Technische Universiteit
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New-Radio millimeter-wave technology for future 5G/6G wireless

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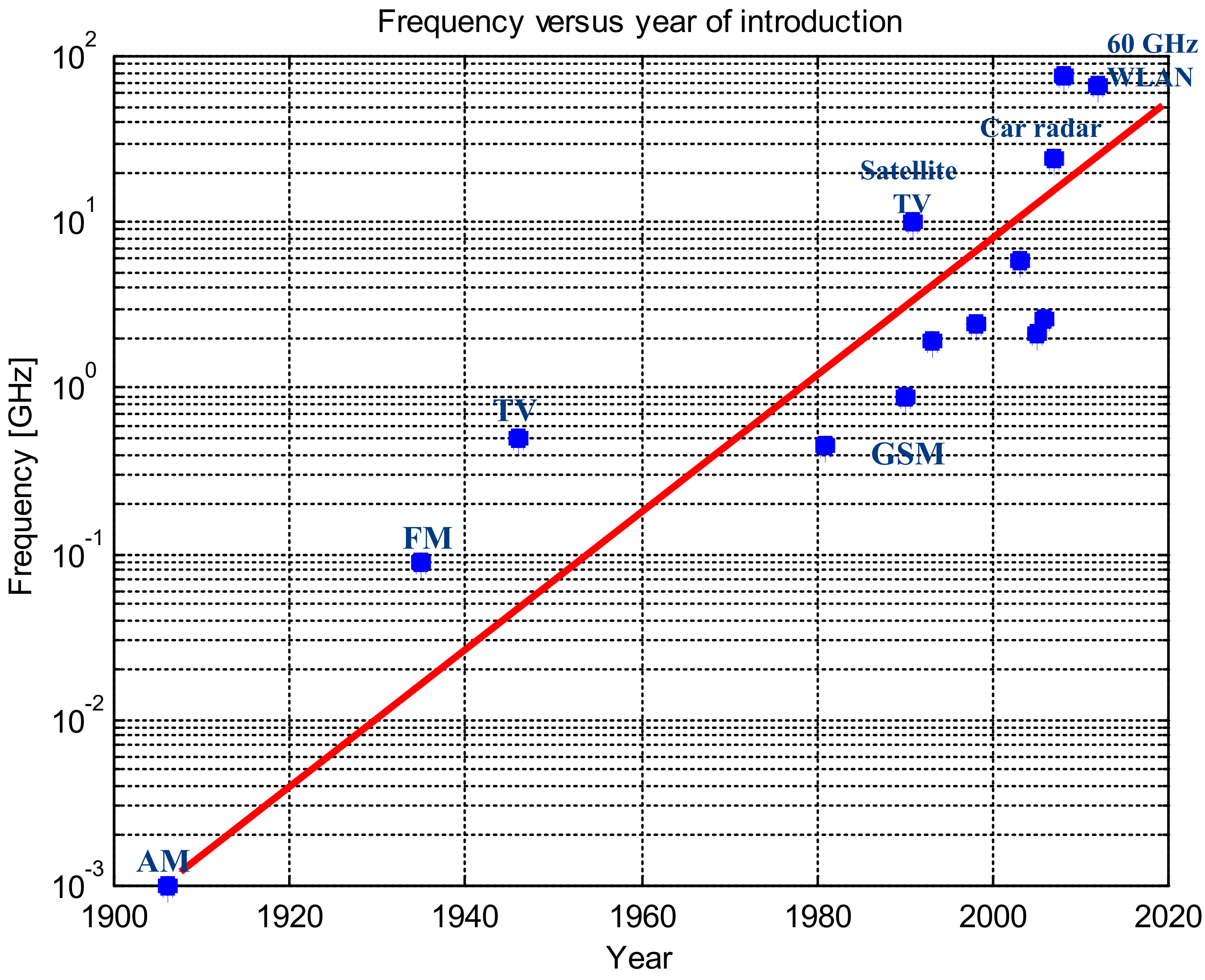
Content

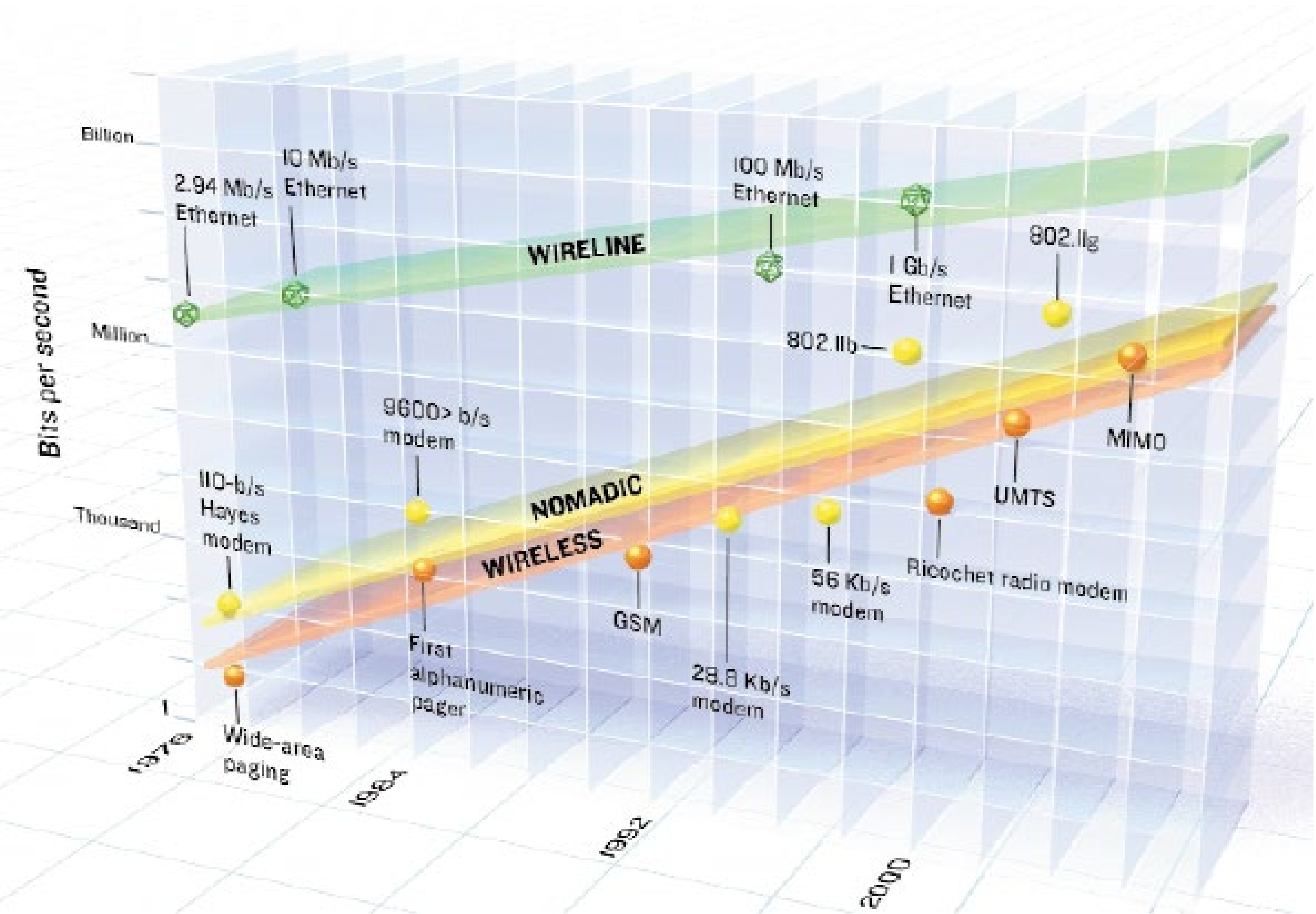
- Trends in wireless communication
- What is 5G?
- Power consumption dilemma in 5G New Radio
- Looking forward towards 6G

Trends in Wireless communications

Trend 1: Increase of operational frequency



Trend 2: Increase in bandwidth:Edholm’s Law



- Wireless growing faster than wired

Required Bandwidth/datarate doubles each 18 months

Source: IEEE spectrum, 2004

Evolution of wireless standards

1G	2G	3G	4G	5G	6G
The foundation of mobile telephony	Mobile telephony for everone	The foundation of mobile broadband	Mobile broadband enhanced	Embracing a networked society	Enabling a smart sustainable society
~1980	~1990	~2000	~2010	~2020	~2030
1st GENERATION wireless network	2nd GENERATION wireless network	3rd GENERATION wireless network	4th GENERATION wireless network		6th GENERATION wireless network
• Basic Voice service • Analog Based Protocols	• Designed for voice • First digital standards (GSM,CDMA)	• Designed for voice and data • First mobile broadband • Voice through circuit & Data-Packet Switching	• Designed Primarily fo Data • IP based protocol • True Mobile broadband.		xtension to ub) mm-wave equencies eal-time cloud computing
2.4 Kbps	*64 Kbps*	*2 Mbps*	*100 Mbps*	*10 Gbps*	*1 Tbps*

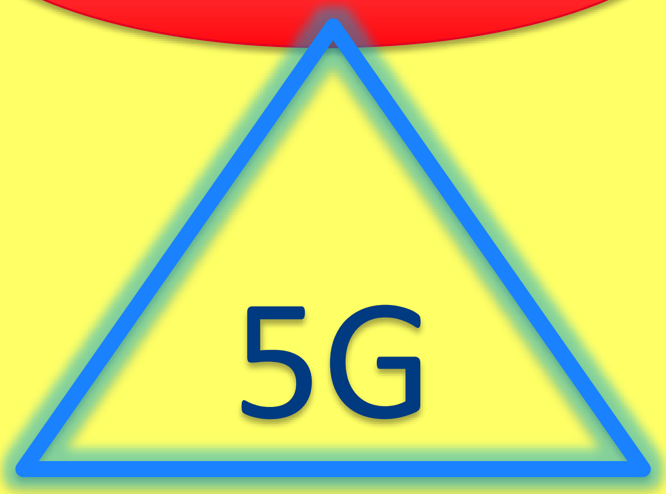
Compare with Edholms law: factor 2 more BW in 1.5 year 2^(10/1.5)=101

What is 5G?

What is 5G?

eMBB
Extreme Mobile Broadband
High date rate, high-traffic volume

Requires New Radio (NR) at mm-waves

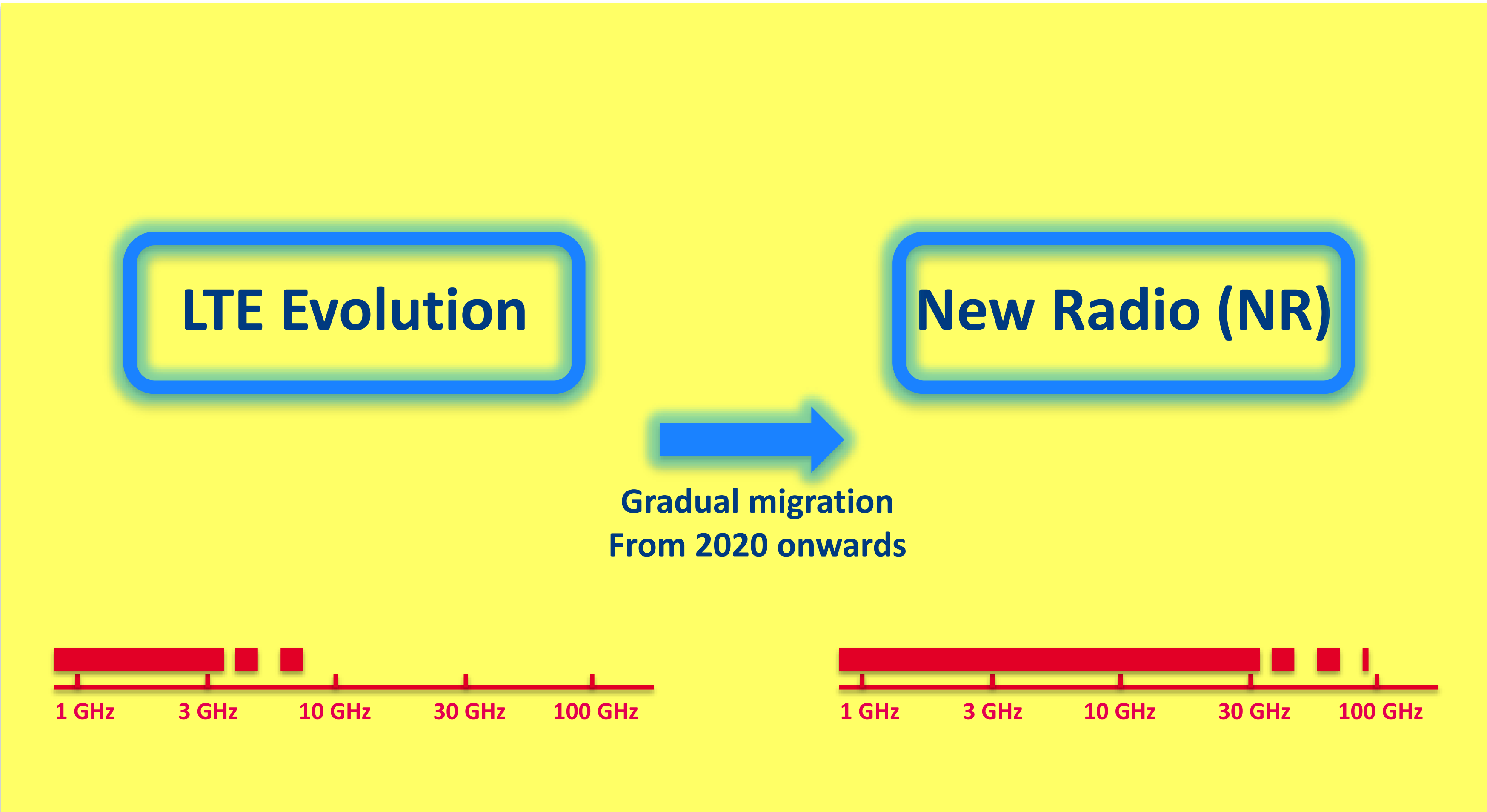


mMTC
Massive Machine Type Communications
Low-cost, low-energy

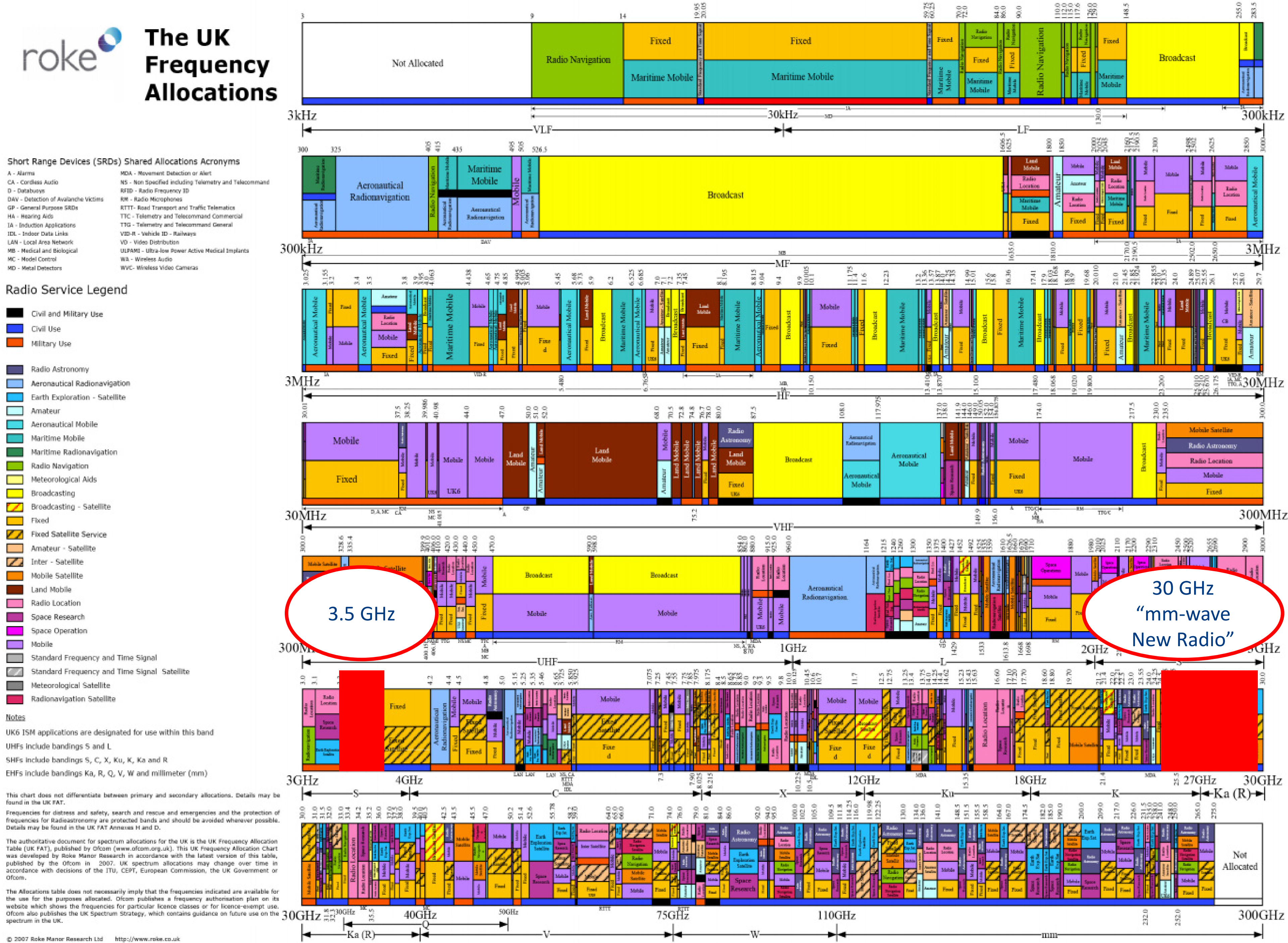
URLLC
Ultra-Reliable and Low Latency Communications
Very high reliability

Source: 5G PPP Architecture Working Group, "View on 5G Architecture (Version 2.0)," July 2017 , www.5g-ppp.eu

Radio Access in 5G



Source: 5G PPP Architecture Working Group, "View on 5G Architecture (Version 2.0)," July 2017 , www.5g-ppp.eu


roke
The UK Frequency Allocations
Short Range Devices (SRDs) Shared Allocations Acronyms
A - Alarms
CA - Cordless Audio
D - Databuoys
DAV - Detection of Avalanche Victims
GP - General Purpose SRDs
HA - Hearing Aids
IA - Induction Applications
IDL - Indoor Data Links
LAN - Local Area Network
MB - Medical and Biological
MC - Model Control
MD - Metal Detectors
MDA - Movement Detection or Alert
NS - Non Specified including Telemetry and Telecommand
RFID - Radio Frequency ID
RM - Radio Microphones
RTTT- Road Transport and Traffic Telematics
TTC - Telemetry and Telecommand Commercial
TTG - Telemetry and Telecommand General
VID-R - Vehicle ID - Railways
VD - Video Distribution
ULPAMI - Ultra-low Power Active Medical Implants
WA - Wireless Audio
WVC- Wireless Video Cameras
Radio Service Legend
Civil and Military Use
Civil Use
Military Use
Radio Astronomy
Aeronautical Radionavigation
Earth Exploration - Satellite
Amateur
Aeronautical Mobile
Maritime Mobile
Maritime Radionavigation
Radio Navigation
Meteorological Aids
Broadcasting
Broadcasting - Satellite
Fixed
Fixed Satellite Service
Amateur - Satellite
Inter - Satellite
Mobile Satellite
Land Mobile
Radio Location
Space Research
Space Operation
Mobile
Standard Frequency and Time Signal
Standard Frequency and Time Signal Satellite
Meteorological Satellite
Radionavigation Satellite
Notes
UK6 ISM applications are designated for use within this band
UHFs include bandings S and L
SHFs include bandings S, C, X, Ku, K, Ka and R
EHFs include bandings Ka, R, Q, V, W and millimeter (mm)
This chart does not differentiate between primary and secondary allocations. Details may be found in the UK FAT.
Frequencies for distress and safety, search and rescue and emergencies and the protection of frequencies for Radioastronomy are protected bands and should be avoided wherever possible. Details may be found in the UK FAT Annexes H and D.
The authoritative document for spectrum allocations for the UK is the UK Frequency Allocation Table (UK FAT), published by Ofcom (www.ofcom.org.uk). This UK Frequency Allocation Chart was developed by Roke Manor Research in accordance with the latest version of this table, published by the Ofcom in 2007. UK spectrum allocations may change over time in accordance with decisions of the ITU, CEPT, European Commission, the UK Government or Ofcom.
The Allocations table does not necessarily imply that the frequencies indicated are available for the use for the purposes allocated. Ofcom publishes a frequency authorisation plan on its website which shows the frequencies for particular licence classes or for licence-exempt use. Ofcom also publishes the UK Spectrum Strategy, which contains guidance on future use on the spectrum in the UK.
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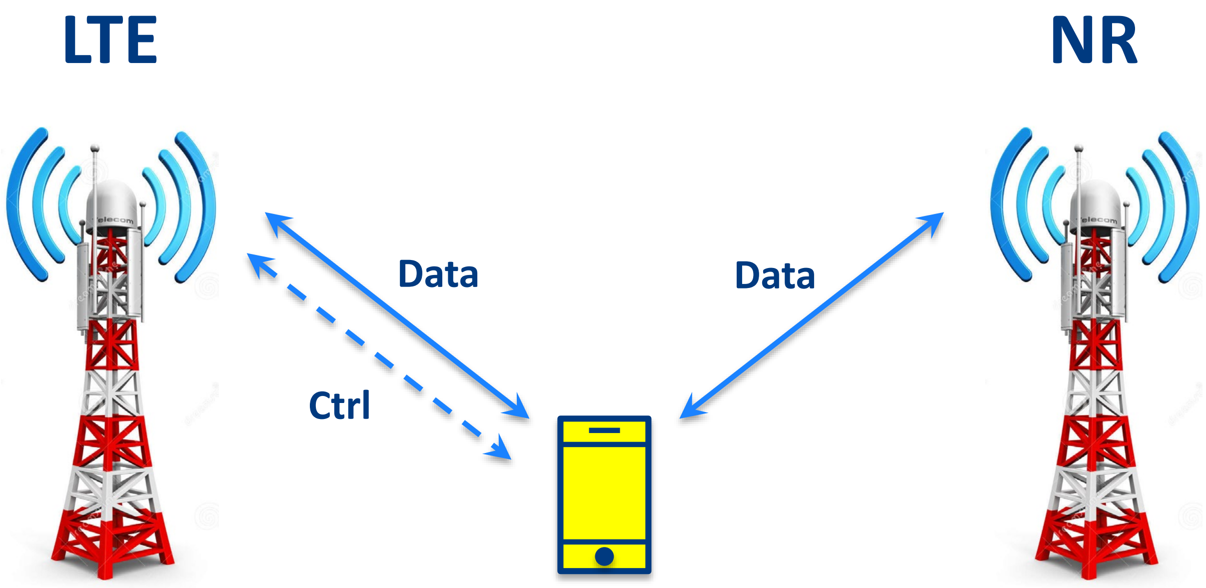
3kHz
30kHz
300kHz
VLF
LF
3MHz
MF
30MHz
HF
300MHz
VHF
1GHz
2GHz
UHF
3GHz
4GHz
12GHz
18GHz
27GHz
30GHz
S
C
X
Ku
K
Ka (R)
40GHz
50GHz
75GHz
110GHz
300GHz
Q
V
W
mm
Not Allocated
Radio Navigation
Fixed
Maritime Mobile
Broadcast
Aeronautical Radionavigation
Mobile
Land Mobile
Radio Astronomy
Aeronautical Mobile
3.5 GHz
30 GHz
“mm-wave
New Radio”

NR System embedding

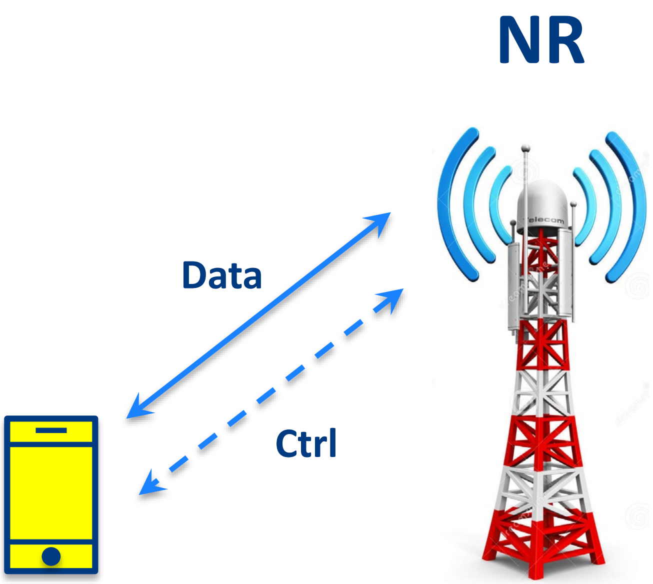
Option 1: Non-standalone operation with LTE master



Source: 5G PPP Architecture Working Group, “View on 5G Architecture (Version 2.0),” July 2017 , www.5g-ppp.eu

NR System embedding

Option 2: Standalone operation (NR master)



Source: 5G PPP Architecture Working Group, “View on 5G Architecture (Version 2.0),” July 2017 , www.5g-ppp.eu

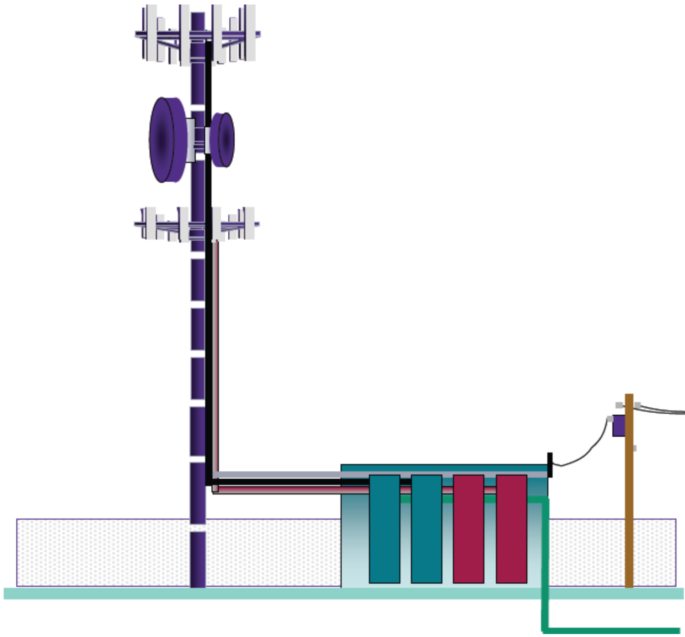
Power consumption in 5G and beyond using New-Radio

Key question

- Can we scale our existing 3G/4G base-station infrastructure to higher frequencies?
- What happens if we scale from 2 GHz to 30 GHz?
- Let us consider only the downlink (TX) case

Existing base-stations for 3G/4G Wireless Communication

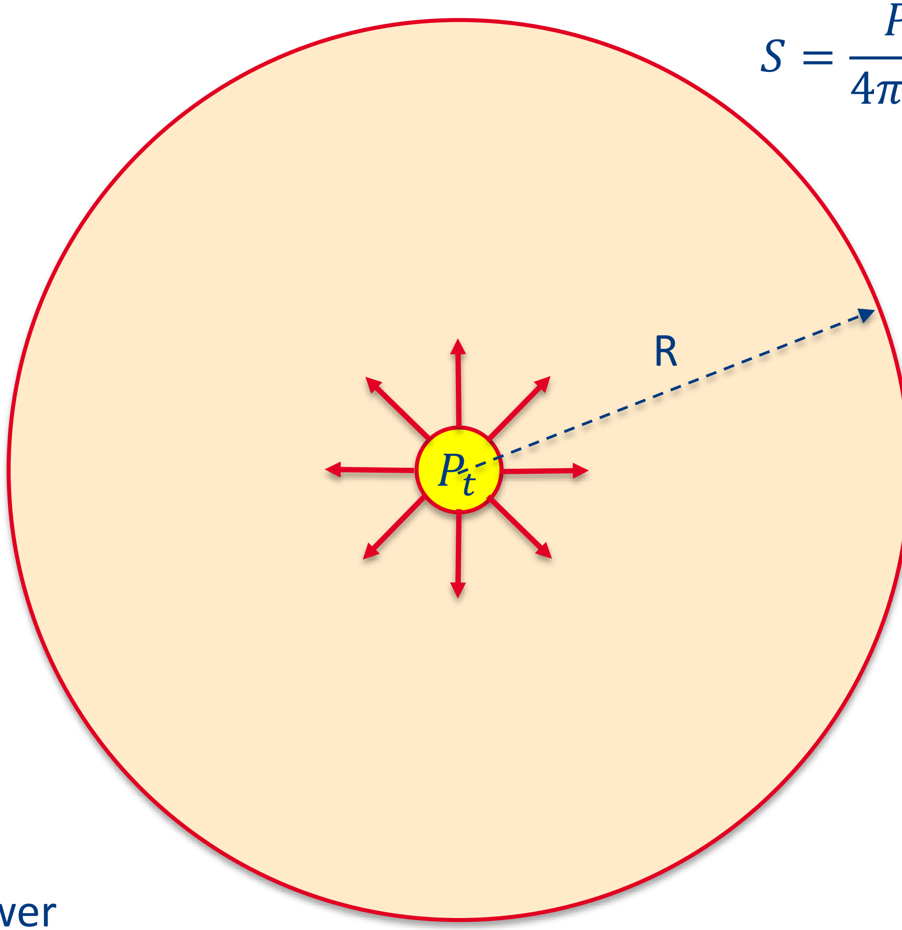
- Frequency 0.8-2.5 GHz
- Power consumption ~ 5kW
- Netherlands: 43933 base stations (2G/3G/4G)[1]
- So currently about 219 MW power dissipation



[1] https://www.antennebureau.nl/onderwerpen/algemeen/antenneregister

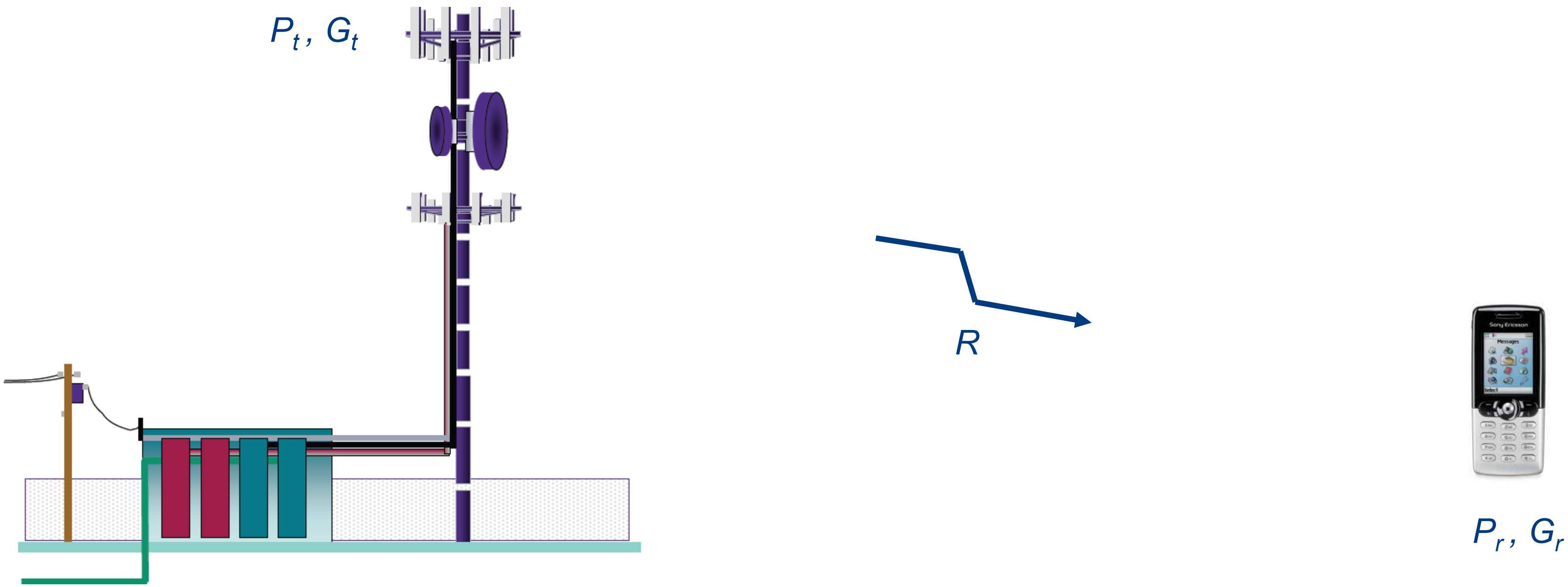
Spherical wave expansion
from point source

$$S = \frac{P_t}{4\pi R^2}$$ Power density at surface sphere



P_t: total radiated power

Downlink, Link Budget



$$P_r = \frac{P_t G_t A_e}{4\pi R^2} = \frac{P_t G_t G_r \lambda_0^2}{(4\pi)^2 R^2} \quad \Rightarrow \quad R = \sqrt{\frac{P_t G_t G_r \lambda_0^2}{(4\pi)^2 P_{r,\min}}}$$

Simple "back-of-the-envelope" calculation, 2 GHz vs. 30 GHz

2 GHz

Wavelength: λ_0=15cm
4 Tx antenna elements with 3dB gain each: G_t=8 (9dBi)
Rx antenna omni-directional: G_r=1.
Output power: 100 W (50 dBm)
Sensitivity $P_{r,min}$ = -70 dBm (=10^{-10}W)

$$R = \sqrt{\frac{P_t G_t G_r \lambda_0^2}{(4\pi)^2 P_{r,\min}}} \approx 33km$$

30 GHz

Wavelength: λ_0=1cm
4 Tx antenna elements with 3dB gain each: G_t=8 (9dBi)
Rx antenna omni-directional: G_r=1.
Output power: 100 W (50 dBm)
Sensitivity $P_{r,min}$ = -70 dBm (=10^{-10}W)

$$R = \sqrt{\frac{P_t G_t G_r \lambda_0^2}{(4\pi)^2 P_{r,\min}}} \approx 2.2km$$

Simple "back-of-the-envelope" calculation, 2 GHz vs. 30 GHz

2 GHz

Wavelength: λ_0=15cm
4 Tx antenna elements, G_t = 9dBi
Rx antenna omni-directional: G_r=1.
Output power: 100 W (50 dBm)
Sensitivity $P_{r,min}$ = -70 dBm (=10^{-10}W)

$$R = \sqrt{\frac{P_t G_t G_r \lambda_0^2}{(4\pi)^2 P_{r,\min}}} \approx 33km$$

30 GHz

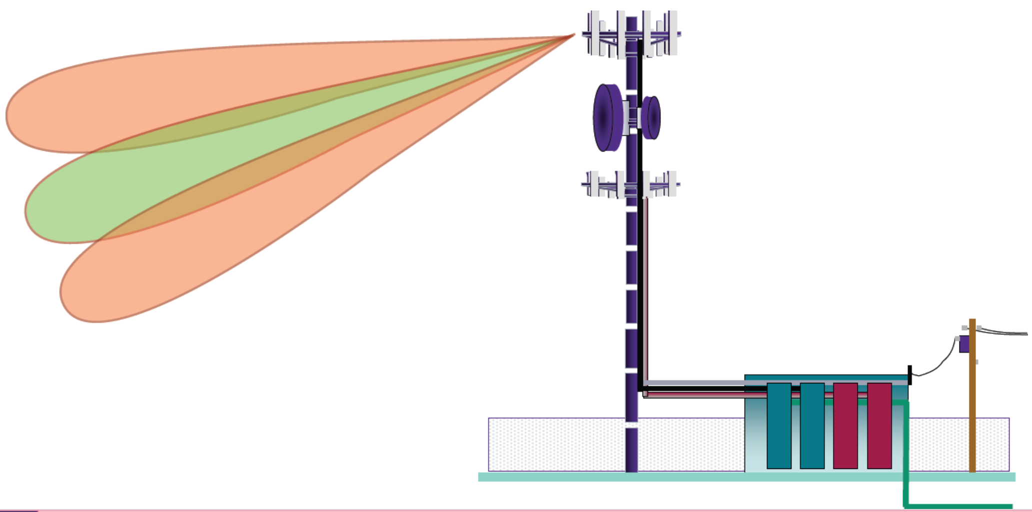
Wavelength: λ_0=1cm
4 Tx antenna elements, G_t= 9dBi
Rx antenna omni-directional: G_r=1.
Output power: **22500 W (73.5 dBm)**
Sensitivity $P_{r,min}$ = -70 dBm (=10^{-10}W)

$$R = \sqrt{\frac{P_t G_t G_r \lambda_0^2}{(4\pi)^2 P_{r,\min}}} \approx 33km$$

Consequence in Power consumption

Estimations!

	3G/4G	5G
Frequency	2 GHz	30 GHz
Power per BST*	4+1=5 kW	4+225*5=1129 kW
Total Power in Netherlands*	219 MW	49 GW
#Wind mills (2 MW each) in NL	109	24500



[1]In May 2017, The Netherlands hosted 43933 2G/3G/4G antennes, see https://www.antennebureau.nl/onderwerpen/algemeen/antenneregister
At this moment the PA efficiency is about a factor 5 worse at 30 GHz as compared to 2GHz. 10% of RF energy effectively radiated

Uplink case

- Uplink might be even more important than downlink at mm-wave.

- Link budget is not symmetrical!
  - Mobile user does not have a lot of power or space.

- We need a large antenna at the base-station with electronic scanning

Solution: Use a large antenna array

2 GHz
Wavelength: λ_0=15cm
4 Tx antenna elements, G_t = 9dBi
Rx antenna omni-directional: G_r=1.
Output power: 100 W (50 dBm)
Sensitivity $P_{r,min}$ = -70 dBm (=10^{-10}W)

$$R = \sqrt{\frac{P_t G_t G_r \lambda_0^2}{(4\pi)^2 P_{r,\min}}} \approx 33km$$

30 GHz
Wavelength: λ_0=1cm
4 Tx antenna elements, G_t= 9dBi
Rx antenna omni-directional: G_r=1.
Output power: 22500 W (73.5 dBm)
Sensitivity $P_{r,min}$ = -70 dBm (=10^{-10}W)

$$R = \sqrt{\frac{P_t G_t G_r \lambda_0^2}{(4\pi)^2 P_{r,\min}}} \approx 33km$$

30 GHz
Wavelength: λ_0=1cm
871 Tx antenna elements, G_t=32.4 dBi
Rx antenna omni-directional: G_r=1.
Output power: 100 W (50 dBm)
Sensitivity $P_{r,min}$ = -70 dBm (=10^{-10}W)

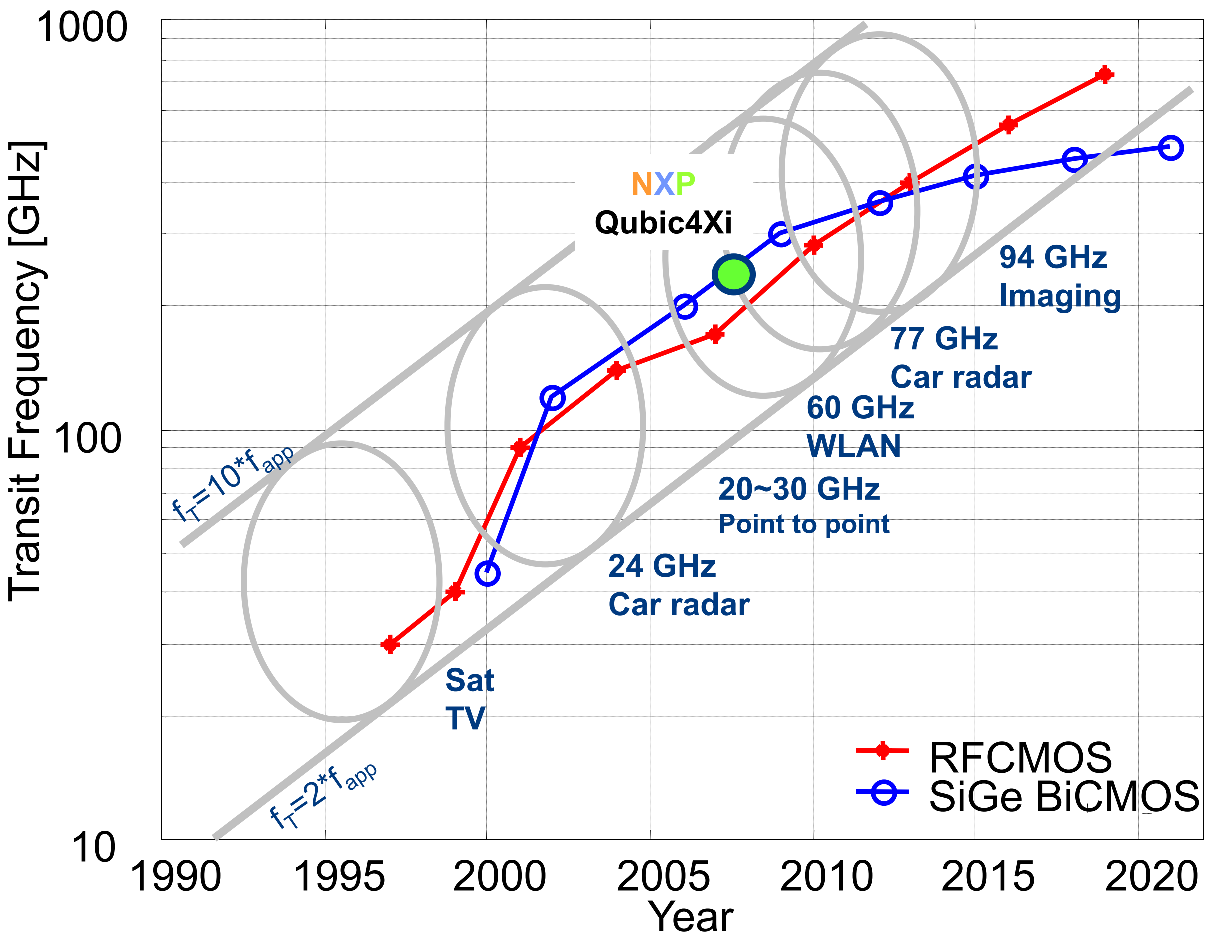
$$R = \sqrt{\frac{P_t G_t G_r \lambda_0^2}{(4\pi)^2 P_{r,\min}}} \approx 33km$$

Can we come up with solutions in NL?

- The Netherlands has a strong position in:
  - Phased-arrays, e.g. Thales, ASTRON, TNO, ESTEC and TU’s.
  - Silicon-integrated technology and Power amplifiers for base stations, e.g. NXP, TNO, Omniradar, Ampleon and TU’s

Silicon Technologies

Ft of IC Technology vs Year [ITRS]



ITRS= International Technology Roadmap for Semiconductors

Do we need more?

- Yes!

- Phased-arrays are too power hungry and too expensive
  - Need new antenna concepts
  - Further integration in Silicon

- At mm-waves, smaller cells will be used (< 300 m)

European project SILIKA

Silicon-Based Ka-Band Massive MIMO Systems for New Telecommunication Services

See: www.silika-project.eu

Objectives:

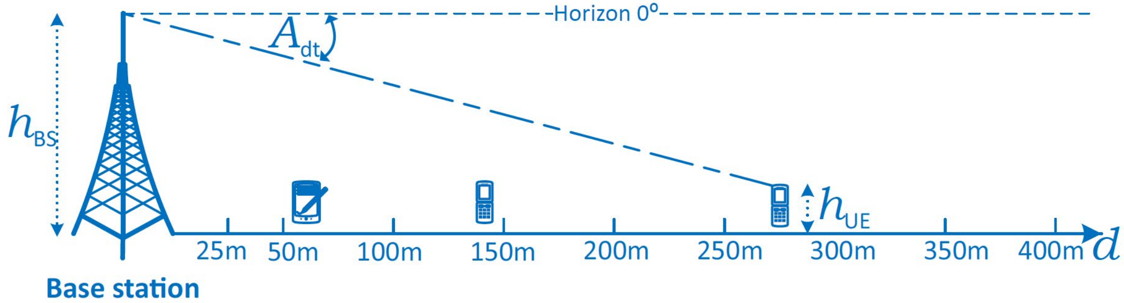
- Development of innovative **integrated antenna systems** for future **5G base stations** operating at **mm-wave** frequencies utilizing highly-integrated and cost-effective **(Bi-)CMOS** technologies.

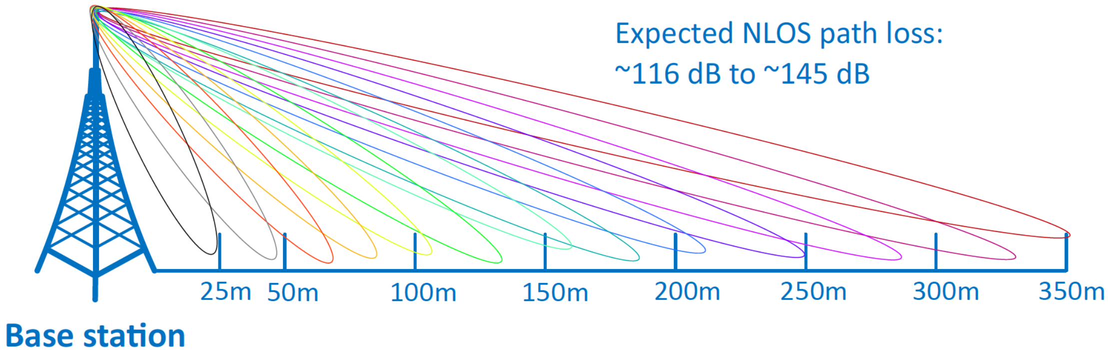
- These antenna systems will rely on the use of multi-antenna **massive MIMO** concepts in which the number of individual antenna elements in the base station is much larger than the number of users ($M >> K$)

- **Training of 12 PhD students** in the domain of mm-wave massive MIMO systems

Base station cell at mm-waves (28.5 GHz)

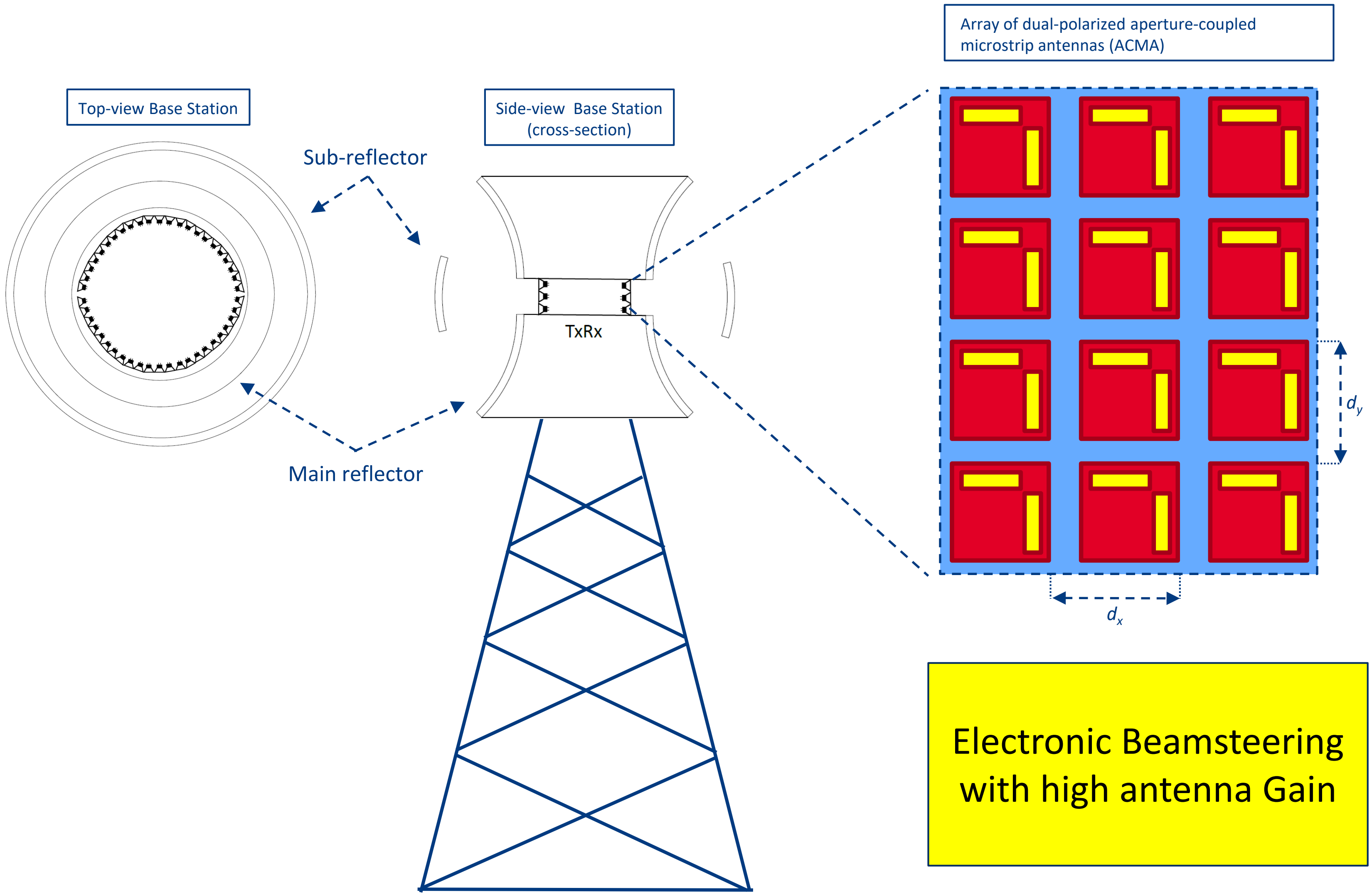
Scenario: Urban environment





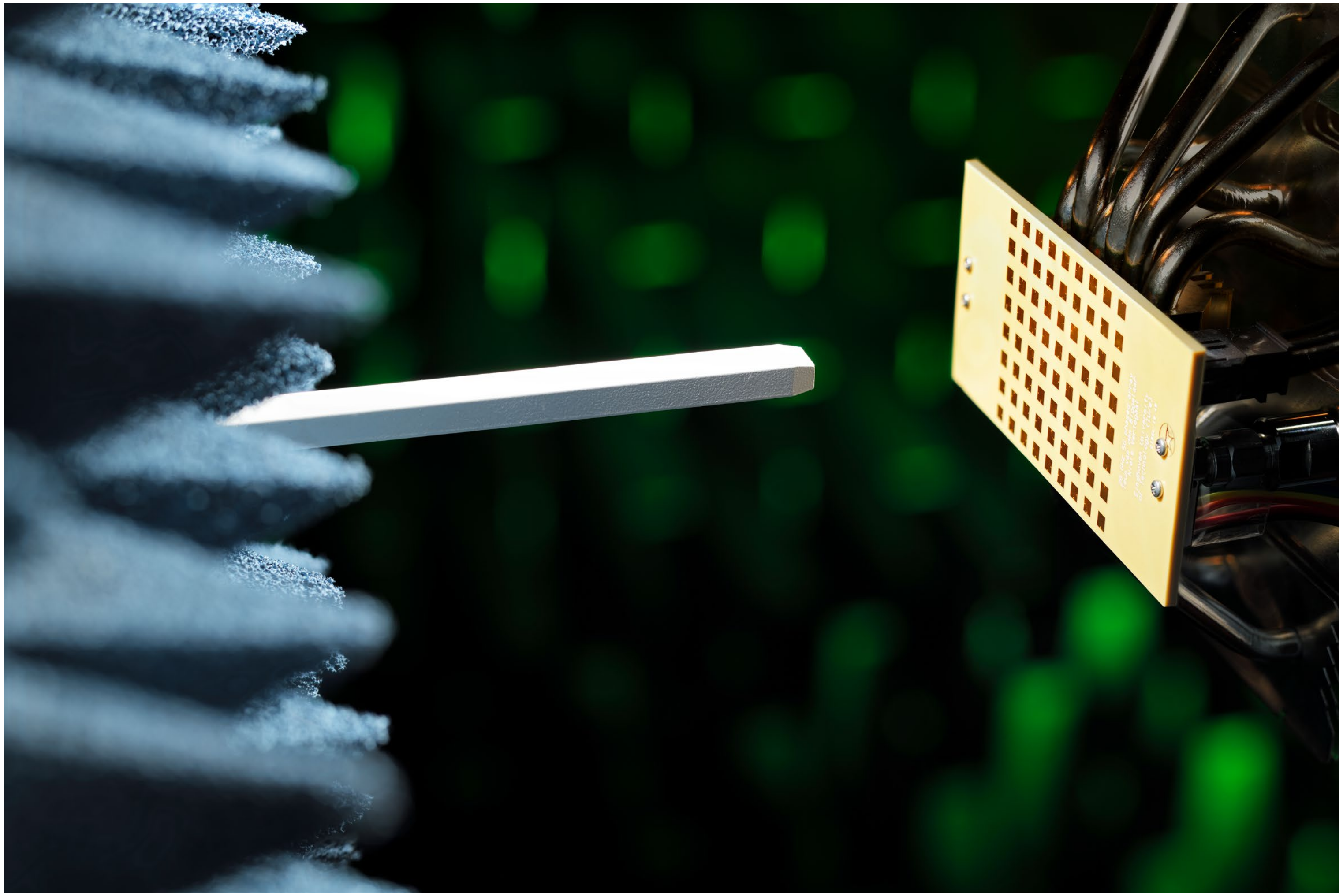
Expected NLOS path loss:
~116 dB to ~145 dB

Focal-plane Arrays

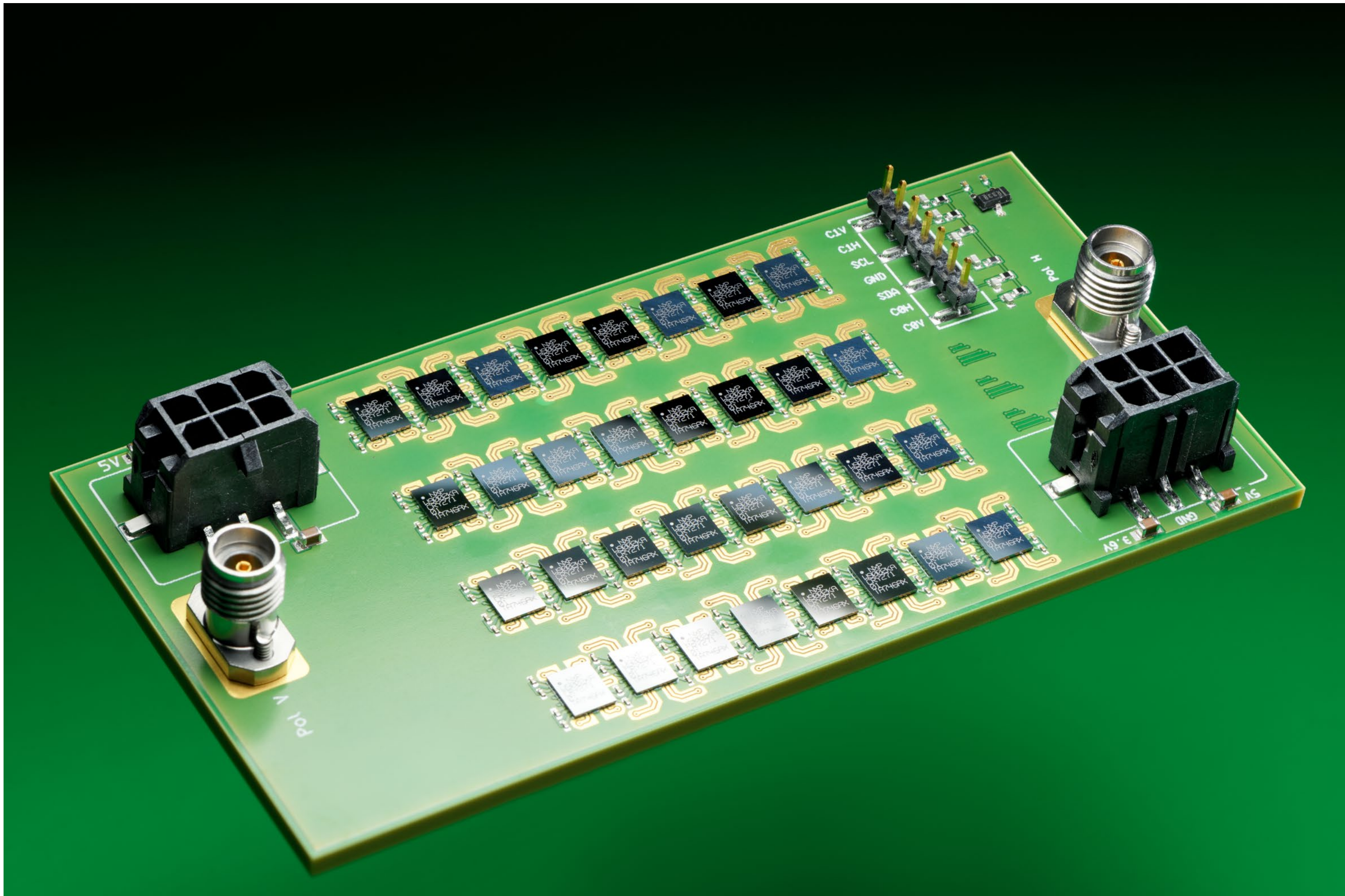


Electronic Beamsteering with high antenna Gain

5G New Radio mm-wave Prototype



5G New Radio mm-wave Prototype



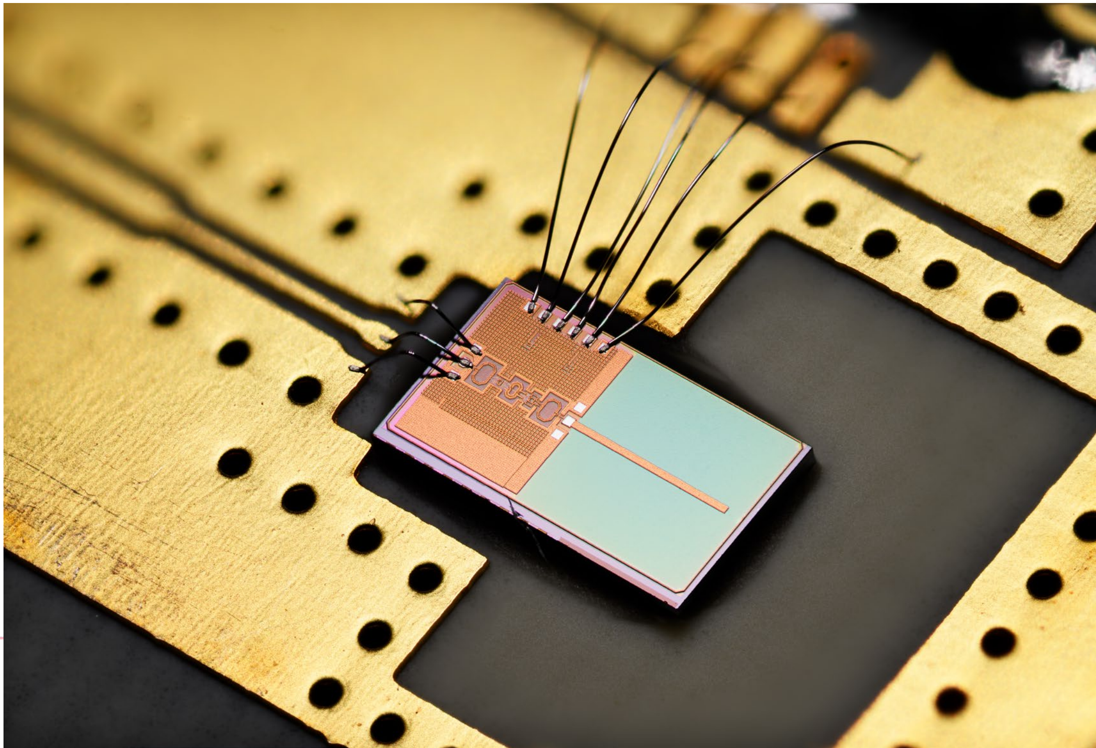
Next step: Feed-array using integrated antennas

Antenna-on-chip (AoC)

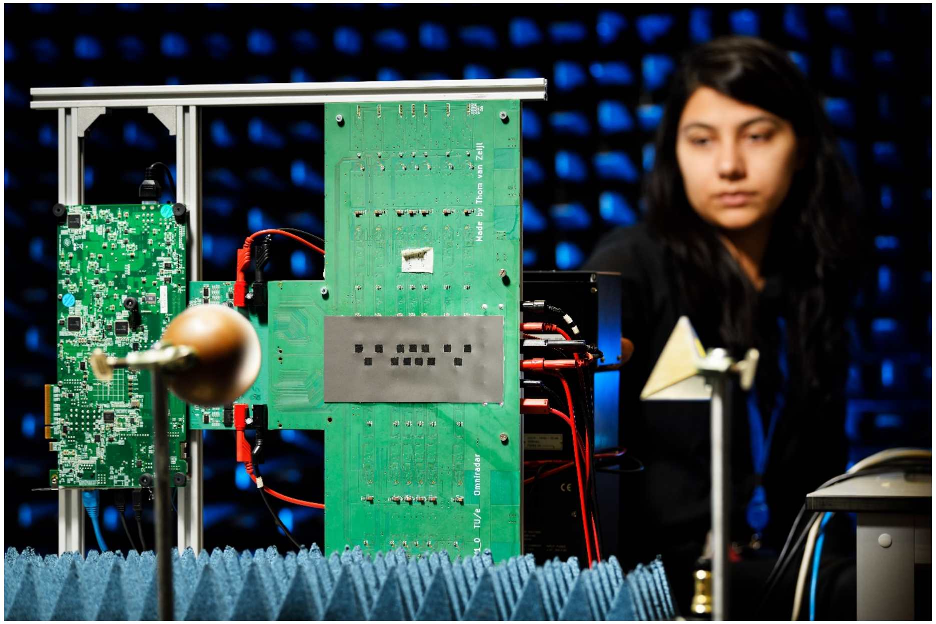
- Antenna launcher integrated in Silicon.
- No RF interconnect required anymore
- Wafer thinning can be applied to reduce silicon losses.

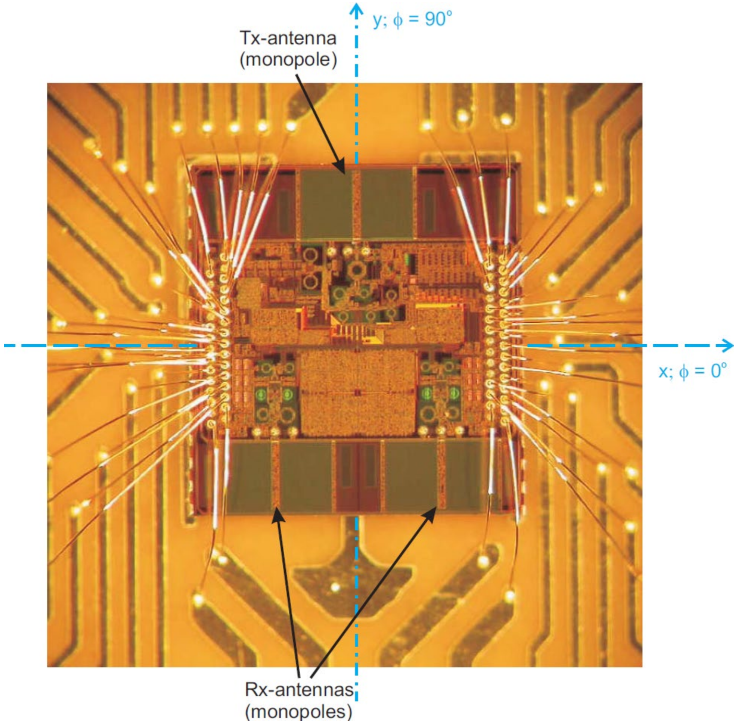
Demonstrator in BiCMOS

- AoC+LNA at 30 GHz



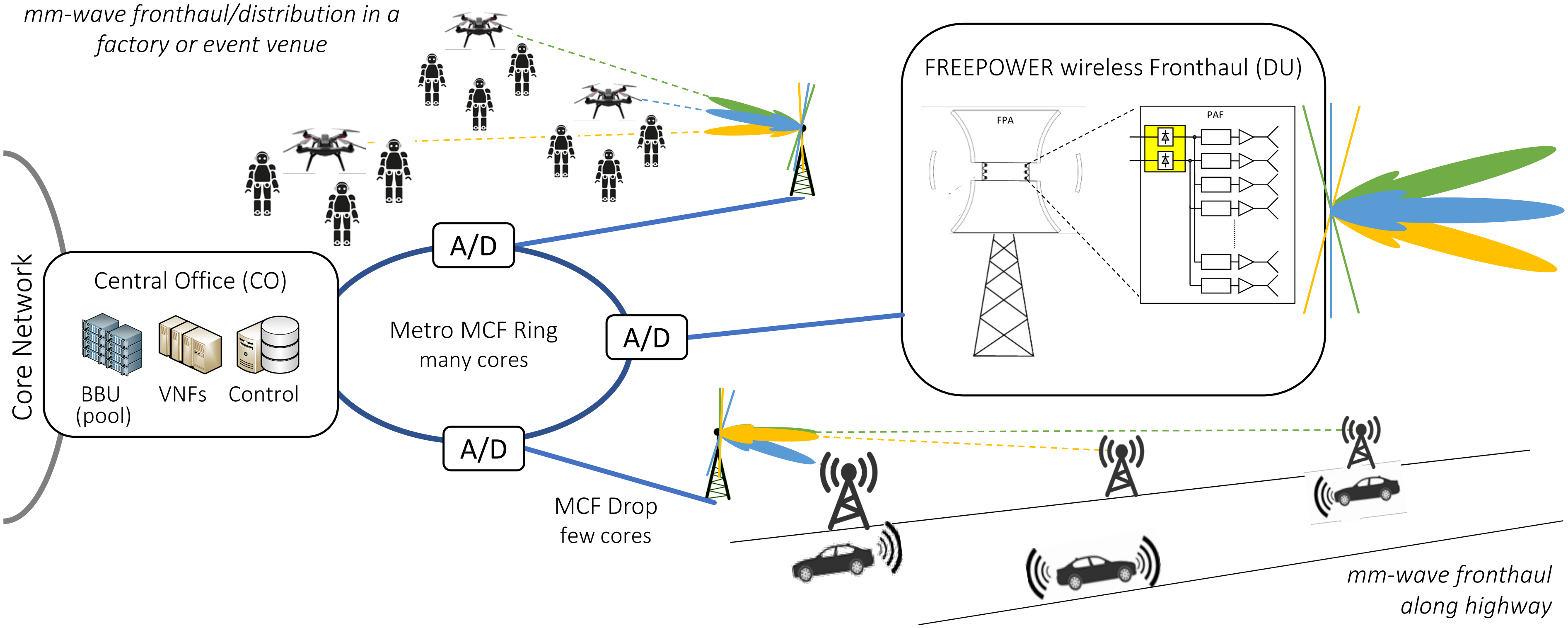
MUSIC: single-chip and MIMO radar at 60 GHz





Looking forward towards 6G

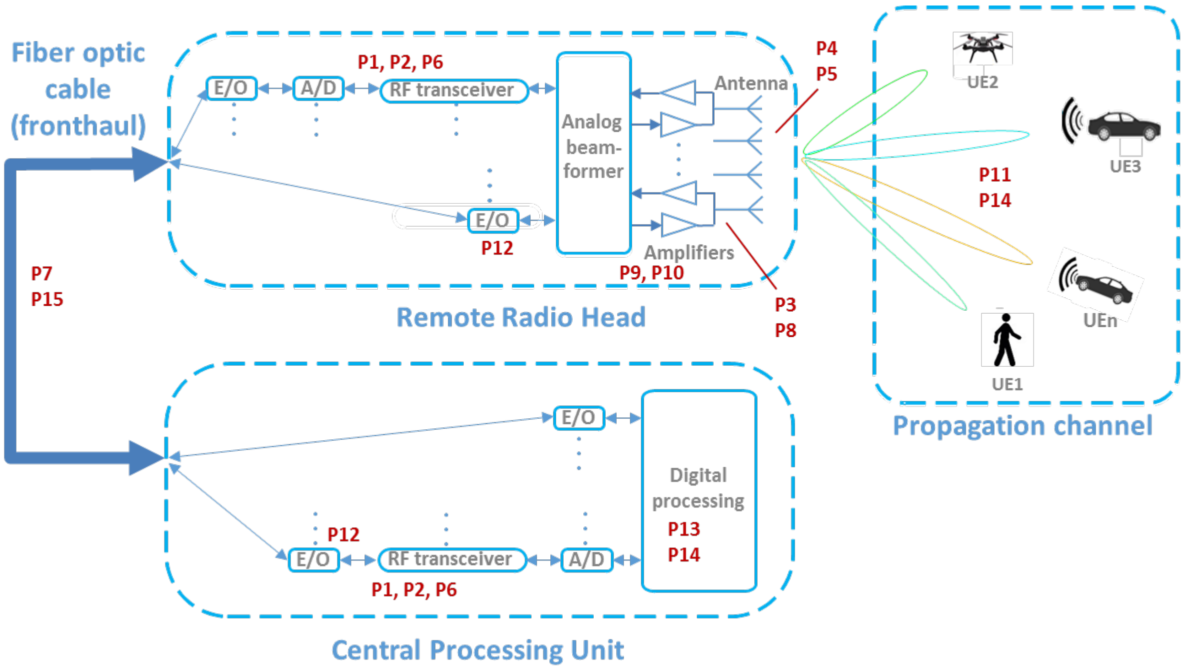
Fiber-connected future 5G/6G centralized radio access network (C-RAN)



According to ETSI terminology

New European project MyWave

Efficient Millimetre-Wave Communications for Mobile Users (15 PhD students)



Spin-off MaxWaves

MAXWAVES

https://www.youtube.com/watch?v=Ga8_qDqKFD4&feature=youtu.be

Summary

- 5G/6G will use mm-wave frequencies
  - 24.25-43 GHz for base stations in small cells
  - 71-86 GHz for Front-Haul/Back-Haul
- Existing concepts are too power hungry and far to expensive
- New distribution concepts are explored, e.g. wireless Front-haul.
- New antenna concepts and high level of integration in Silicon technologies are required.