5G: Building a European Digital Society
Wireless data growth

Future Network Traffic Growth
• 38% annual data traffic growth
• Slightly faster than in the past!

Network Throughput = Available Spectrum x Cell Density x Spectral Efficiency

bits / s / km² × Hz × cell / km² = bits / s / Hz/cell

Exabyte/month

3.2 GB/month/person

410 MB/month/person

Source: 'Ericsson' (November 2014)

Exponential increase
Extrapolation: $5x$ in $5$ years
$25x$ in $10$ years
$125x$ in $15$ years

Martin Cooper's law
The number of voice/data connections has doubled every 2.5 years (+32% per year) since the beginning of wireless

Last 45 years: 1 Million Increase in Wireless Traffic

Two R way radio, FM/AM radio, satellites, cellular, WiFi, etc.

Source: 'Wikipedia
Cooper’s law: Spectrum utilization has doubled every 30 months last > 100 years

> 1 Million/60 Y
How was it done? Can it be continued?

- **Link Capacity**: 5X
  - Closing the gap with Shannon’s bound

- **More Bands**: 25X
  - Conquering the spectrum

- **Spatial reuse**: 1600X
  - Densifying the network

- **Frequency Division**: 5X
  - Improving the hardware
WILL DENSIFICATION BE THE DEATH OF 5G?

- Physical limits: interference
- Mobility constraints: handover complexity

[Courtesy, L. Van der Perre]
Prof. Jeffrey Andrews – UT Austin
The resurrection of 5G: a positive look at massive MIMO covering both throughput and implementation for sub 6GHz

[Courtesy, L. Van der Perre]
145.6 bit/s/Hz demonstrated!

Raw: 176 bit/s/Hz
  • 256 QAM, 22 users
  • 17% was lost for practical reasons.
  • 2 users omitted

4G IMT Advanced spec: 3 bit/s/Hz
Illustration of downlink Massive MIMO in line-of-sight communication

Massive MIMO = always MU-MIMO
5G in three main flavors: Massive MIMO for all!? 

**Coverage & Capacity**

- Operators
  - Anytime, anywhere, guaranteed
  - Expensive sites, exclusive licensing, Prime frequency bands

**Indoor Capacity**

- Building owners
  - Ultra dense deployment – interference & virtual ad hoc networking
  - No site cost, pay for backhaul (FFTH or wireless)
  - Unlicensed spectrum for access

**Massive & Critical**

- Thin operators
  - Extremely optimized for cost, power, reliability, delay
  - Few sites, long range
  - Prime unlicensed spectrum

- Operators
  - Anytime, anywhere, guaranteed
  - Expensive sites, exclusive licensing, Prime frequency bands

Indoor capacity: prime use case for mmWave

mmWave backhaul

mmWave (802.11ad) capacity

No mobility

Walled/no interference

Unbalance Traffic Distribution

Indoor 80%

Outdoor 20%
5G killer app???: from virtual reality to IoT

Billion Dollar Question: What is “Sufficient” Performance & Flexibility?

[after J. Zander]
WILL 5G BE A DESIGN NIGHTMARE?
H2020 project ORCA

Filling the gap between **high versatility** and **low latency** with real-time SDR

- **ASIC**
  - parallelization, quantization, debug, backend and chip processing, testing

- **FPGA**
  - parallelization, quantization, FPGA compilation and debug

- **DSP**
  - vectorization, calling intrinsic functions, debug

- **CPU (1)**
  - parallelization, debug

- **CPU (N)**
  - compilation and debug

- **DSP firmware coding**
  - vectorization, calling intrinsic functions, debug

- **Real-time SDR SW library & reconfiguration architecture**

- **Run-time latency**
  - < 10 μs
  - 10 μs
  - 1 ms
  - 30 ms
Conclusions

There are clear flavors in 5G

Diversity in technology (indoor, outdoor) and spectrum (bands, licensed versus unlicensed)

Massive MIMO (Europe) and mmWave trials (US) show technology maturity

Key challenge: system deployment with sufficient scalability and versatility... for the 5G killer app!