Wireless Communication Channels
Lecture 13: Wireless channels and 5G

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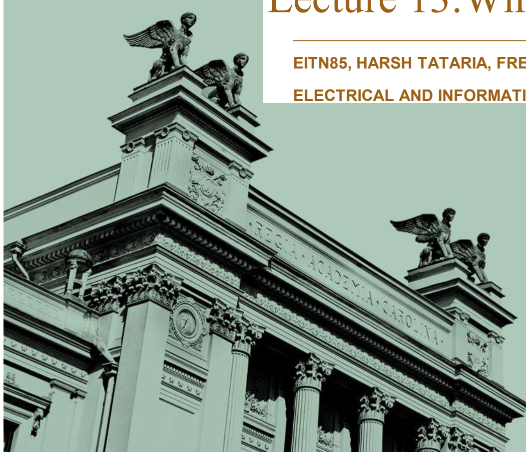

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Mobile phone generations: 1G to 4G

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.

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What is 5G? Why is it needed?

- Aims of 5G:
  - Tens of Mbps for ten thousands of users.
  - 100 Mbps for metropolitan areas
  - 1 Gbps for several workers on the same floor.
  - 100,000's of simultaneous connections for sensors.
  - Improved coverage and spectral efficiency.
  - 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

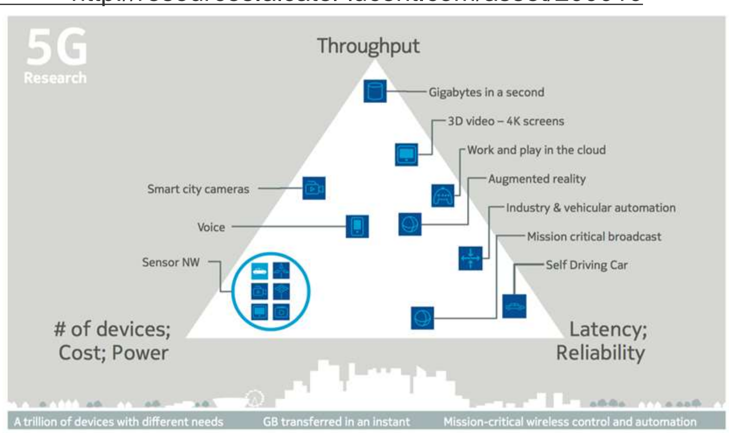

Figure 3: Diversity of services, use cases and requirements

5G: Uses cases envisioned by Ericsson

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

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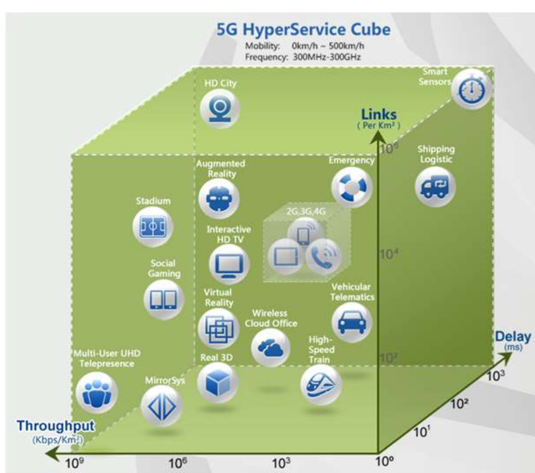
5G: Uses cases envisioned by Huawei

- 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.

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5G: Above and below 6 GHz

We will distinguish between two different technologies:

- Massive MIMO for bands below 6 GHz.

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

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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

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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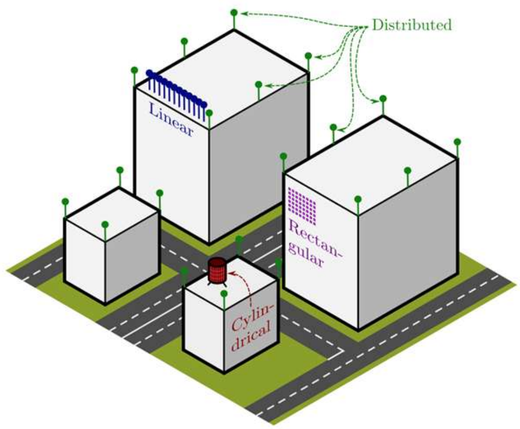
Massive MIMO below 6 GHz

Different array configurations can be used:



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Massive MIMO: 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.

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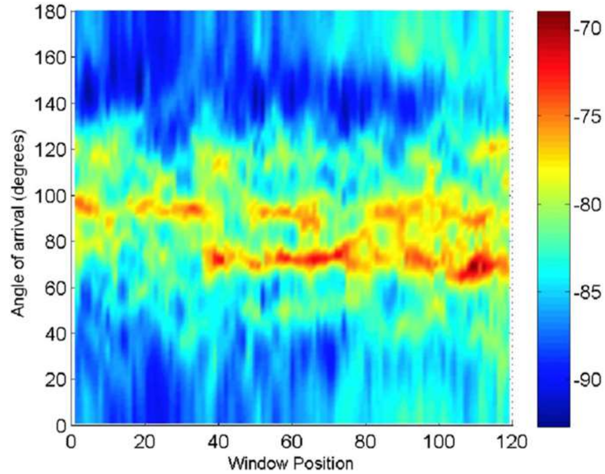
Massive MIMO channels

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



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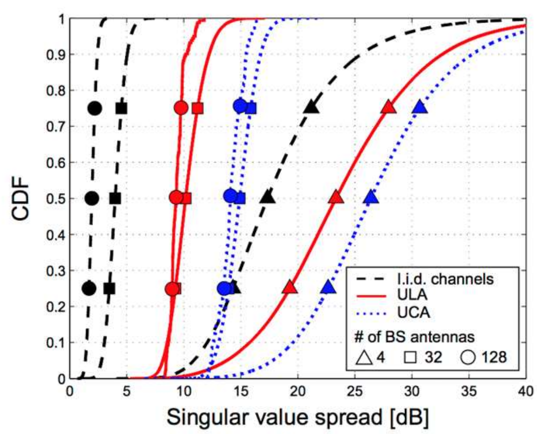
Massive MIMO channels

Favorable propagation; nearly orthogonal channels for 128 antennas:



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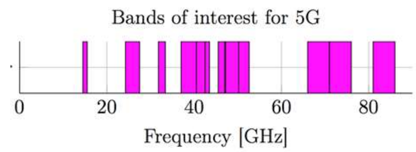
cm-wave and mm-wave bands for 5G

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

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

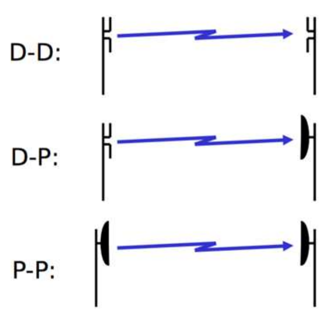
Free space loss at 100 m for a frequency of 60 GHz: 108 dB

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}:



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**.

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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.

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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.

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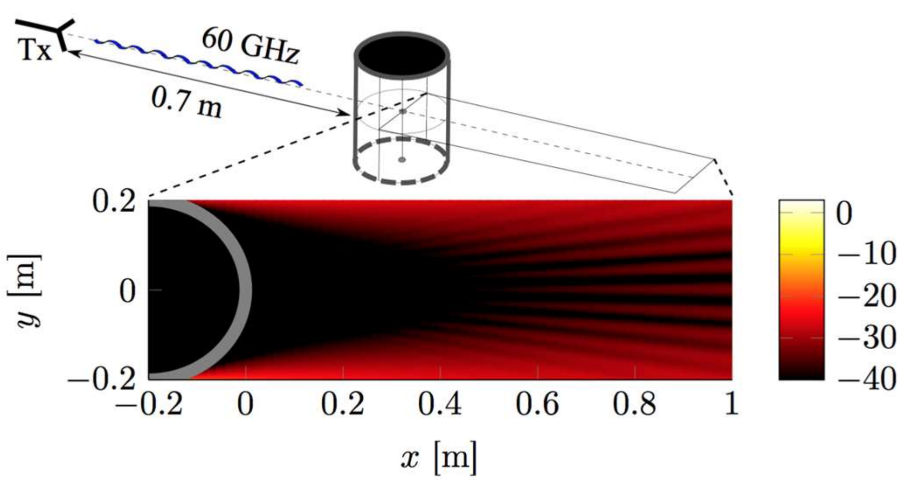
Shadowing by metallic cylinder



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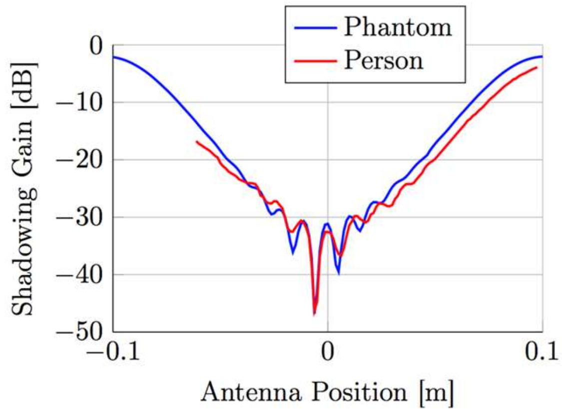
cm-wave and mm-wave bands for 5G

Shadowing by human at 60 GHz:



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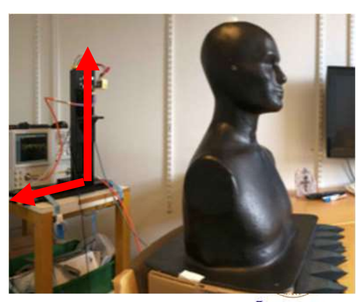
mm-wave Channel sounding

- Popular channel sounding approaches:
  - ❑ Virtual antenna arrays (Antennas elements are moved to form array)
  - ❑ 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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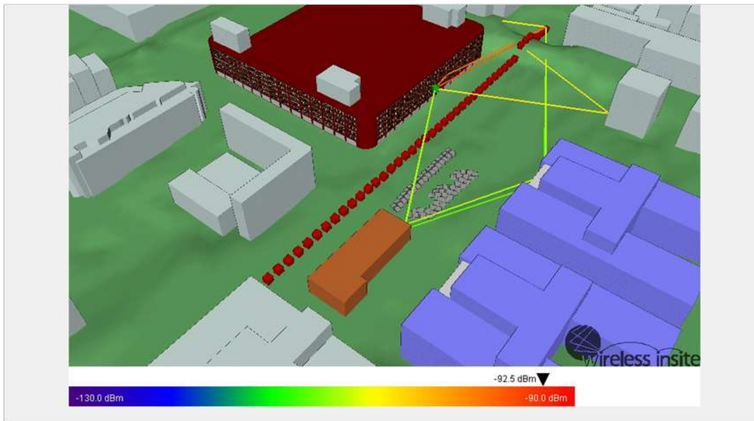
mm-wave Ray Tracing

- 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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