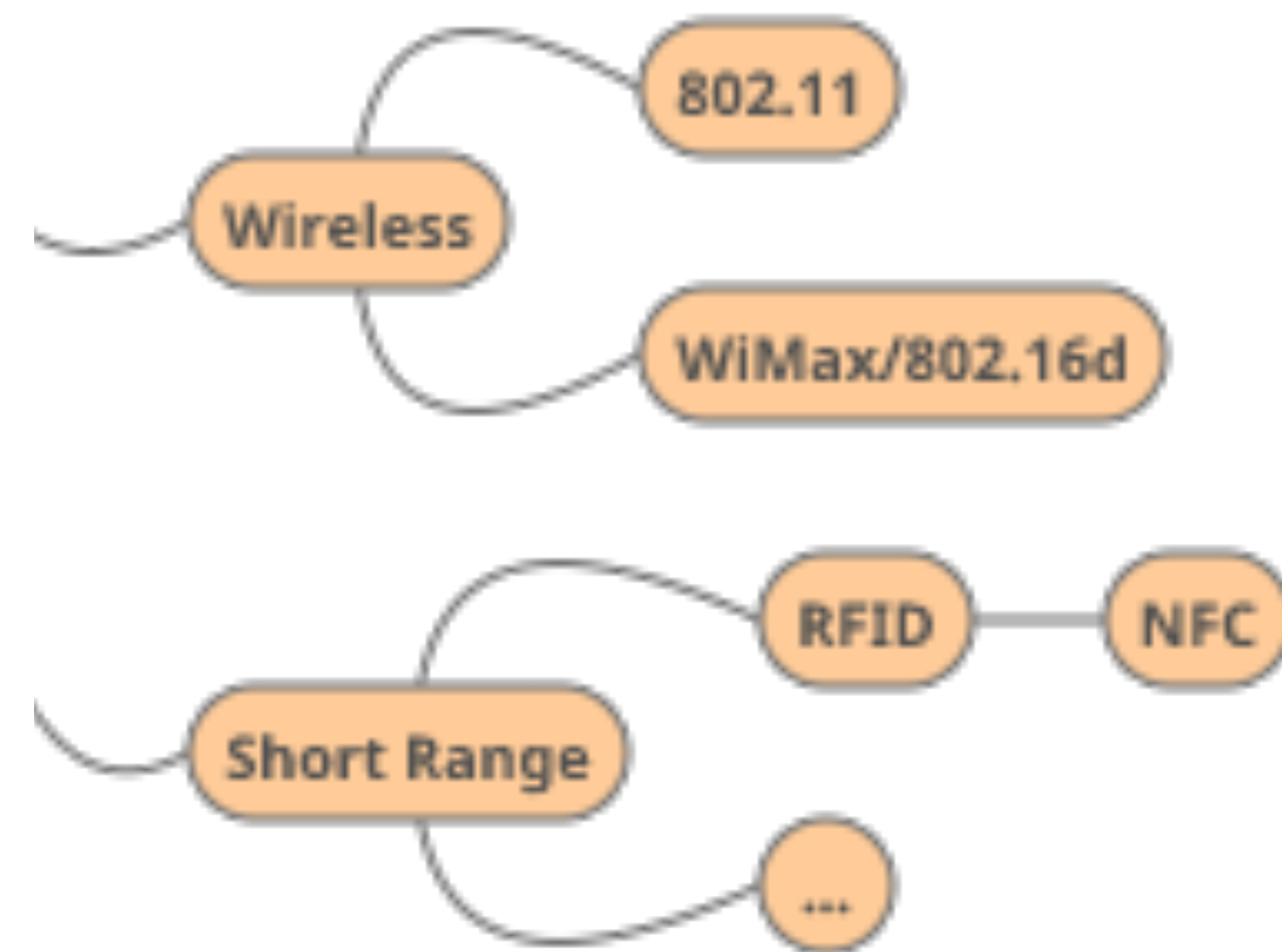
# Receiver characteristics - impulse responses

- Sliding 16  $\mu$ s window and integration of power in this window (typical GSM)
- Rake receiver, where each finger of the receiver points to one reflection (typical enhanced GSM, UMTS)
- MIMO (Multiple input, multiple output) or smart antenna arrays. Spatial filtering, with radiation from different directions (typical 802.11n, smart antennas for UMTS)



# Mobile Systems and Propagation Characteristics

# Mobile and Wireless Systems



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# ITU-R propagation scenarios

→ indoor, outdoor to indoor, vehicular

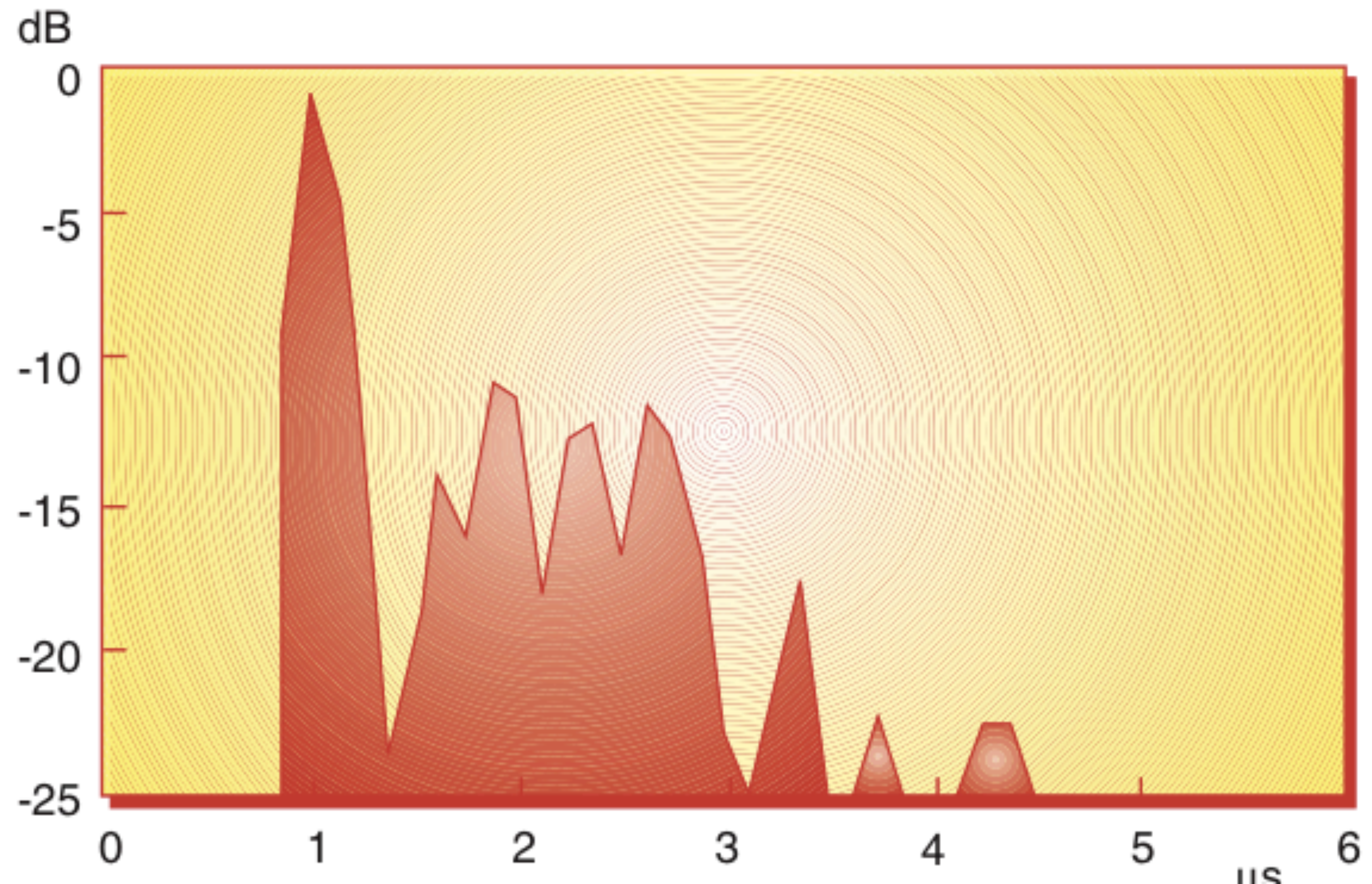
## Typical Propagation parameters

|                           | Radio coverage [km <sup>2</sup> ] | Distance [km] | speed of mobile [km/h] | type of cell                       |
|---------------------------|-----------------------------------|---------------|------------------------|------------------------------------|
| Indoor office environment | 0.01                              | 0.1           | 3                      | picocell in open space environment |
| Pedestrian mode           | 4                                 | 2             | 3                      | Microcell                          |
| Vehicle                   | 150                               | 13            | 120                    | Macrocell                          |

■ see page 31 of ETSI TR 101 120 report for test environments

# Impulse Response, rural farmland

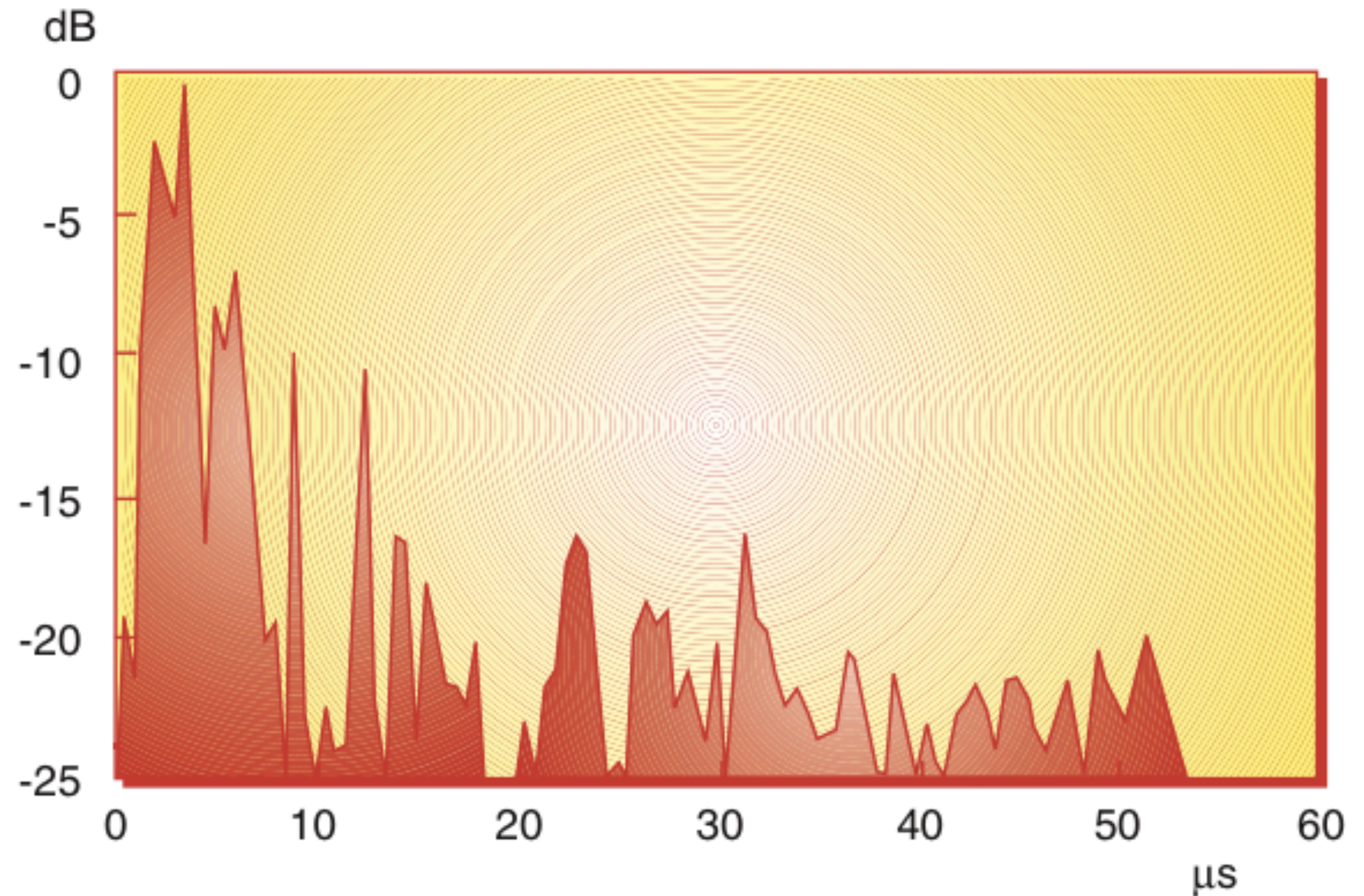
- 1718 MHz.  $P_{\{RX\}} = -84$  dBm,
- 20 dB above GSM sensitivity level
- Q (all impulse responses):
  - describe characteristics of reflection
  - from delay, calculate reflection factor and free space attenuation



[Source: R Rækken, G. Løvnes, Teletronikk]

# Impulse Response, rural farmland

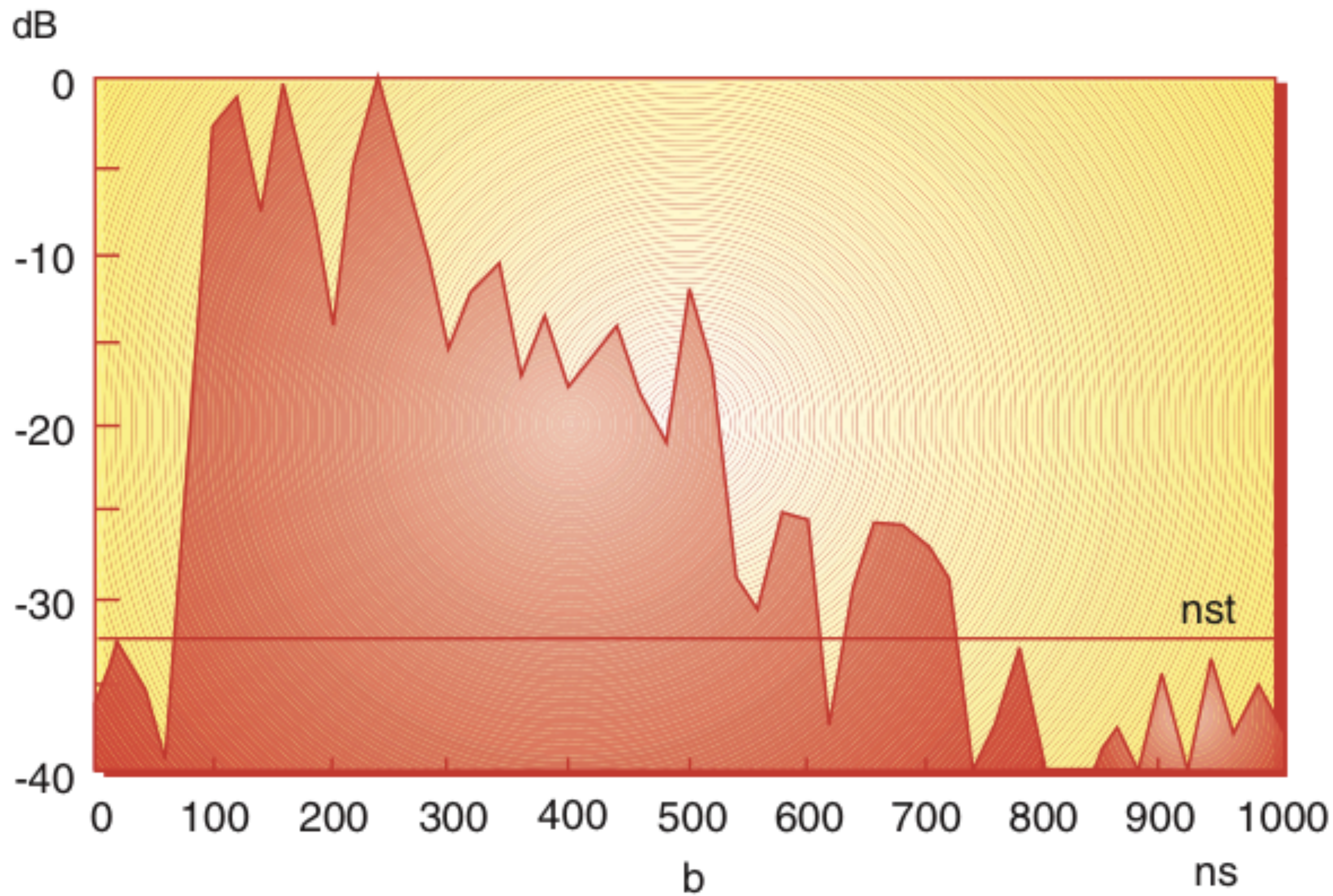
- 953MHz.
- Total received power was  $< 93\text{dBm}$
- Q (all impulse responses):
  - describe characteristics of reflection
  - from delay, calculate reflection factor and free space attenuation



[Source: R Rækken, G. Løvnes, Teletronikk]

# Impulse Response, Urban Measurements

- 1950 MHz, Oslo.
- Output power 25 dBm
- Q (all impulse responses):
  - describe characteristics of reflection
  - from delay, calculate reflection factor and free space attenuation
  - why almost equal distribution?
  - Physical effects?



[Source: R Rækken, G. Løvnes, Teletronikk]

# How did we measure?



# ETSI urban pedestrian

$$L_{pedest}[dB] = 40\log r + 30\log f + 49$$

- Outdoor to indoor and pedestrian test environment, based on Non LOS (NLOS)
- Base stations with low antenna height are located outdoors, pedestrian users are located on streets and inside buildings and residences
- TX power is 14 dBm,  $f = 2000$  MHz and  $r$  is distance in m
- Assumes average building penetration loss of 12 dB
- Q: Difference to Free space propagation model?

# COST Walfish-Ikegami Model

- propagation over roof tops
- assumes antennas below roof top

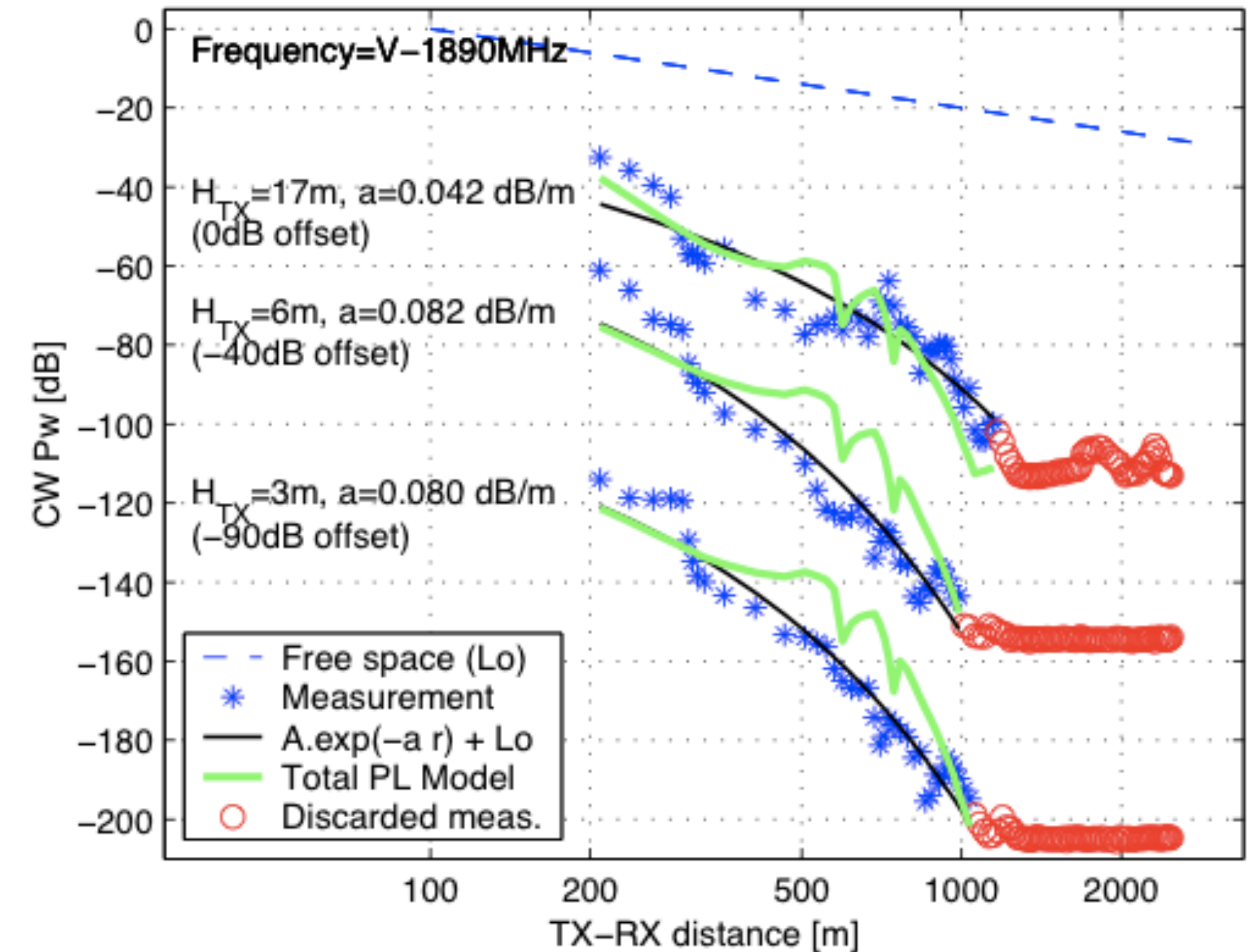
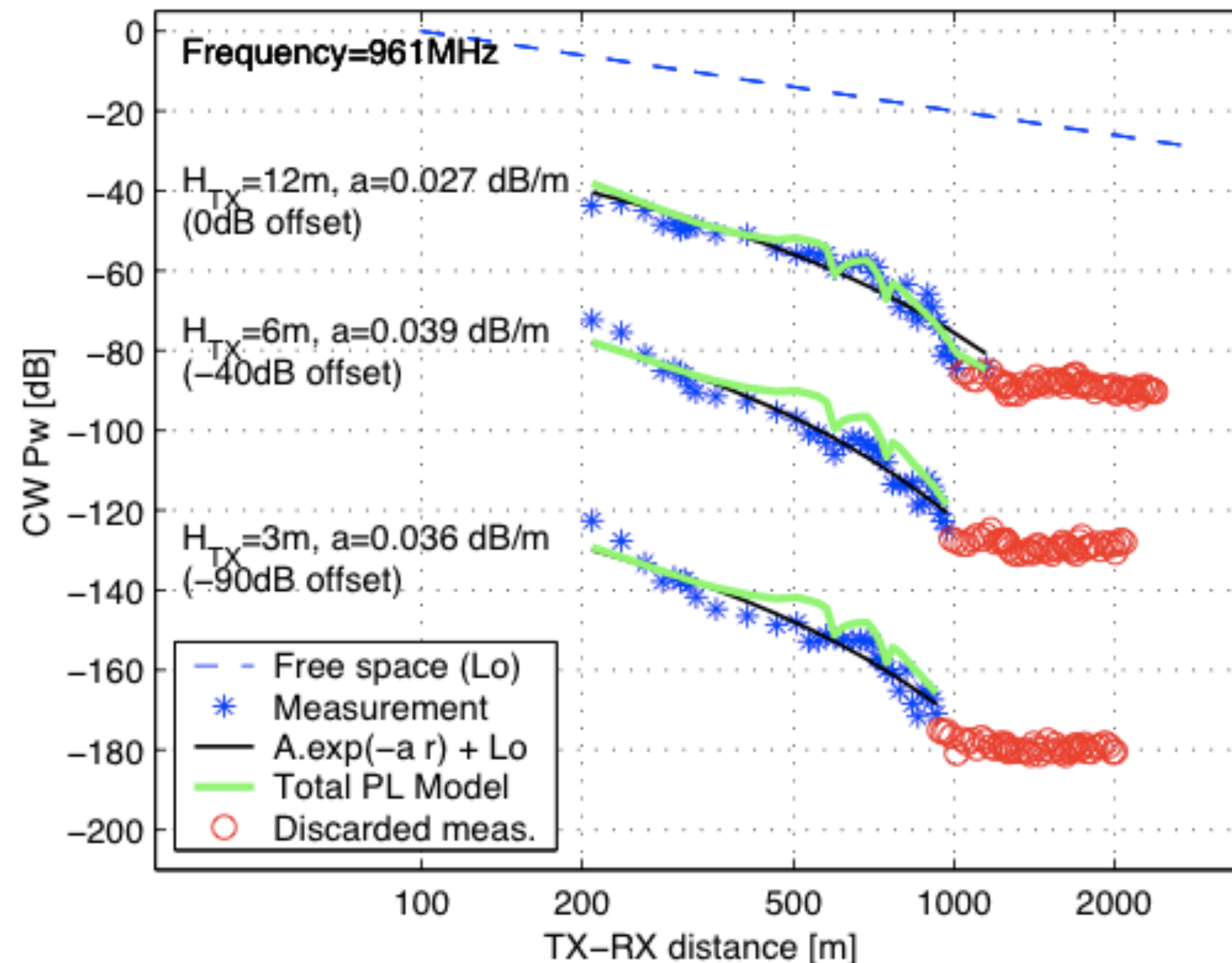
$$L_{rooftop}[dB] = 45\log(r + 20) + 24$$

# ETSI vehicular

- large cells, typical few km
  - TX power 24 dBm for mobile phone,
  - transmit antenna height  $\Delta h$  over roof top (typical 15 m),
  - distance  $r$  in km,
  - $f = 2000 \text{ MHz}$

$$L_{vehicular}[DB] = 40(1 - 4 \cdot 10^{-3} \Delta h) \log r - 18 \log \Delta h + 21 \log f + 80$$

# Forest, Path Loss $L$ , slightly hilly terrain, forest



(Source:István Z.Kovács,Ph.D.Lecture,CPK, September6, 2002;p.27/45 )

# Exercise

- establish table (L free space, pedestrian, outdoor vehicular) with typical values
- $f = 900 \text{ MHz}$ ,  $f = 2000 \text{ MHz}$
- $r = 100 \dots 3000 \text{ m}$

# ETSI indoor office environment

- $r$  is transmitter-receiver distance in m;
- $n$  is number of floors in the path
- path loss  $L$  should always be more than free space loss. Log-normal shadow fading standard deviation of 12 dB

$$L_{indoor}[dB] = 37\log r + 18.3n^{((n+2)/(n+1)-0.46)}$$

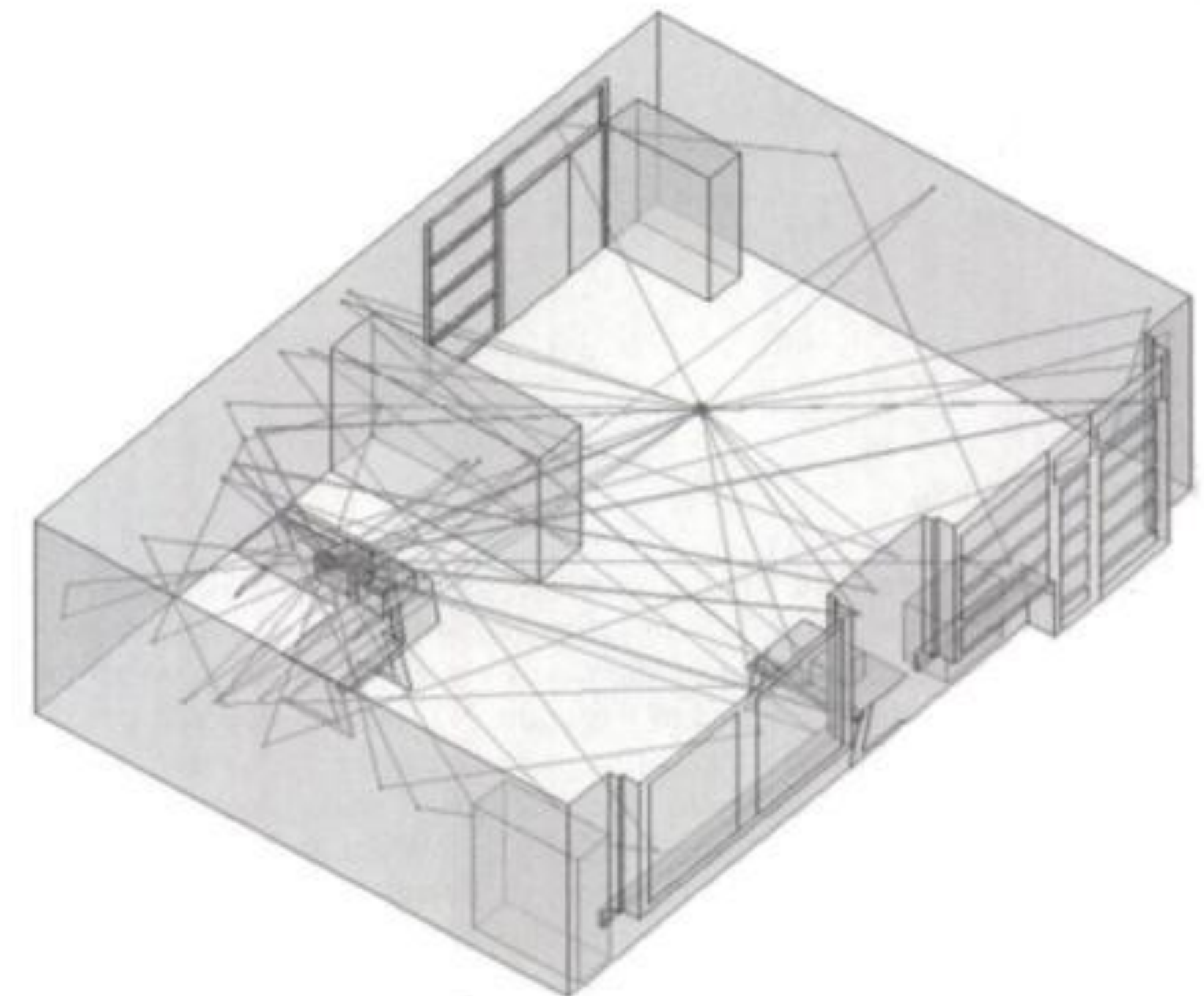
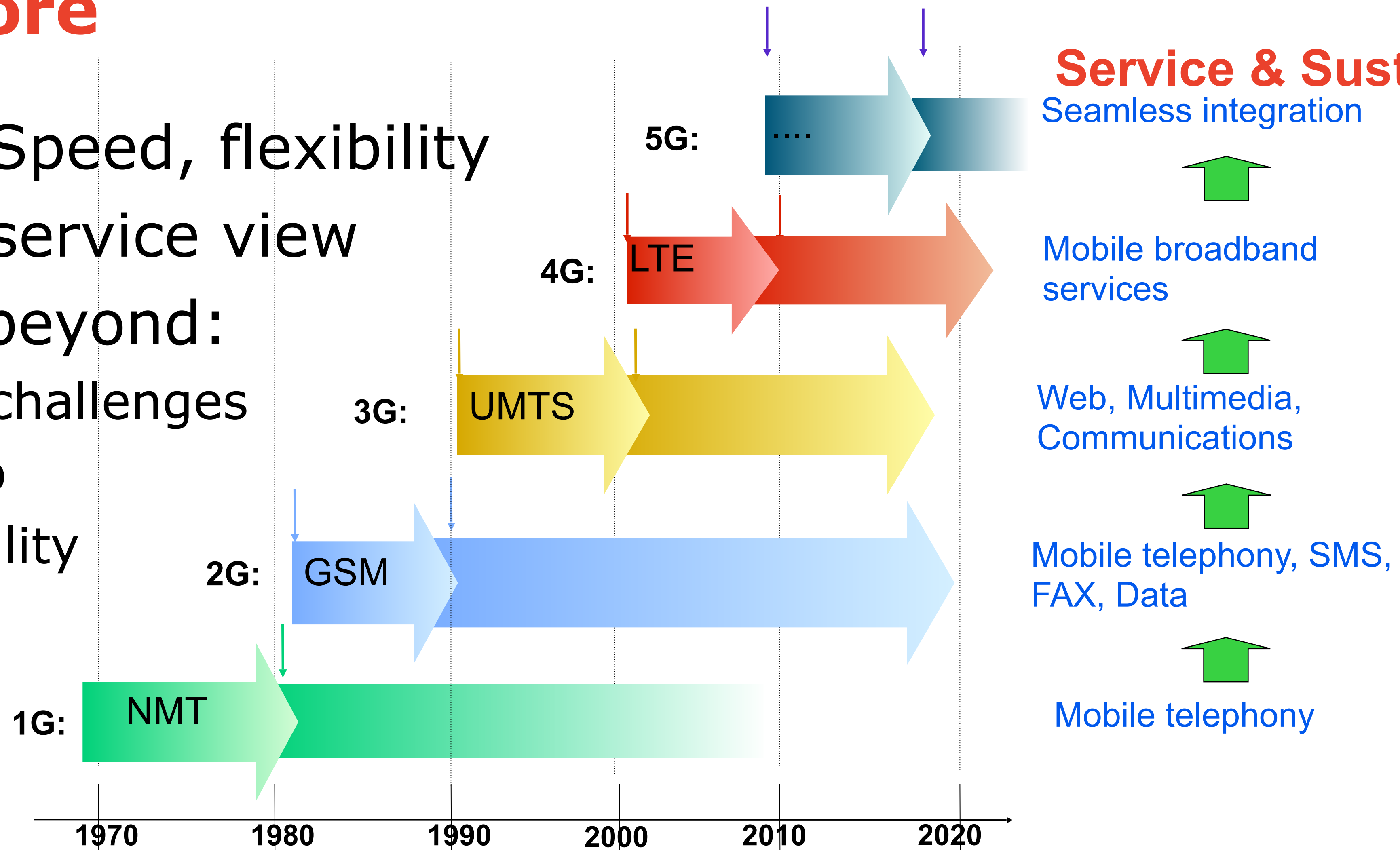


Fig. 7.26. Ray tracing in indoor environment

# 5G: Speed, Bandwidth, latency and much more

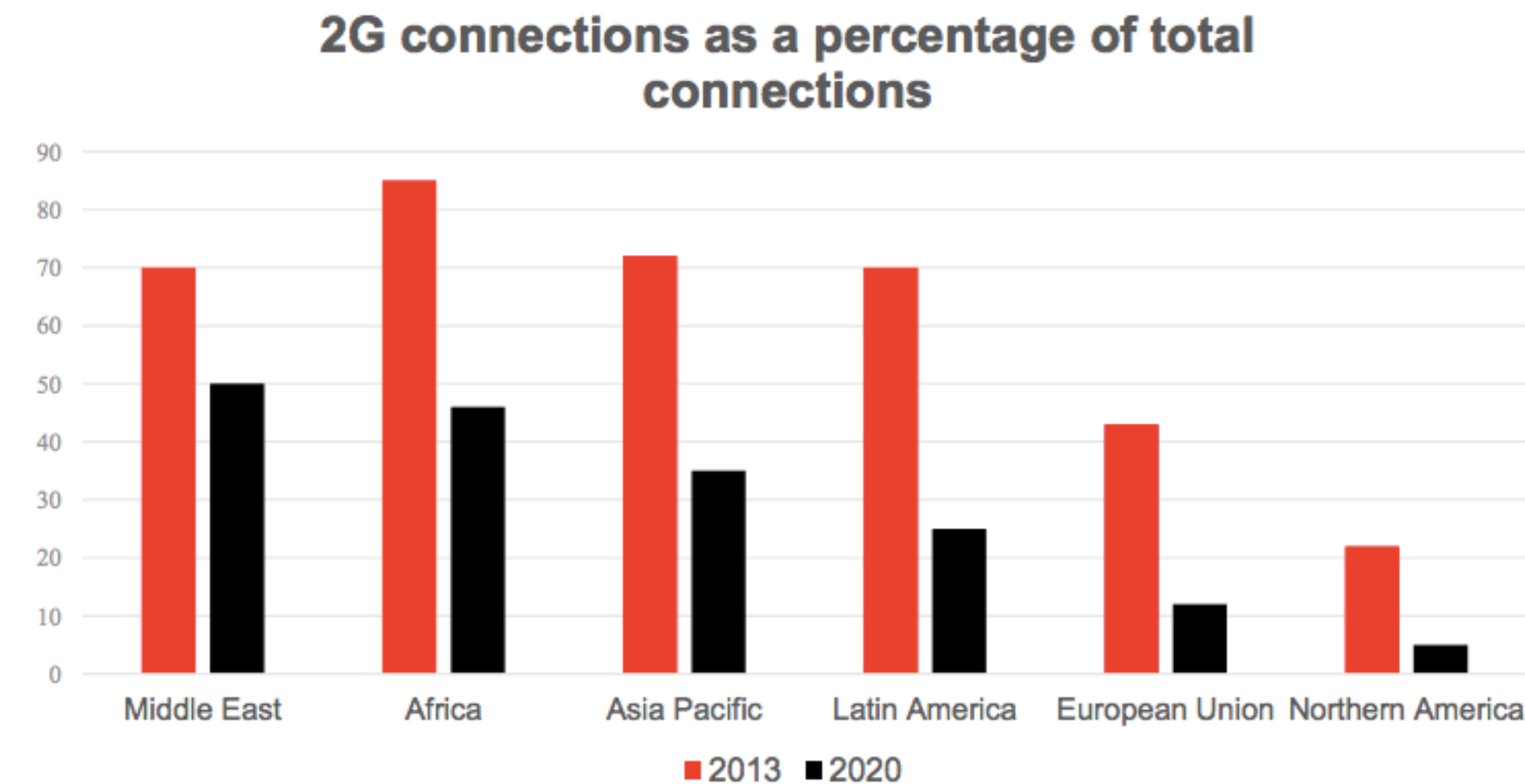
- 1G-3G: Speed, flexibility
- 3G-4G: service view
- 5G and beyond:
  - Business challenges
  - ownership
  - sustainability



[adapted from Per Hjalmar Lehne, Telenor, 2000]

# The challenge of area coverage

- Land area Norway, 385.178 km<sup>2</sup> - 7500 basestasjons
- <http://www.mynewsdesk.com/no/telenor/pressreleases/sjekk-naar-du-faar-4g-der-du-bor-1399662>
- Tanzania 947,303 km<sup>2</sup> = 3 x Norway,
- Mali 1.240.000 km<sup>2</sup> = 4 x Norway
- DR Congo 2.345.000 km<sup>2</sup> = 8 x Norway
- Economy in building Wireless Broadband
  - #5Gforall - *Discuss*



# Upcoming Topics

# Upcoming Topics / To do for next week

## Upcoming Topics

→ Measurement of radio propagation

## To Do:

→ Ideas for Group Work

→ State-of-the-art Literature papers

# L3 - Propagation take away

- Free space propagation equation
  - real-world changes
  - reflection, scattering, diffraction,...

$$P_r = P_t G_t G_r \left( \frac{\lambda}{4\pi r} \right)^2$$

Receive Power

Shannon

$$C = W \log_2(1 + P/N) \text{ [bits/s]}$$

Capacity      Signal-to-Noise

- Shannon & MIMO
  - Signal to Noise (SNR)
  - MIMO
- Impuls response characteristics

