Technical Challenges of Wireless Networks

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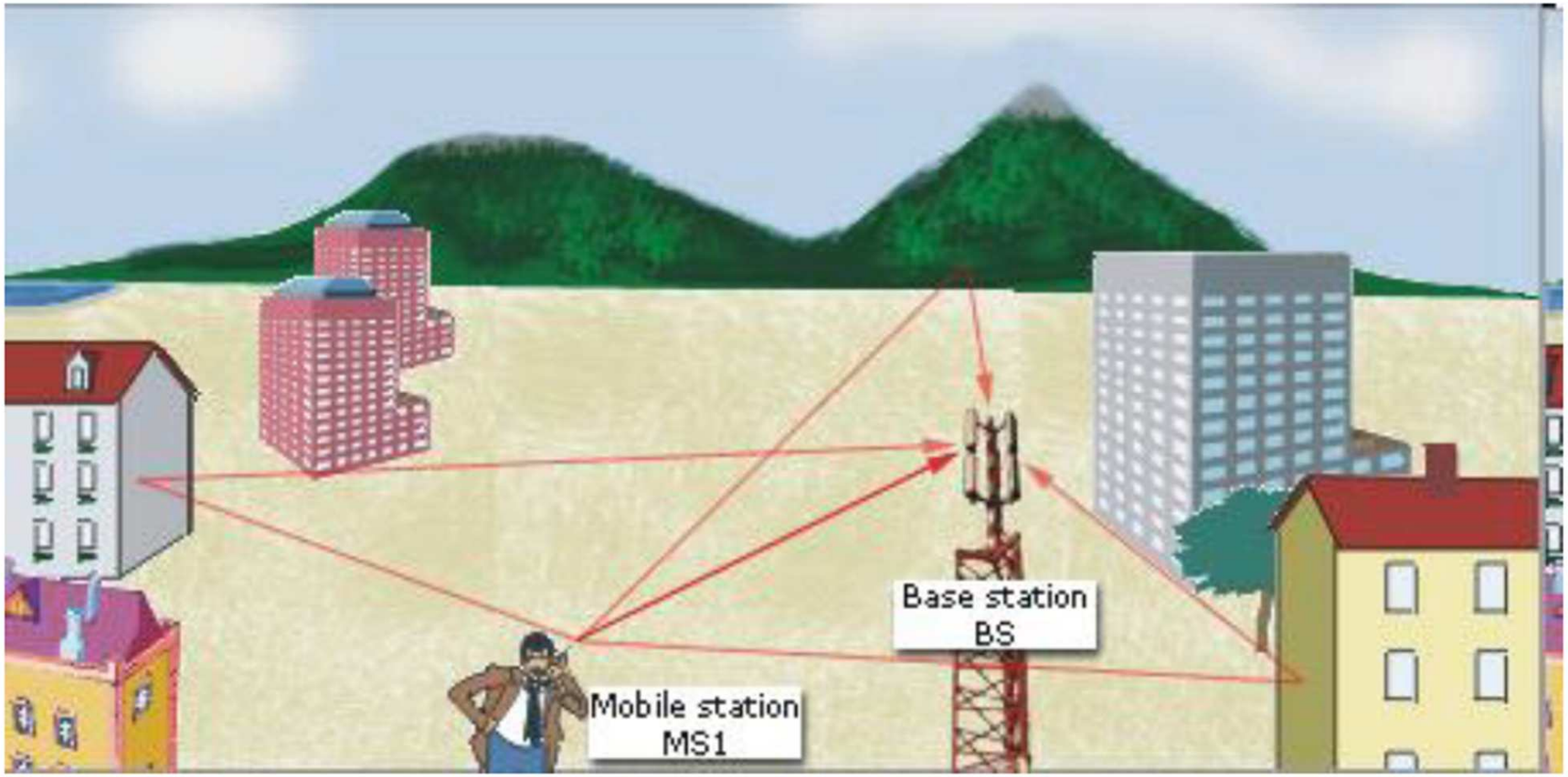
Comparison of Wired & Wireless Communications

Wired Communications	Wireless Communications
Time-invariant Medium	Time-variant Medium
Adding capacity is easy (add a new cable)	Available spectrum is limited
Range is only limited by attenuation	Range is limited by the medium (attenuation, fading, signal distortion) and spectral efficiency.
Interference is rare	Interference is common
Delay is constant	Delay is time-variant (TX-RX distance)
BER decreases almost exponentially with increasing SNR.	BER decreases slowly with increasing SNR.
Jamming & interception is almost impossible	Jamming & interception is easy.
Usually not energy limited	Usually energy limited

Technical challenges of wireless communications

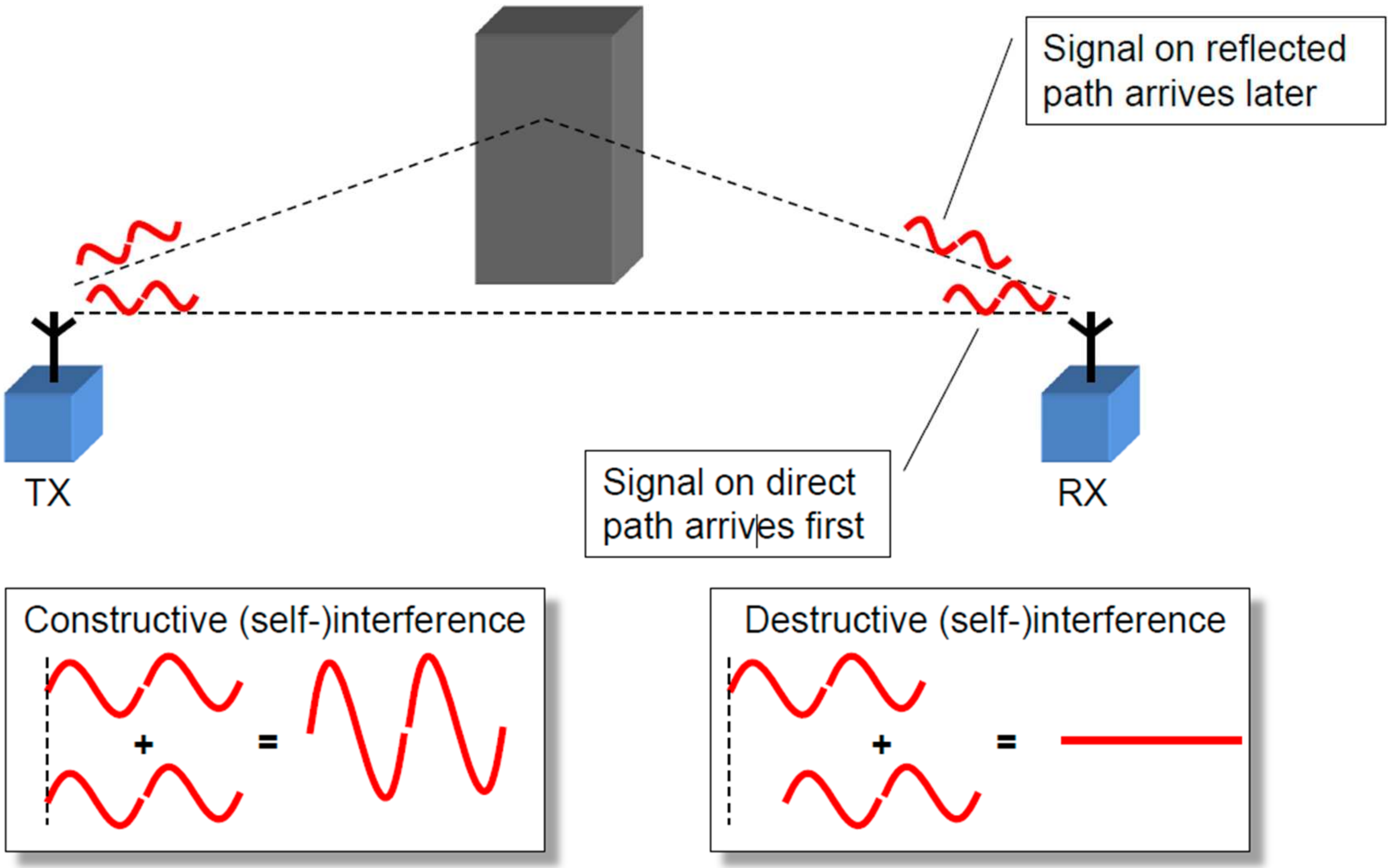
- **Multipath Propagation**
  - Fading
  - Inter-symbol Interference
- **Spectral Limitation**
- **Limited Energy**
- **User Mobility**

Multipath Propagation

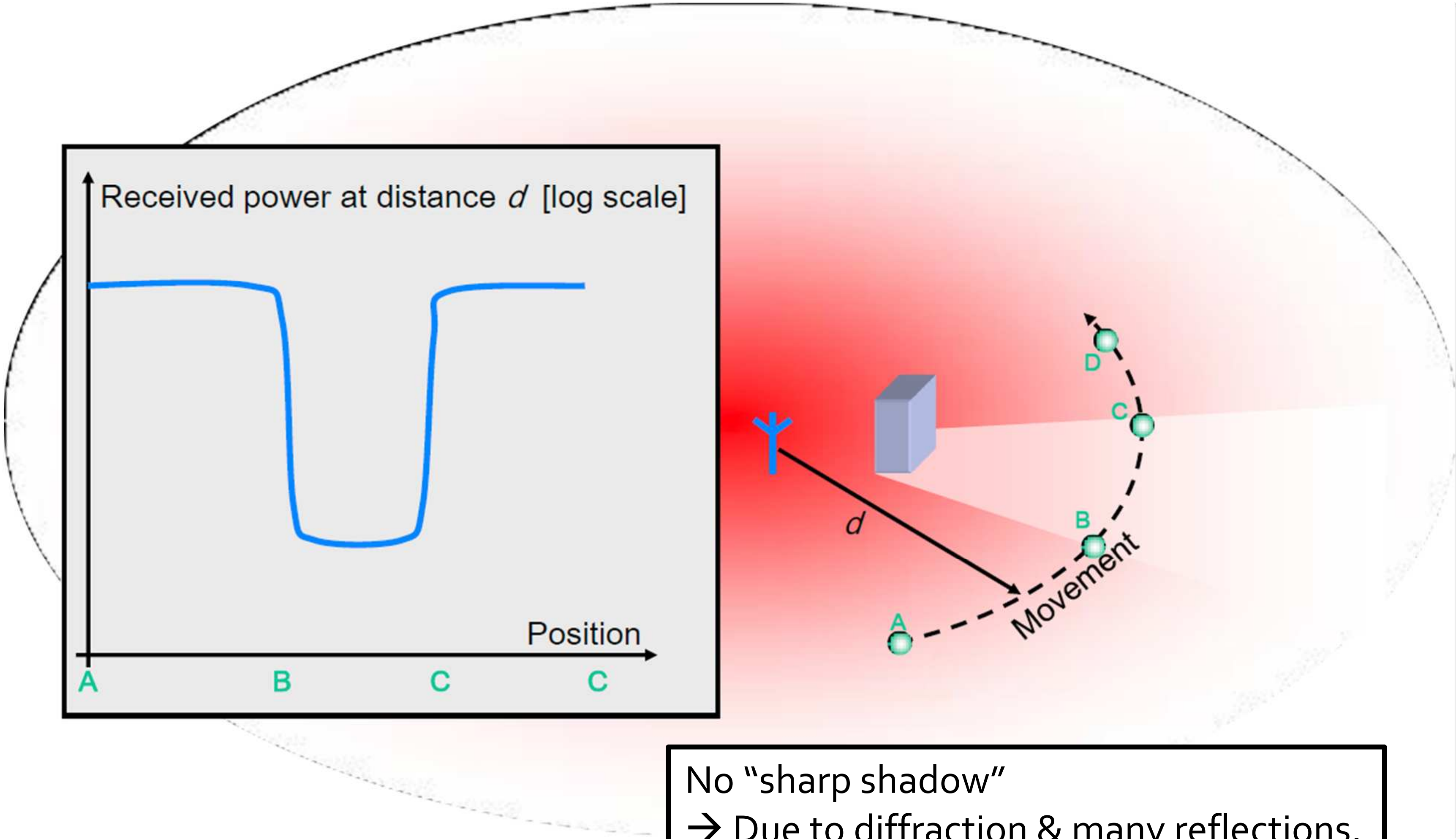


RX just sums up all Multi Path Component (MPC).

Small-scale Fading



Large-scale Fading

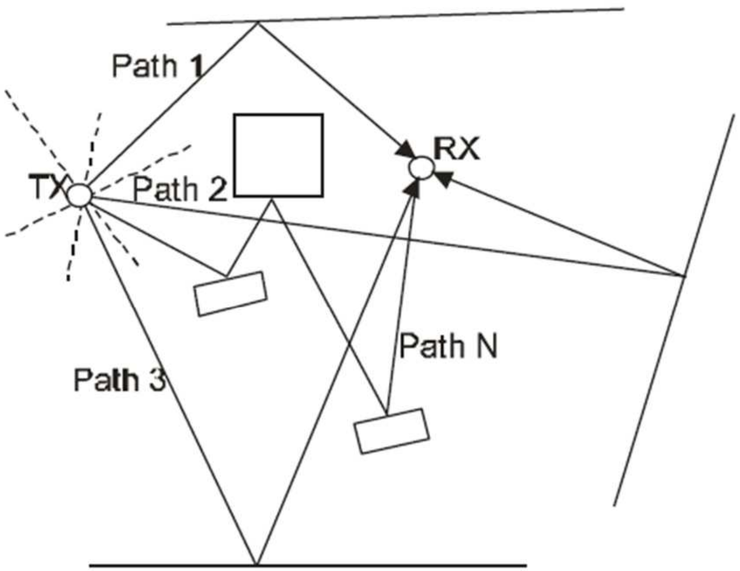


No "sharp shadow"
→ Due to diffraction & many reflections.

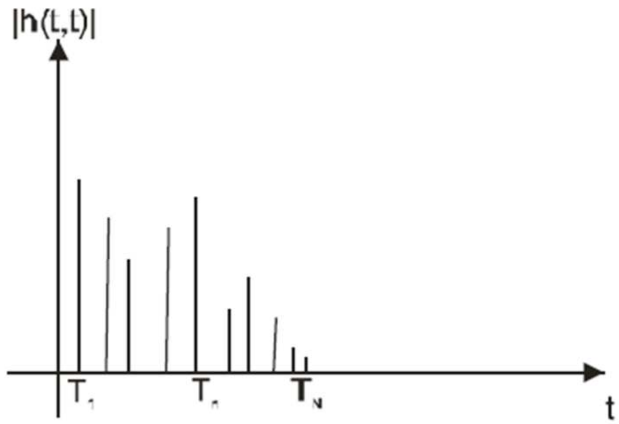
Consequences of Fading

- Error probability is dominated **by probability of being in a fading dip**
- Error probability decreases only linearly with increasing SNR (will see this later in the semester)
- Fighting the effects of fading becomes **essential** for wireless transceiver design
- **Deterministic** modeling of channel at each point very **difficult**
- **Statistical** modeling of propagation and system behavior

Inter-symbol Interference

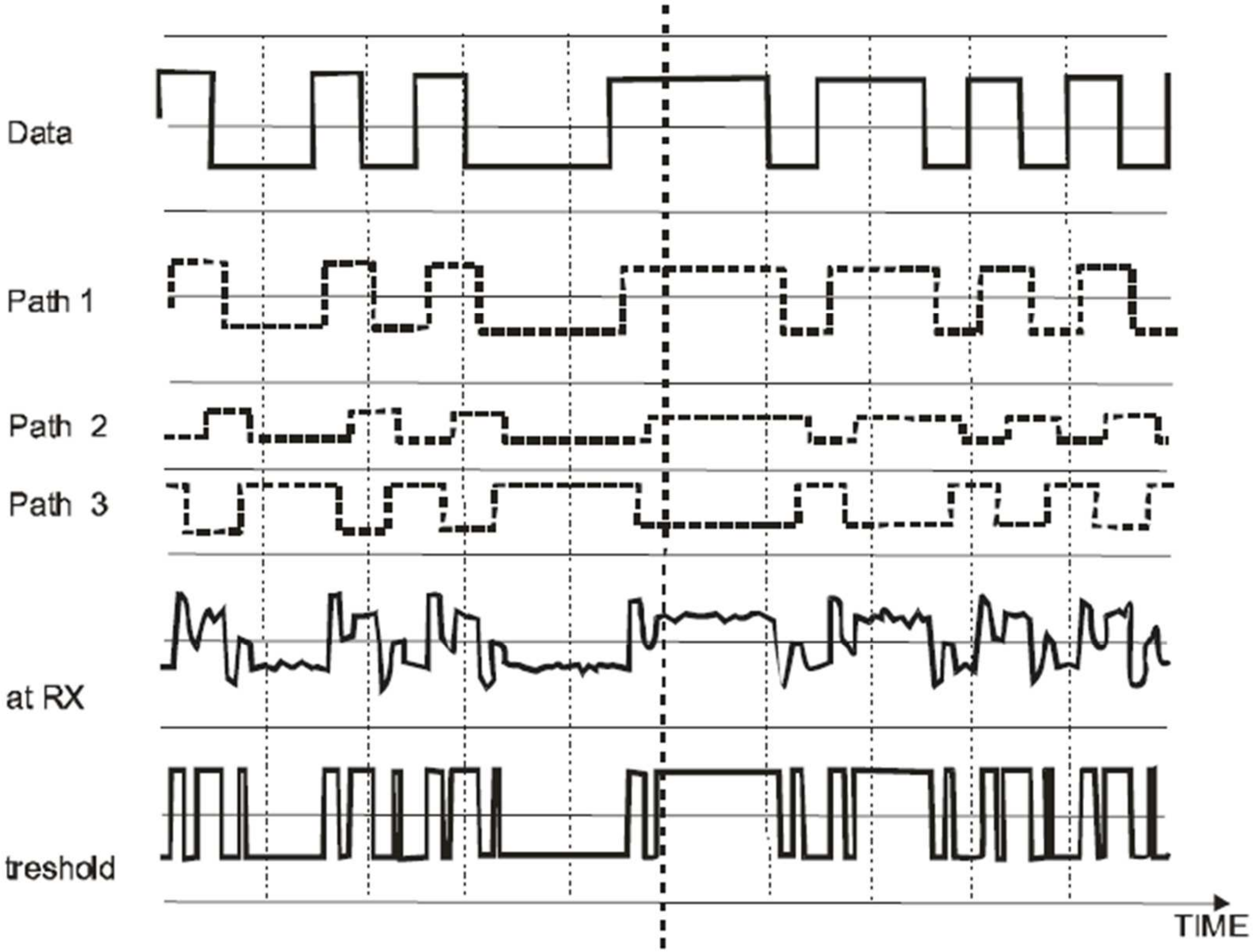


Multipath components with different runtimes



Channel impulse response

Inter-symbol Interference



Spectrum assignment

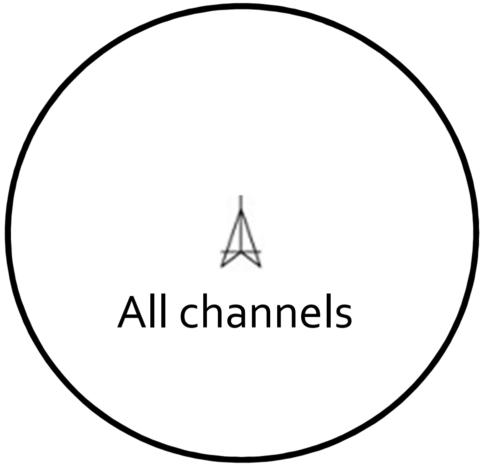
- <100 MHz: CB radio, pagers, and analogue cordless phones.
- 100-800 MHz: broadcast (radio and TV)
- 400-500 MHz: cellular and trunking radio systems
- 800-1000 MHz: cellular systems (analogue and second-generation digital); emergency communications
- 1.8-2.0 GHz: main frequency band for cellular and cordless
- 2.4-2.5 GHz: cordless phones, wireless LANs and wireless PANs (personal area networks); other devices, e.g., microwave ovens.
- 3.3-3.8 GHz: fixed wireless access systems
- 4.8-5.8 GHz: wireless LANs
- 11-15 GHz: satellite TV

1. High frequency → higher loss
2. High frequency → available bandwidth is larger

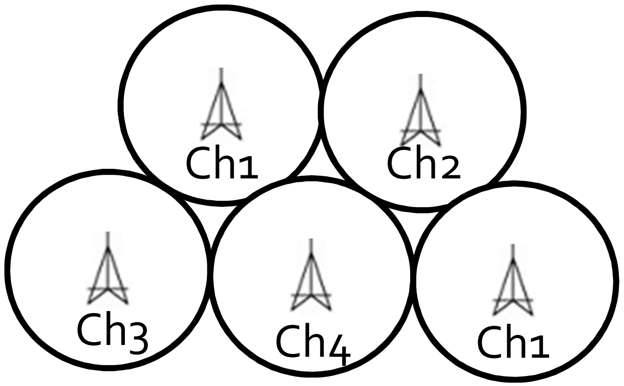
Frequency reuse

- Available spectrum is limited
- → the same frequency (range) has to be used at many different locations
- Regulated spectrum:
  - a single operator owns the spectrum, and can determine where to put TXs
  - cell planning so that interference adheres to certain limits
- Unregulated spectrum:
  - Often only one type of service allowed,
  - Nobody can control location of interferers
  - Power of interferers is limited by regulations

Example:
Cellular Network



- **Why do we need to create lots of cells?**
- **Maximum number of active users = number of available channels**
  - No way to increase the "capacity"
- **Note: wireless transmissions in different channels (frequencies) will not affect each other**
- **So we create lots of smaller cells …**
  - Each cell uses the same set of channels?
  - Co-channel (inter-cell) Interference
  - Final solution: divide the channels into groups, Reuse when BS's are **far enough apart**.
  - Think about the trade-offs
    - Cell size, hand-overs, interference



Limited Energy

- **Power amplifiers: linear v.s. non-linear**
  - Non-linear amplifiers have > 50% efficiency. Linear amplifiers do not.
  - Implications: "signal format" (modulation)
- **Signal processing components**
  - CMOS: slower, but energy-efficient
  - ECL: faster, but energy-hungry
- **Receive Sensitivity: minimum required received power**
  - GSM BS: -100 dBm
  - If -80 dBm (100 times larger):
    - TX power is 100 times larger
    - Battery has to have 100 times more capacity
    - 200g → **20 kg!**

Example:
Wireless Sensor Networks

1. $E_{rx} \approx E_{tx} >> E_{idle}$

Operation	Current consumption at 3V
Radio Transmitting	17.4 mA
Radio Receiving	18.8 mA
Microprocessor	6 mA
Radio Idle + Microprocessor Idle	**0.0002 mA**

2. $E_{tx,0} > E_{tx,-5} > \ldots > E_{tx,-25}$

- Lower transmission power → power control
- Communication Reliability!

Transmission Power	Current consumption at 3V
0 dBm	17.4 mA
-5 dBm	13.9 mA
-10 dBm	11.2 mA
-15 dBm	9.9 mA
-25 dBm	**8.5 mA**

User Mobility

- **User can change position**
- **Mobility affects wireless channels (fading)**
- **Example: cellular network**
  - The system needs to be aware of the user's position (which BS?)
  - Home Location Register (HLR): central user location database
  - Visitor Location Register (VLR): BS's local user database
  - Hand-over:
    - User moves from one BS's coverage to another BS's coverage
    - Need to update the VLR/HLR
    - Trade-offs? (smaller cell size?)