Wireless Communication Channels Lecture 11:Wireless channels and 5G

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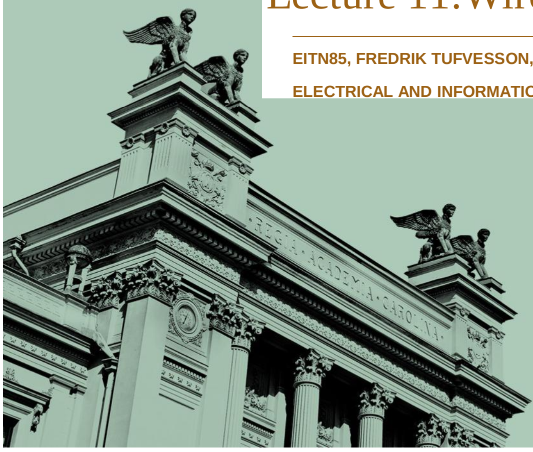
ELECTRICAL AND INFORMATION TECHNOLOGY



Mobile phone generations: 1G to 4G

1G: First generation of mobile telephony (~1980s)

2G: GSM standard. Encryption, SMS, MMS. Launched in 1991.

3G: Supports mobile broadband – initial rates of 200 kbps.
Later releases support several Mbps. Launched in 1998.

4G: Mobile broadband internet access to modems, laptops, etc.
Peak data rates of 100 Mbps even under high mobility.
Standardized as LTE (Long-Term Evolution) and WiMAX.
Launched in 2009 in Stockholm and Oslo.
Current LTE release: 13. Release 14 and 15 are under development.

What is 5G? Why is it needed?

- There is no current standard for deployment of 5G systems, and there are no mobile phones that support 5G.
- Aims of 5G:
  - Ø Tens of Mbps for ten thousands of users.
  - Ø 100 Mbps for metropolitan areas
  - Ø 1 Gbps for several workers on the same floor.
  - Ø 100,000's of simultaneous connections for sensors.
  - Ø Improved coverage and spectral efficiency.
  - Ø Reduced latency compared to LTE/4G.
- Several different techniques and systems are under consideration for use in future 5G systems.

5G: Uses cases envisioned by Nokia

http://resources.alcatel-lucent.com/asset/200010

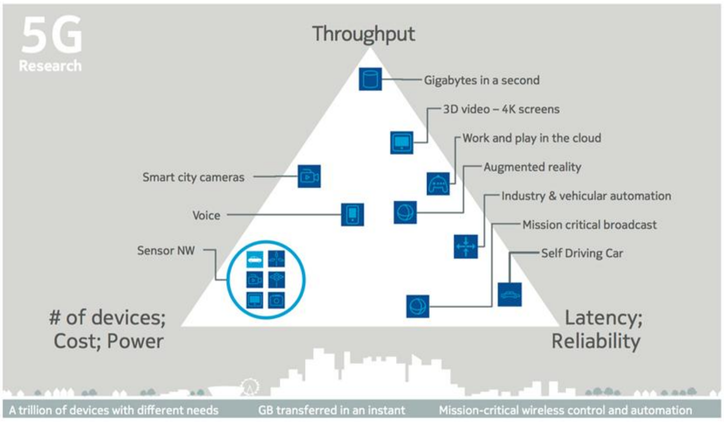


Figure 3: Diversity of services, use cases and requirements

5G: Uses cases envisioned by Ericsson

https://www.ericsson.com/5g/use-cases/sensors-measurement-and-report

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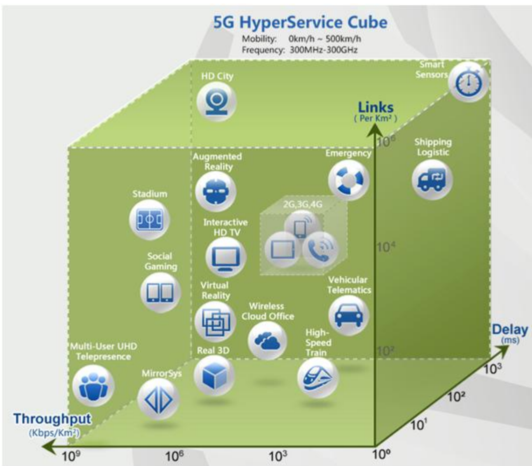
5G: Uses cases envisioned by Huawei

- http://www.huawei.com/5gwhitepaper/



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5G: Uses cases

5G covers many different use cases, with different demands:

- Low-latency, low data rates
- Ultra-reliable networks
- Ultra-dense networks (sensors, etc.)

- High data rates for cellular systems with many users
- Improved coverage and spectral efficiency

- Intelligent transport systems and V2V communication
- We will focus on techniques for cellular systems in this lecture.

5G: Above and below 6 GHz

We will distinguish between two different techniques:

- Massive MIMO for bands below 6 GHz.
- cm-Wave and mm-Wave bands for 5G above 6 GHz.

Massive MIMO below 6 GHz

The main idea behind Massive MIMO:

- Equip base station with ≥100 antennas
- Use spatial multiplexing to serve multiple users, i.e., multi-user MIMO (MU-MIMO).
- Users can be served using the same time-frequency resources (at the same time and at the same frequency).

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Massive MIMO below 6 GHz

Youtube video describing the principle behind MaMIMO.

The BS transmits orthogonal pilots to each user.
Then, the channel is estimated to each user.

By doing this, the users can be separated.

Compared to LTE techniques:
Can improve spectral efficiency by > 10 times.
Can improve energy efficiency by > 100 times.

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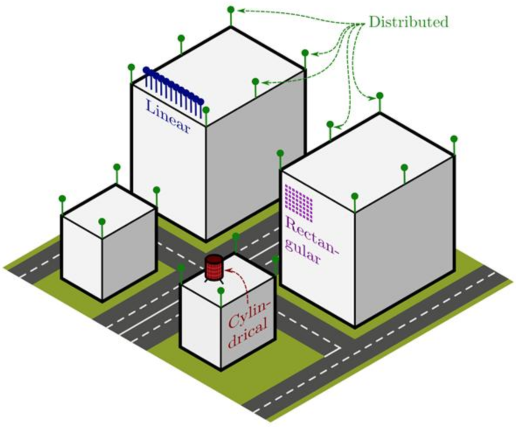
Massive MIMO below 6 GHz

Different array configurations can be used:



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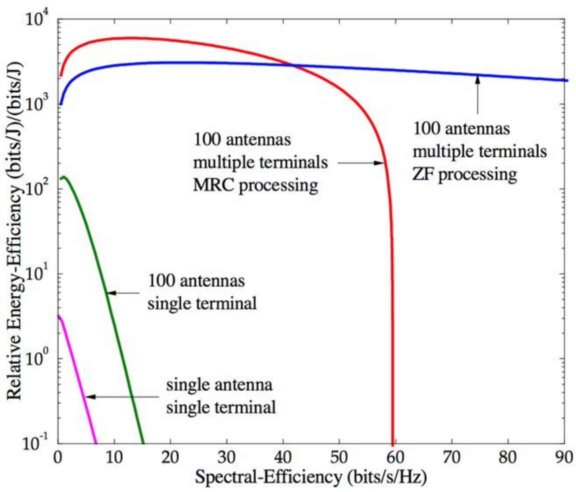
Massive MIMO below 6 GHz



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Massive MIMO: World record

Researchers at Lund University and Bristol University set a world record in spectral efficiency:

145.6 bits/s/Hz for 22 users, with a 20 MHz shared bandwidth.

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Lund Massive MIMO testbed

LuMaMI – Lund University Massive MIMO testbed.

Real-time MaMIMO data transmission.

100 coherent RF transceiver chains.

OFDM-based signalling using a 20 MHz band.

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Massive MIMO channels

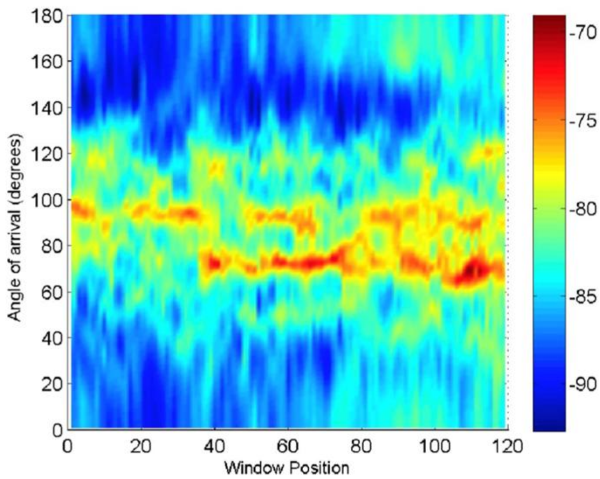
Massive MIMO channels are different:

- Large scale fading can be present over the antenna array (if it is large enough).
- The spherical wavefront can be visible over the array.

- With many antennas, the channel vectors between the BS and UEs can be nearly orthogonal.
- Measurements have shown that this is the case also in real environments.

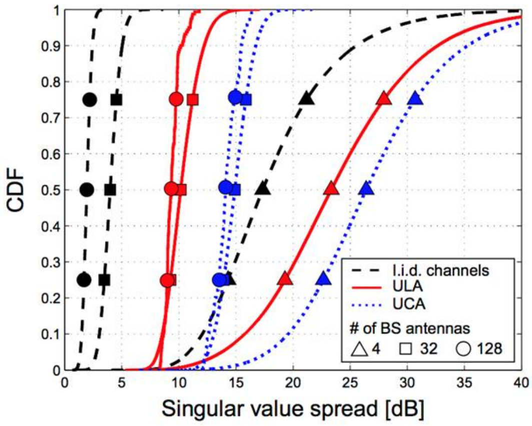
Massive MIMO channels

- Large scale fading can be present over the antenna array:



Massive MIMO channels

Favorable propagation; nearly orthogonal channels for 128 antennas:



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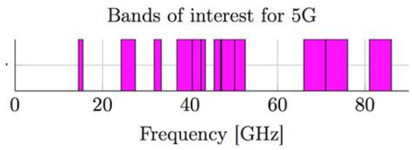
cm-wave and mm-wave bands for 5G

There are several bands above 6 GHz that are under-utilized.
These bands can offer a large bandwidth -> higher capacity
These bands are being investigated for use in 5G systems:



30 GHz	24.25 – 27.5 GHz, 31.8-33.4* GHz
40 – 55 GHz	37-40.5,40.5-42.5*,42.5-43.5 GHz, 45.5-47 GHz, 47-47.2*, 47.2-50.2 GHz, 50.4-52.6 GHz
66 – 86 GHz	66-71 GHz, 71-76 GHz, 81-86 GHz

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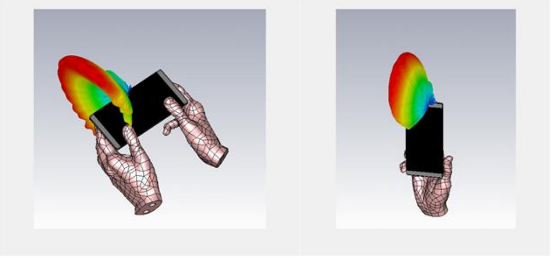
cm-wave and mm-wave bands for 5G

High-frequency channels are different from lower freqeuncy bands!

- Large pathloss, severe shadowing and increased doppler shifts.
- Beamforming/array gain is needed to overcome the increased losses.



- Beamforming in the UE is not easy to achieve

cm-wave and mm-wave bands for 5G

The free space loss increases with freqeuncy!

Free space loss at 100 m for a frequency of 6 GHz: 88 dB

Free space loss at 100 m for a frequency of 60 GHz: 108 dB

A 20 dB increase in loss per decade of increase in freqeuncy.
How to deal with this?

cm-wave and mm-wave bands for 5G

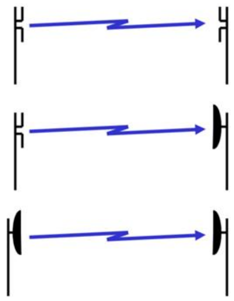
The free space loss increases with freqeuncy!

Assume following three free-space scenarios with λ/2 dipoles and parabolic antennas with fixed effective area A_{par}:

D-D:

D-P:

P-P:



Antenna gains

$$G_{dip|dB} = 2.15$$

$$G_{par|dB} = 10\log_{10}\left(\frac{A_{par}}{A_{iso}}\right) = 10\log_{10}\left(\frac{A_{par}}{\lambda^2/4\pi}\right) = 10\log_{10}\left(\frac{4\pi A_{par}}{\lambda^2}\right)$$

cm-wave and mm-wave bands for 5G

Evaluation of Friis' law for the three scenarios:

D-D:

$$P_{RX|dB}(d) = P_{TX|dB} + 2.15 - 20\log_{10}\left(\frac{4\pi d}{\lambda}\right) + 2.15$$

$$= P_{TX|dB} + 4.3 - 20\log_{10}(4\pi d) + 20\log_{10}\lambda$$

Received power decreases with decreasing wavelength λ, i.e. **with increasing frequency**.

D-P:

$$P_{RX|dB}(d) = P_{TX|dB} + 2.15 - 20\log_{10}\left(\frac{4\pi d}{\lambda}\right) + 10\log_{10}\left(\frac{4\pi A_{par}}{\lambda^2}\right)$$

$$= P_{TX|dB} + 2.15 - 20\log_{10}(4\pi d) + 10\log_{10}(4\pi A_{par})$$

Received power independent of wavelength, i.e. **of frequency**.

P-P:

$$P_{RX|dB}(d) = P_{TX|dB} + 10\log_{10}\left(\frac{4\pi A_{par}}{\lambda^2}\right) - 20\log_{10}\left(\frac{4\pi d}{\lambda}\right) + 10\log_{10}\left(\frac{4\pi A_{par}}{\lambda^2}\right)$$

$$= P_{TX|dB} + 20\log_{10}(4\pi A_{par}) - 20\log_{10}(4\pi d) - 20\log_{10}\lambda$$

Received power increases with decreasing wavelength λ, i.e. **with increasing frequency**.

cm-wave and mm-wave bands for 5G

Combat extra losses with beamforming/array gain.

The decrease in wavelength makes it possible to put a larger number of antennas on the same physical area.

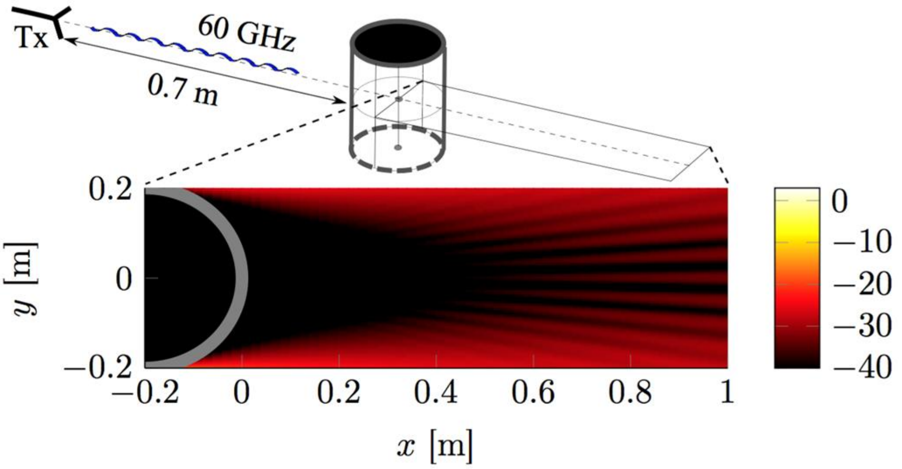
However, beamforming makes it neccessary to have more complex hardware.

cm-wave and mm-wave bands for 5G

Specific propagation related challenges:

1. Shadowing due to objects and humans.
2. Hand effects for handheld devices.
3. Transmission losses through building materials and objects.

Shadowing by metallic cylinder



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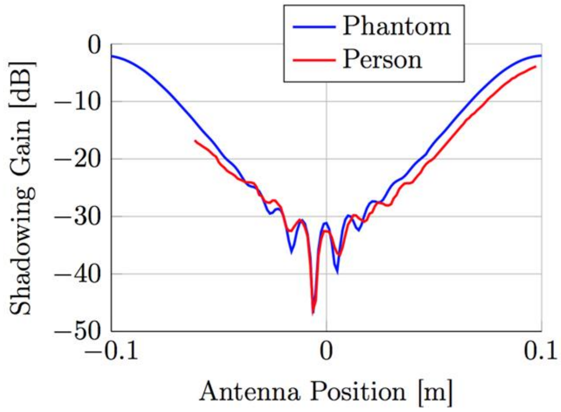
cm-wave and mm-wave bands for 5G

Shadowing by human at 60 GHz:



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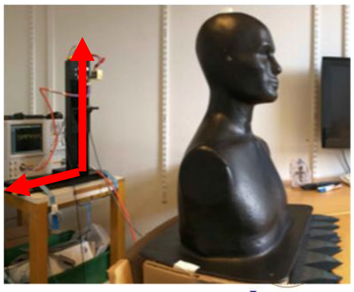
mm-wave Channel sounding

- Popular channel sounding approaches:
  - q Virtual antenna arrays (Antennas elements are moved to form array)
  - q Rotating highly directional antennas

- Limited to static channels
- Extremely time consuming
- Limited amounts of data
- Cannot measure Doppler or dynamic events



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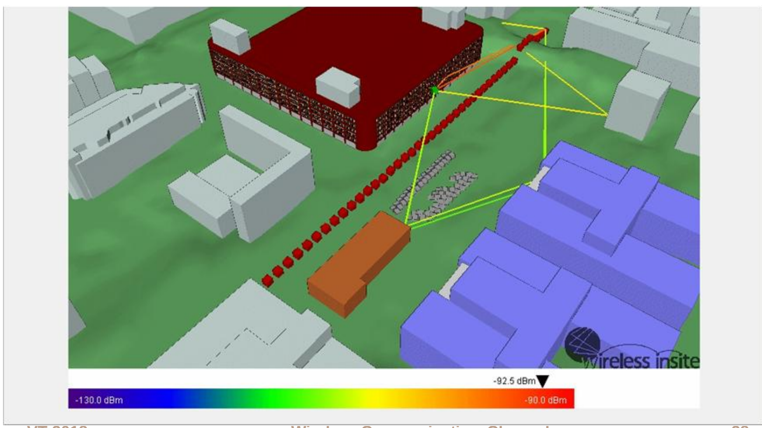
mm-wave Ray Tracing

- Ray tracing can be used to generate large amounts of simulated data.
- Difficult to get results close to reality and to capture the diffuse power.



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mm-Wave Channel Models

- mm-Wave channel models need to be wideband models.
- Since beamforming is expected to be used, it should include directional properties.

- For these reasons, most mm-wave channel models are based on double-directional cluster models.

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