A key parameters based vision of trends in Wireless systems

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Outline

- What do we speak about ?
- Tradeoff between key parameters
- Technology progress
- From low-end to high-end technologies
- Conclusion

What do we speak about ?

- **Key parameters: data rate – power – propagation loss**
  - Data rate can be traded against radiated power: **the energy/bit is a KPI**

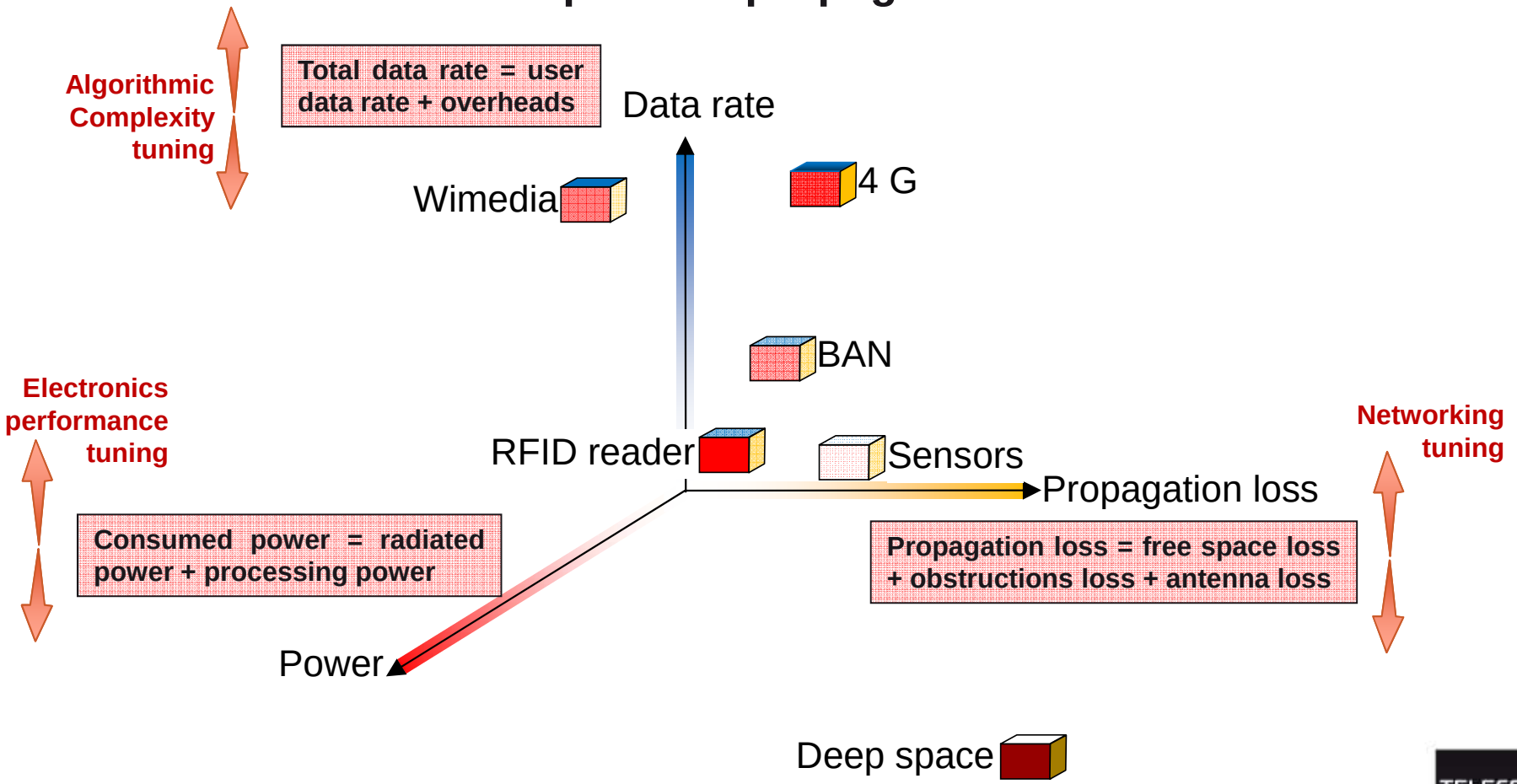
data rate ↗ ⇒ power ↗

  - Data rate can be traded against propagation loss: by increasing the distance, there is less energy available/bit

  - Power can be traded against propagation loss: for a given data rate, less transmitted power reduces the correct reception distance (trivial)

What do we speak about ?

- **The data rate – power – propagation loss tradeoff**



What do we speak about ?

How do we use the resource

- Wireless signals occupy a certain spectral band. This resource is expensive. Do we use it well ?

➔ **Concept of spectral efficiency (bits/second/Hertz)**

- Shannon maximum capacity (bits/s) $C = B \cdot \log_2\left(1 + \frac{P_{received}}{Noise\ \ power}\right)$

Band width (Hz)

$$P_{received} = B \cdot PSD_{received} \qquad Noise\ \ power = B \cdot N_0$$

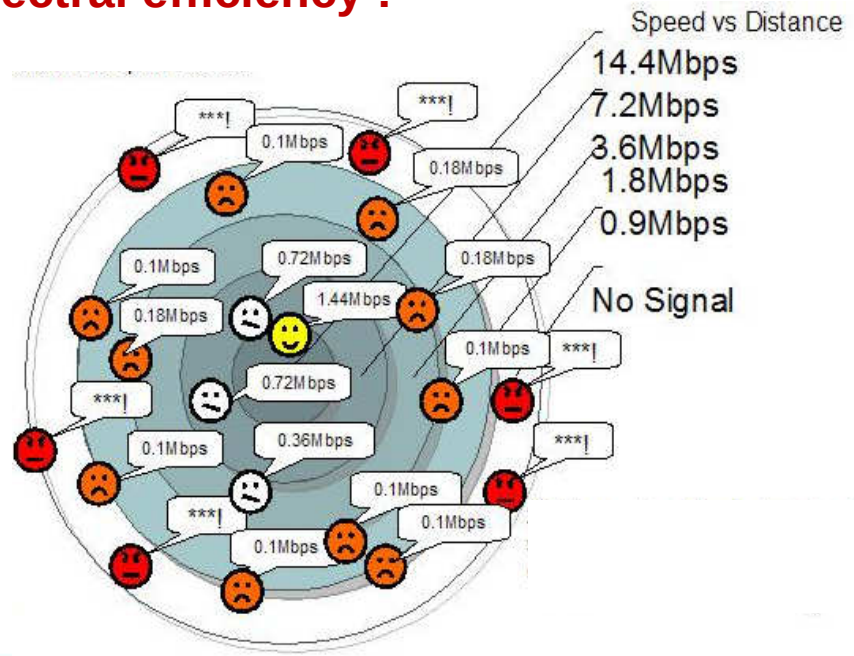
➔ $C = B \cdot \log_2\left(1 + \frac{PSD_{received}}{N_0}\right)$ Max. spectral efficiency

➔ **The maximum SE is limited by the SNR (logarithmically)**

What do we speak about ?

- **Cell center vs. cell edge throughput**
  - Since the received power is small far from the base station, the effective throughput is low !

➔ **Big lag between maximum spectral efficiency and mean spectral efficiency !**

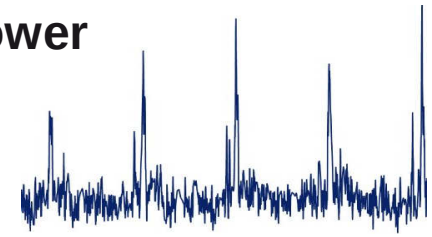


What do we speak about ?

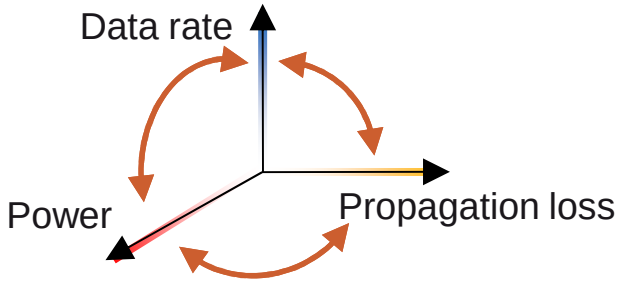
- **Asymmetry**
  - Most often the devices at both link ends differ in their capabilities/performance/complexity/power consumption
  - Most often spectral efficiency and data rate are higher in DL than UL
  - ➔ **UL and DL spectral efficiency differ**

- **Duty cycle**
  - The radiated signals are often bursty:

low **average power**, high **peak power**



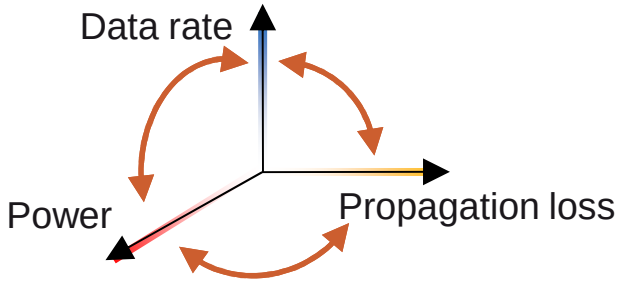
Tradeoff between key parameters



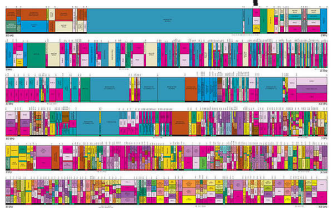
- **The tradeoff is a matter of specifications / constraints**
  - How much power is available ? (also a tradeoff vs. Battery capacity and required lifetime)

  - What is the needed data rate ? (application dependent)

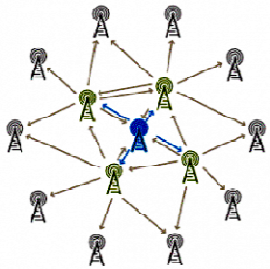
Tradeoff between key parameters



- **The tradeoff is a matter of specifications / constraints**
  - What is the allowed transmission power ? (regulation spectral masks)



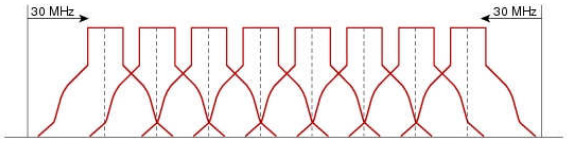
  - What is the acceptable device / access points density (max. distance)

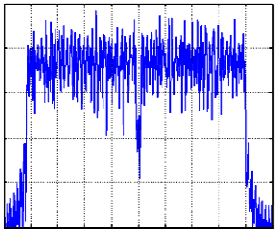


Technology progress

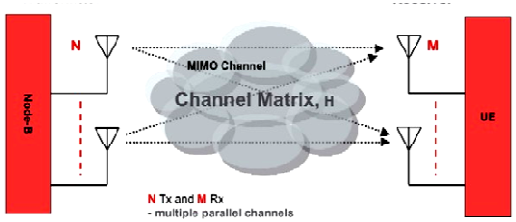
- **How to shift / turn around the tradeoff ?**
  - Improve data rate under fixed power/propagation loss: increase the **spectral efficiency (b/s/Hz) – closer to Shannon – :**
    - OFDM (already in many standards): efficient use of the spectrum

    1bps/Hz, 2bps/Hz… 12 bps/Hz, **reduced by overhead**





    - Multiple antennas (MIMO): may multiply the spectral efficiency by the number of antennas … **BUT : may consume processing power**



Technology progress

- **How to shift / turn around the tradeoff ?**
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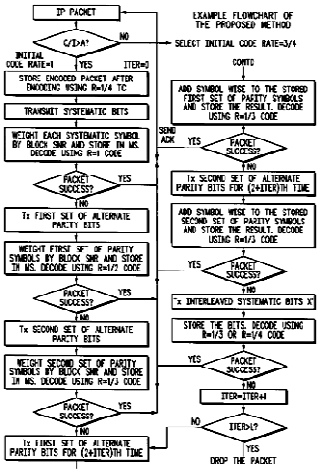
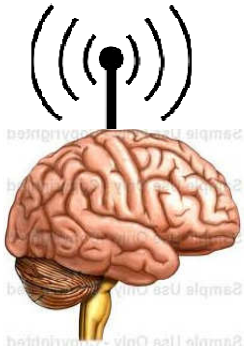


- Advanced coding schemes: to reduce the energy/bit at a given error rate
  - Turbo codes, LDPC… **BUT : may consume processing power**

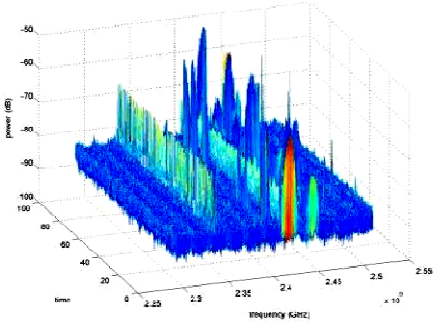
- Flexible, adaptive techniques (crosslayer, link level…)

Technology progress

- **How to shift / turn around the tradeoff ?**



- Make a better use of the spectral resource: fill the gaps, opportunely benefit of available spectrum:
  - Cognitive radio and dynamic spectrum access: future networks, cellular / local …

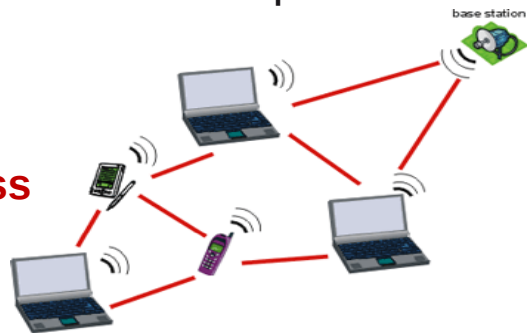


  - Spectral bands agregation: use of several bands simultaneously

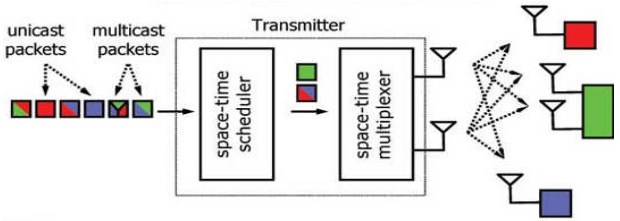
  - Use of higher frequencies: 60 GHz
    ➔ enormous band width, excellent frequency re-use

Technology progress

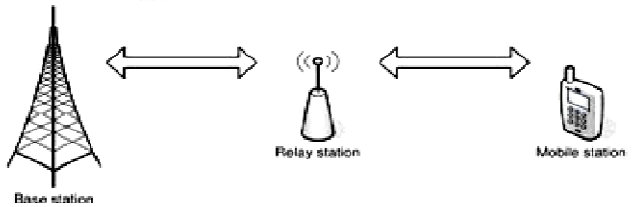
- **How to shift / turn around the tradeoff ?**
  - PHY/link/Network level advanced techniques:
    - Cooperative communications
      ➔ **improves link robustness**



    - Multi-user communications
      ➔ **improves agregated throughput**



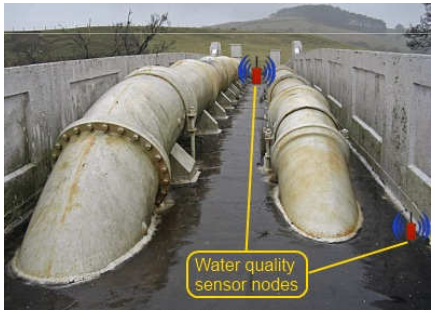
    - Relaying, BST cooperation
      ➔ **reduces propagation loss**

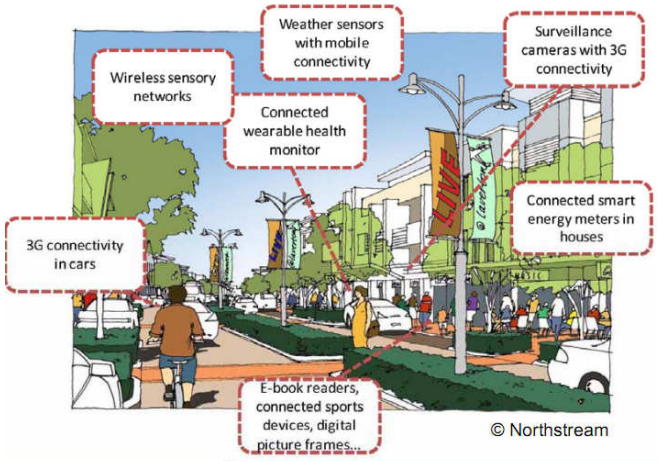


From low-end to high-end technologies

- **Some examples / trends / upcoming technologies**
  - « Low end »: sensors in houses, smart cities/grids, industrial premises... **very low power & data rate** (kb/day), UHF down to VHF
    - No battery, low processing power, low cost, green technologies…

M2M

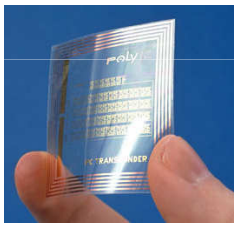


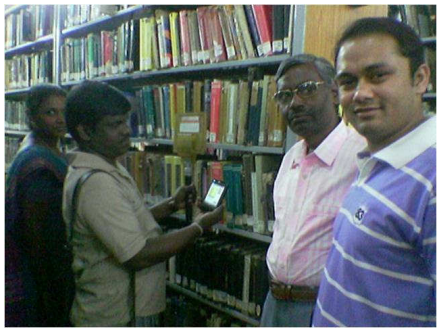


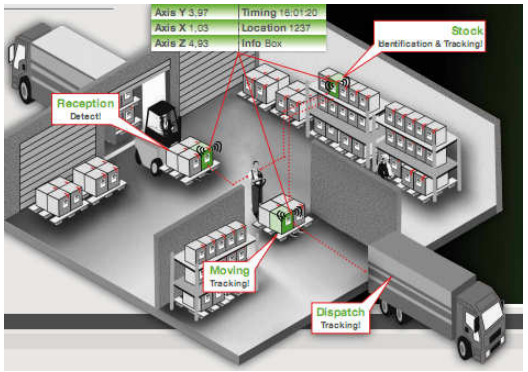
From low-end to high-end technologies

Some examples / trends / upcoming technologies

- « Low end »: RFID
  - UHF(865-960 MHz, < 2W radiated): active reader, passive tag: from kbps to ~100 kbps, ~5 m detection range, ➔ **EPC Gen2**
  - Microwave (2.4 GHz, <1 mW radiated) : active reader, passive or active tag: from kbps to ~1000 kbps, ~10-100 m detection range, ➔ **6loPAN**
  - UWB (~3-5, 6-8.5 GHz, <0.2 mW) active reader, passive or active tag: from kbps to ~250 kbps, ~10-100 m detection range, ➔ **802.15.4a, location enabled**



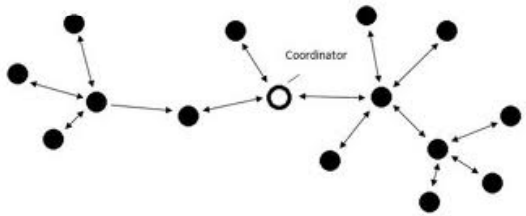




From low-end to high-end technologies

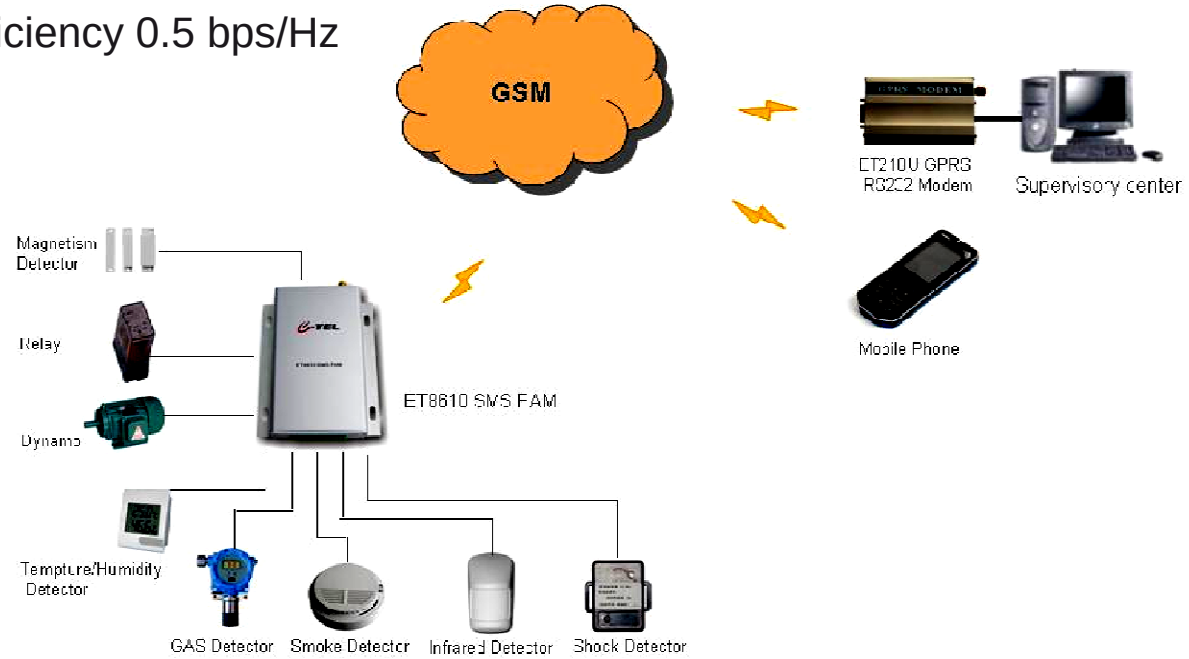
- **Some examples / trends / upcoming technologies**
  - « Low-end »: **the main target is low power (batteryless), low cost, interference management, multipath fading, NOT spectral efficiency as such**

    ➔ very low duty cycle protocols, compressed sensing, energy harvesting…



From low-end to high-end technologies

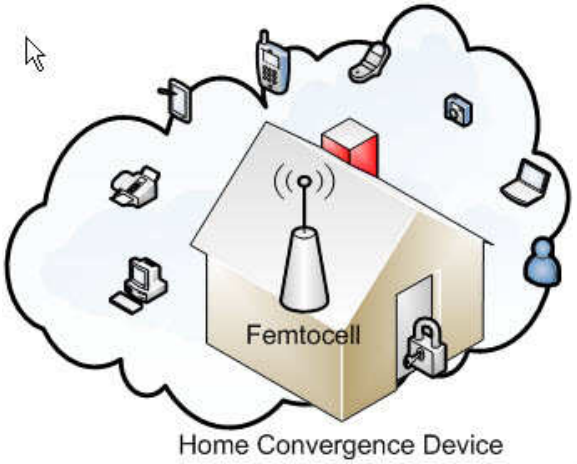
- **Some examples / trends / upcoming technologies**
  - « medium-end »: GSM/GPRS/EDGE. The plain old GSM is not dead: still many virtues (cost, coverage…) for e.g. home & industrial automation
    - Spectral efficiency 0.5 bps/Hz



From low-end to high-end technologies

- **Some examples / trends / upcoming technologies**
  - « medium/high-end »: WIFI, femtocell (<100 mW): gateway to internet + home multimedia platform
    - Spectral efficiency : **43 bps/Hz agregated SE in 160 MHz** (802.11ac, MU-MIMO) ➔ **up to ~7 Gb/s !**
    - Cognitive WIFI in white spaces (802.11af <1 GHz)

➔ Major issue: how to deal with interference ?



From low-end to high-end technologies

- **Some examples / trends / upcoming technologies**
  - « high-end »: UMTS → HSDPA → LTE → LTE-Advanced
    - Peak data rate 0.38 Mb/s → 14 Mb/s → 300 Mb/s → 1000 Mb/s
    - Peak spectral efficiency 0.4 bps/Hz → 8.4 bps/Hz → 16 bps/Hz → 30 bps/Hz (8x8 MIMO)
    - Future massive MIMO ?

  ➔ **A lot of work ahead on terminals, network architectures, green BST…**

Conclusion

- **Trends in wireless communications technologies:**
  - Play around the **tradeoff power/data rate/propagation loss**
  - Depends on the applications:
    - Wireless technologies become « diffuse »
    - Many very low power devices, low data rate
    - High-end networks for interconnected media devices and internet gateway
  - Densification of the network: access points, femtocells: mostly (by far) contributes to the total b/s capacity ; **lower radiated power, more smoothly distributed**
  - Progress in the technologies: **better use all wireless resources**, less waste of the expensive frequencies: more Mb/s for fewer Watts. Short term & long term progress to come


MUST HAVE SOMETHING TO DO WITH WIRELESS TECHNOLOGY...