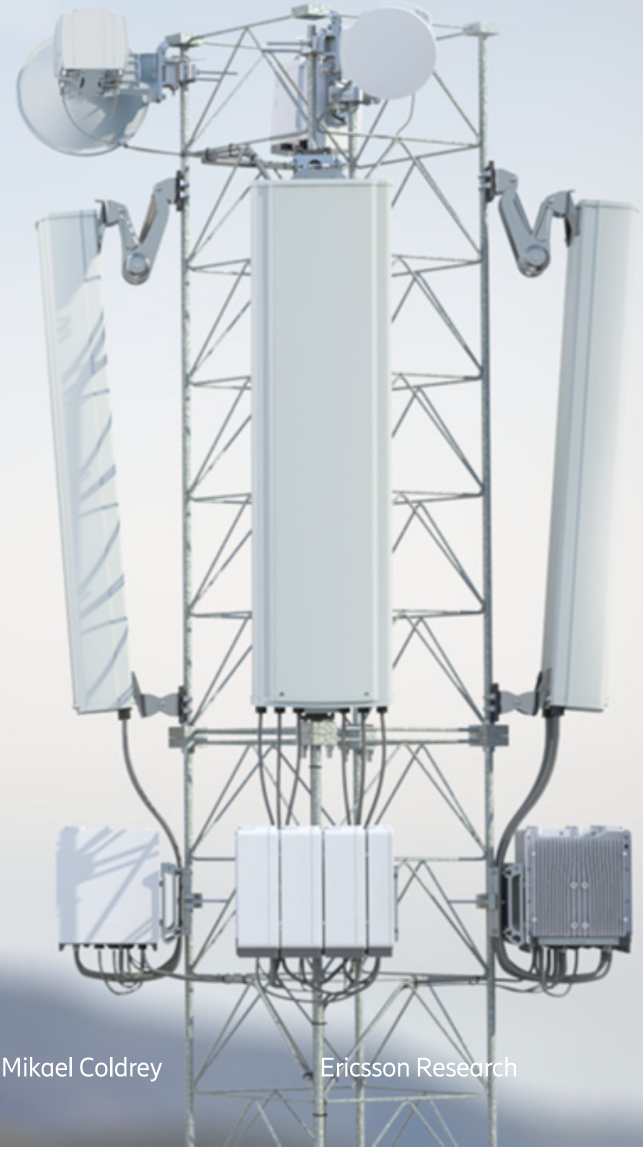
# The role and evolution of wireless backhaul technology



## Wireless Networks

2020-05-04

Dr. Mikael Coldrey
Ericsson Research

# Content

— Ericsson Research
— Introduction to backhaul
— Backhaul in the 5G era
— Spectrum & licensing
— Wireless backhaul technology
— MIMO "deep-dive"
— Conclusions


ERICSSON
THIS IS
ERICSSON RESEARCH

# Ericsson Research – innovate together

## 2G, 3G, 4G, 5G

it's all invented here

## >50%

involvement in all of Ericsson patents

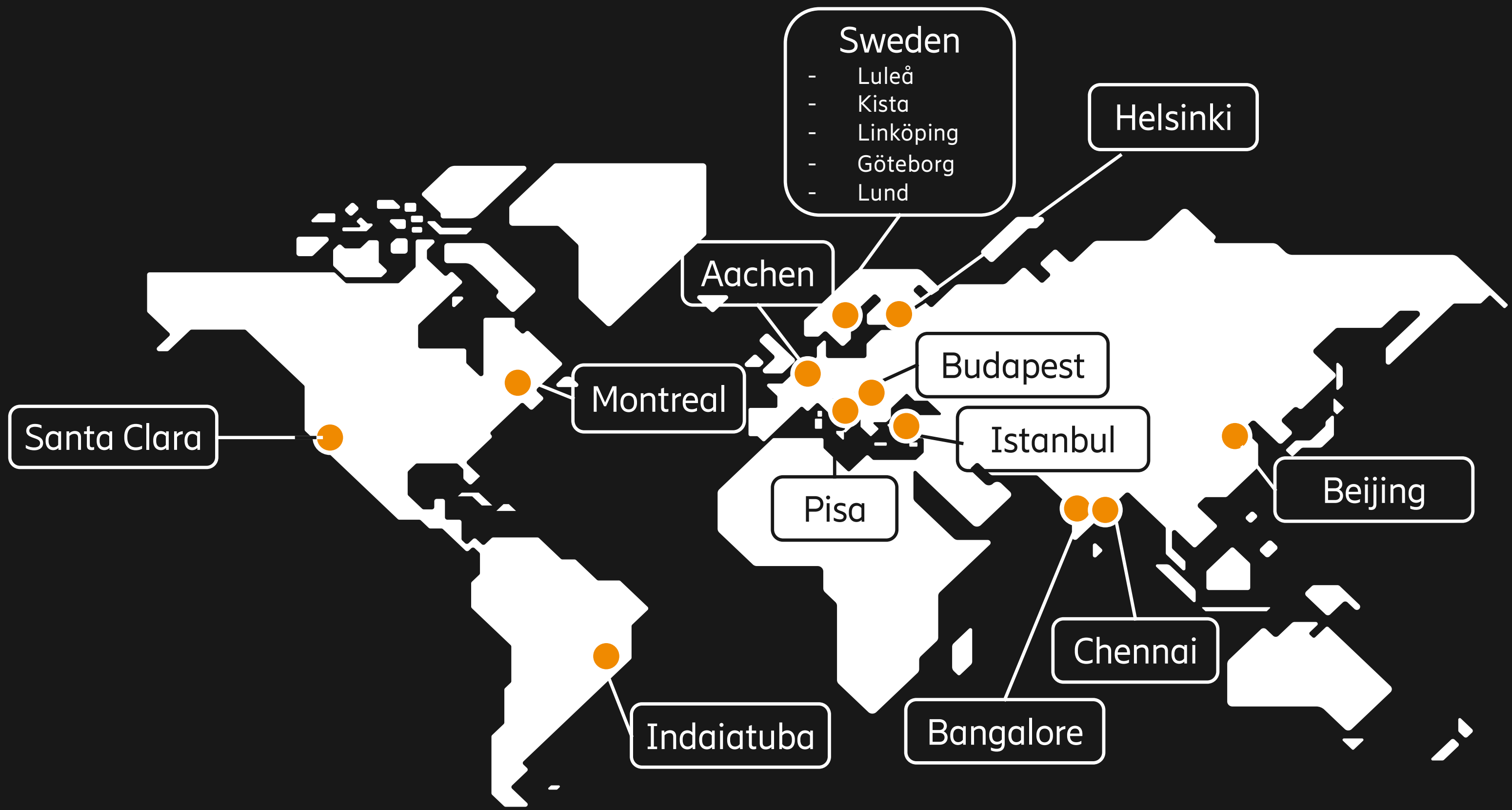
## Global networking

collaboration with operators, academia and industries

## >180 countries
## >100k employees

a unique Ericsson footprint

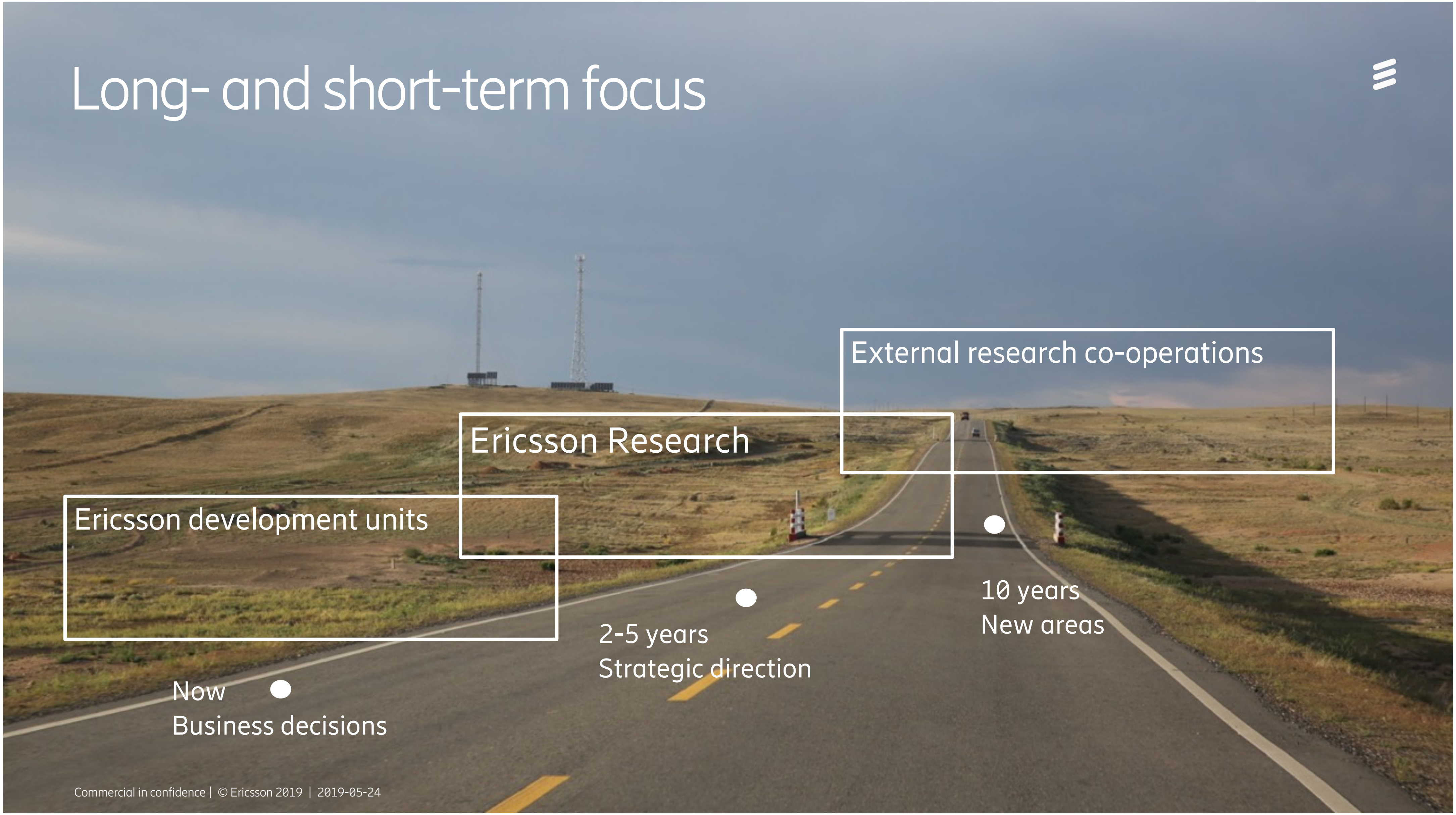
# Ericsson Research global presence

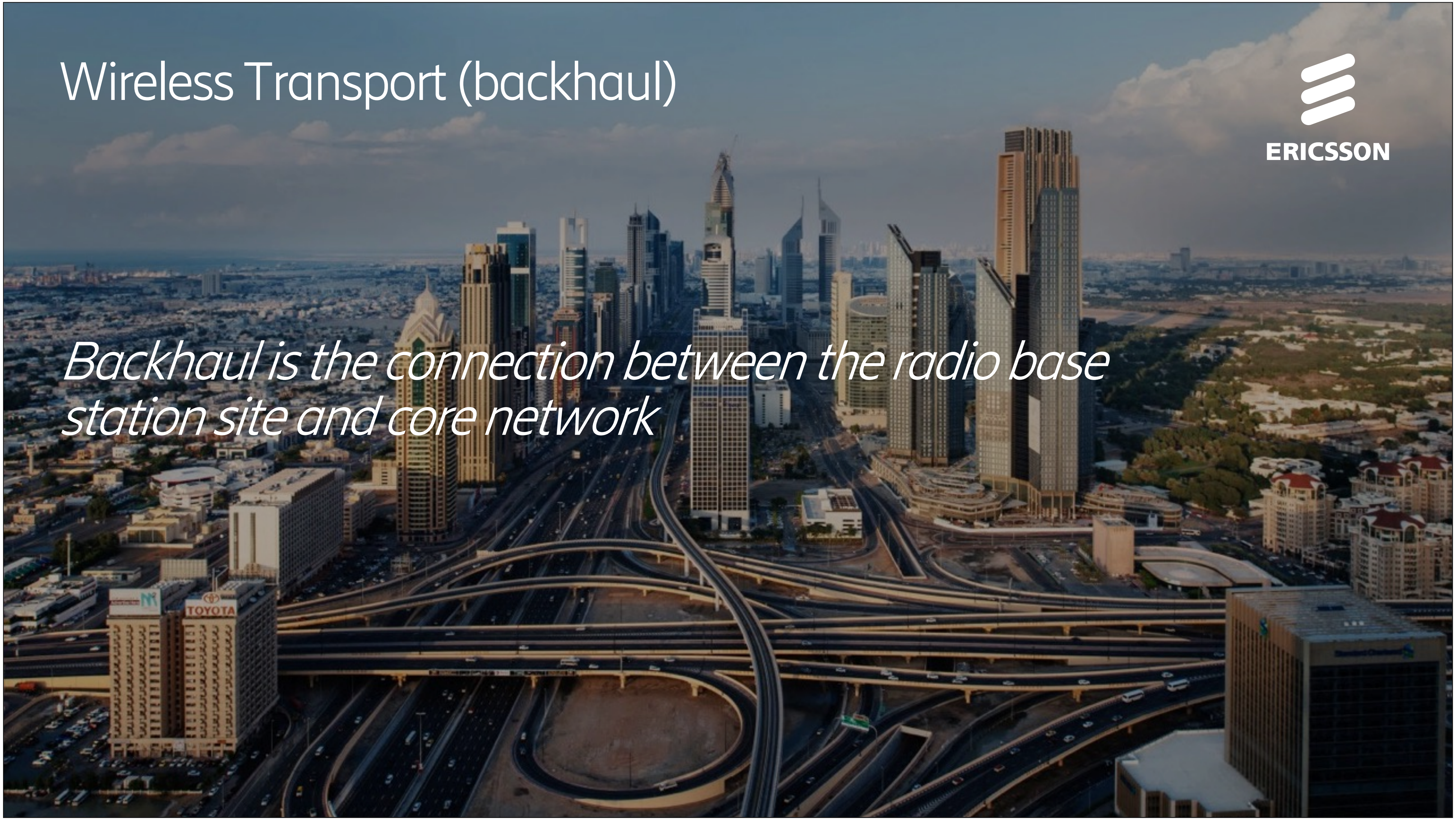



750
employees worldwide

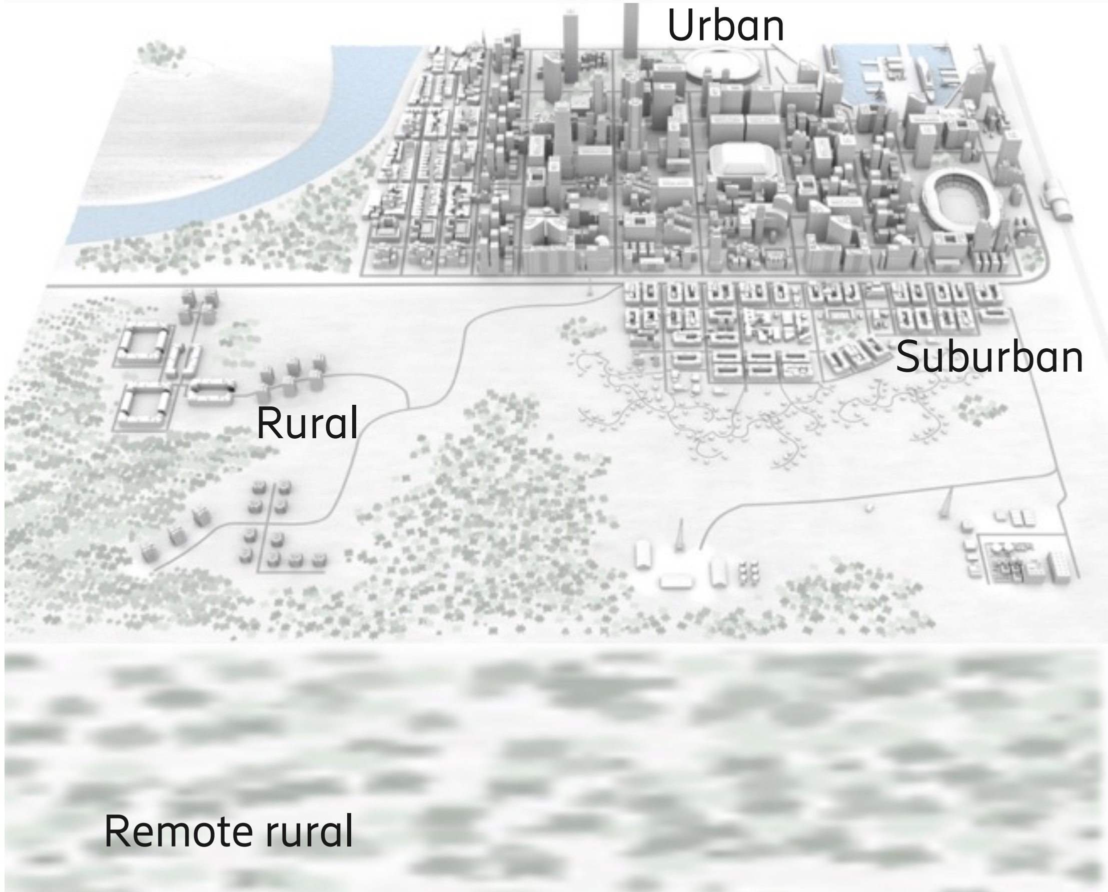
~50%
PhDs

10
countries

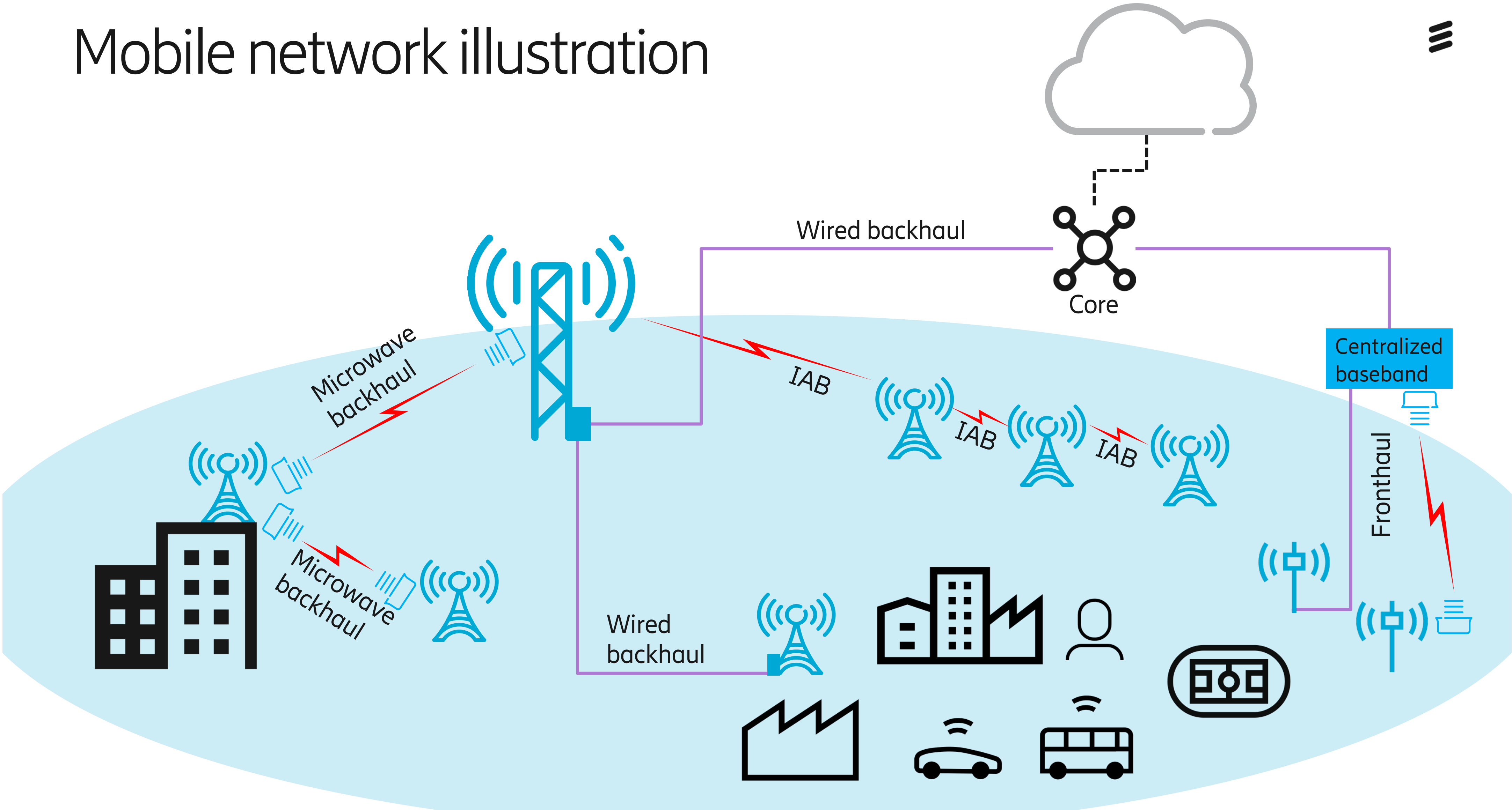

Long- and short-term focus
External research co-operations
Ericsson Research
Ericsson development units
10 years
New areas
2-5 years
Strategic direction
Now
Business decisions
Commercial in confidence | © Ericsson 2019 | 2019-05-24


Wireless Transport (backhaul)
ERICSSON
Backhaul is the connection between the radio base station site and core network
TOYOTA

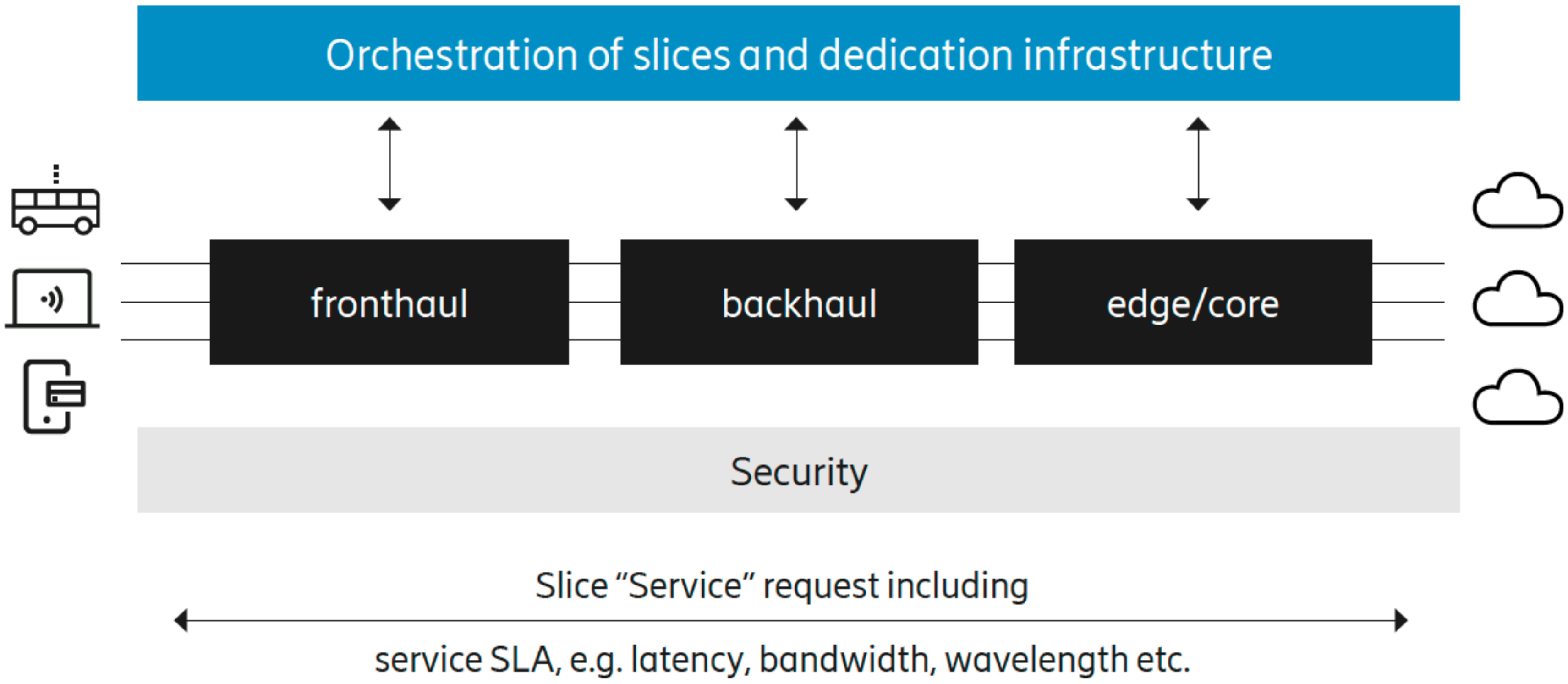
# Site deployments




# Mobile network illustration



# Network slicing
## Optimize for different 5G services




Network slicing and demanding services drive requirements on e.g. transport

# Capacity forecast

Backhaul capacity per site

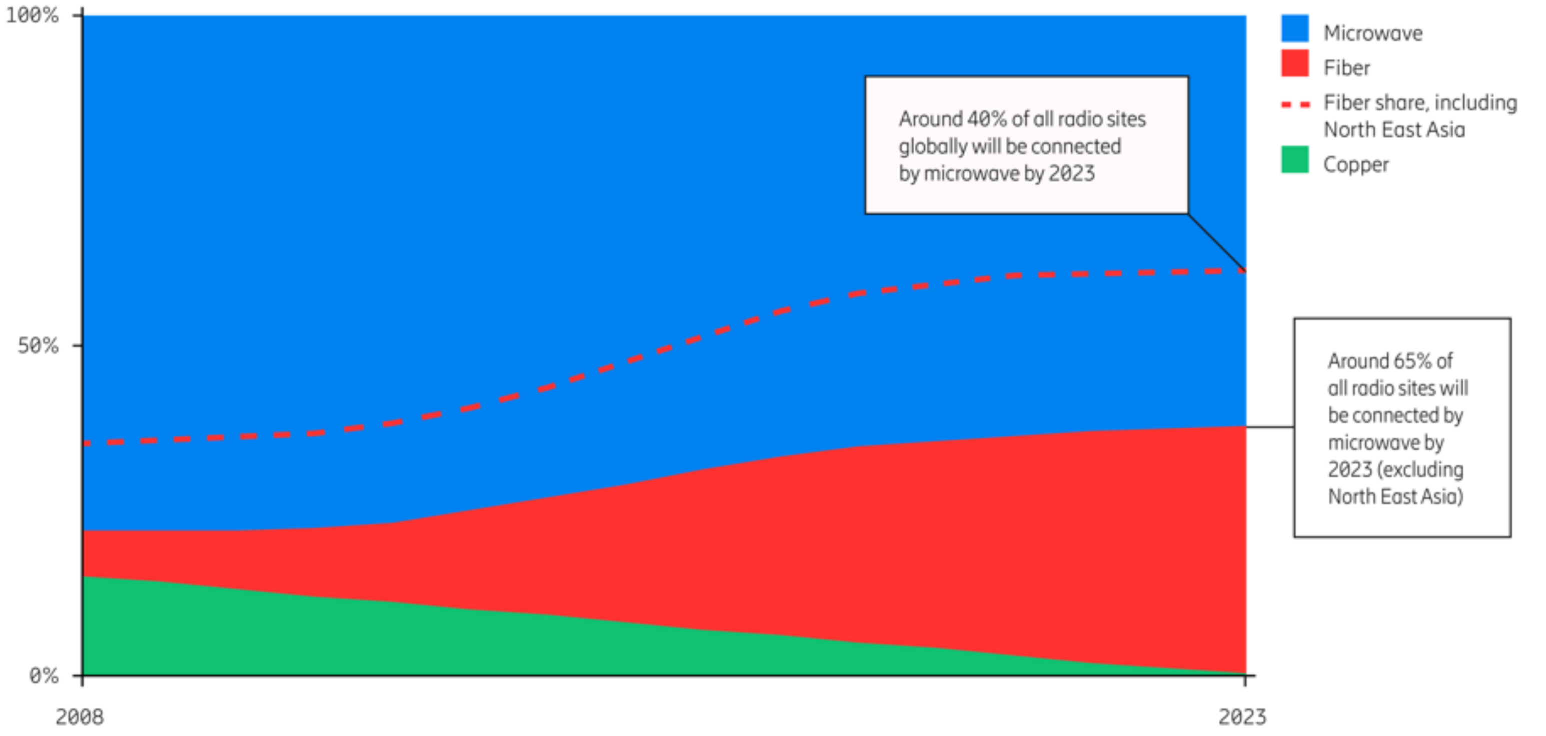
| | 2019<br>Low – high cap. sites | 2022<br>Low – high cap. sites | Towards 2025<br>Low – high cap. sites |
|---|---|---|---|
| Urban | 250Mbps – 2Gbps | 450Mbps – 10Gbps | 600Mbps – 20Gbps |
| Suburban | 100Mbps – 500Mbps | 200Mbps – 2Gbps | 300Mbps – 5Gbps |
| Rural | 50Mbps – 150Mbps | 75Mbps – 350Mbps | 100Mbps – 600Mbps |

Fronthaul capacity per site

| | 2019 | 2022 | Towards 2025 |
|---|---|---|---|
| Antenna site | up to 10Gbps | up to 25Gbps | up to 100Gbps |

Source: Ericsson (2019)

# Global backhaul media distribution




Source: Ericsson (2018)

Winning transport strategy:

Fiber and microwave

The choice between fiber and microwave will not be about capacity, it will be about fiber presence and TCO

# Spectrum outlook

## 5G spectrum is essential for society

The quest for more 5G spectrum will continue beyond WRC2019

- WRC2023 is next

And also outside WRC process to allow early deployments

- e.g. 28 GHz

Each regulator decides within its own country (guided by ITU)

## Backhaul spectrum remains important

Some essential global bands, other bands will differ in use

Use spectrum, or loose it

- e.g. 38 GHz in Europe & Middle East is heavily used for backhaul but is transitioned to 5G in North America

Efforts to share backhaul spectrum

- e.g. unlicensed radio in 6 GHz band

# 5G in former backhaul spectrum

## 70/80 GHz band

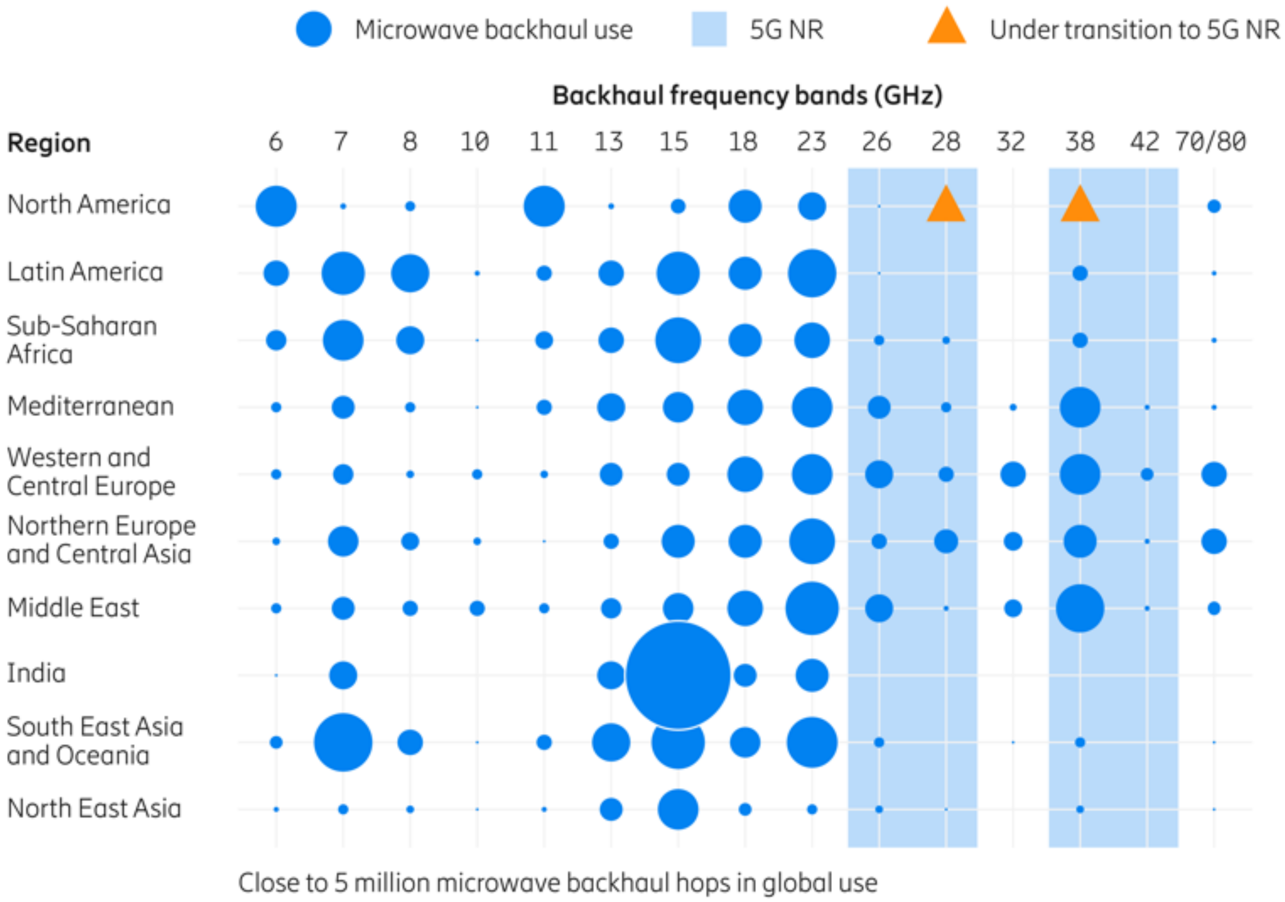
— Essential for backhaul with large global momentum

## 32 GHz band

— A backhaul replacement for 26 GHz and 28 GHz

## 11 to 23 GHz bands

— Support for 112 MHz channels is important



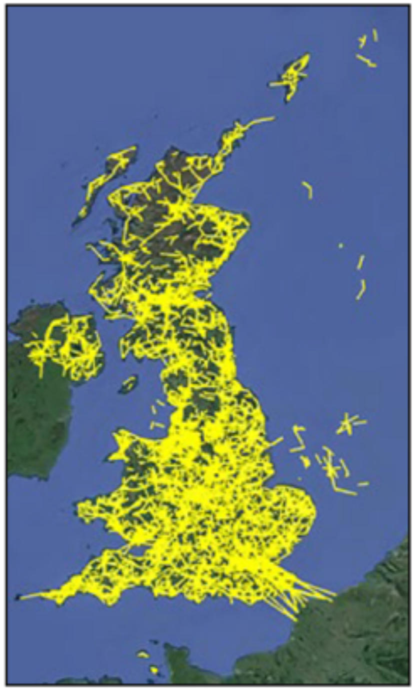

Source: Ericsson (2018)

# Example of backhaul spectrum use in the UK

6 and 7GHz

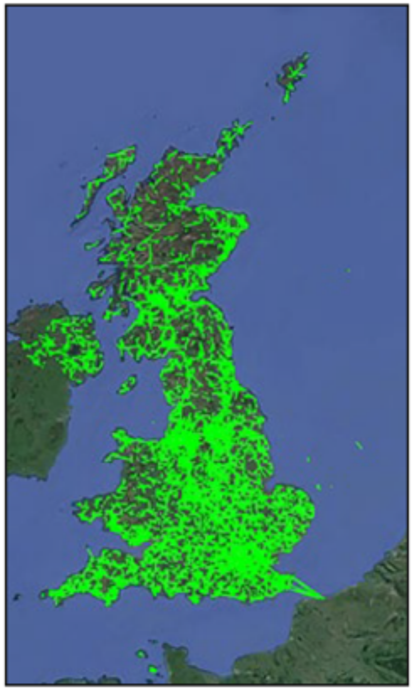
5% of all hops
30km average hop length

13 and 15GHz



23% of all hops
15km average hop length

18, 23 and 26GHz



46% of all hops
7km average hop length

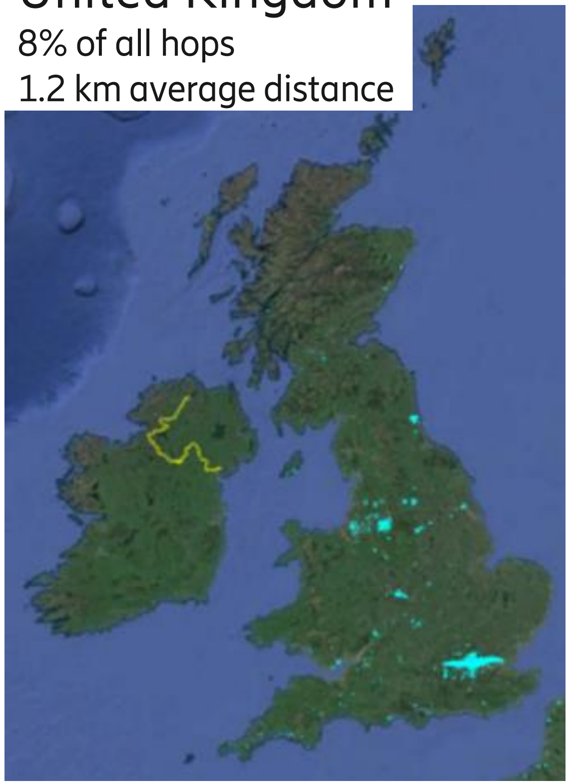
38 and 70/80GHz

26% of all hops
2.4km average hop length

Source: Ericsson based on OFCOM open data (2018)

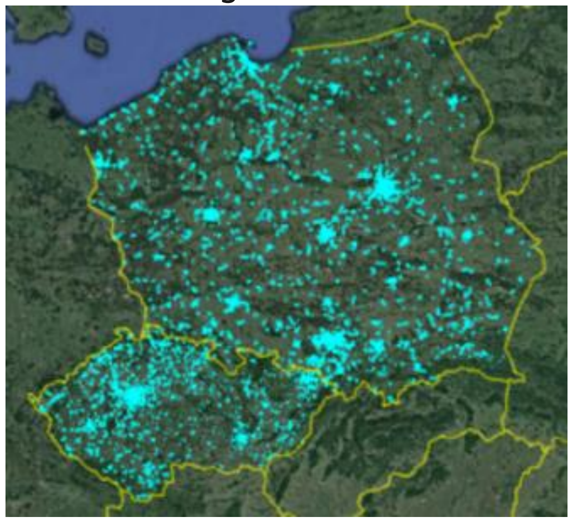
# The momentum of 70/80 GHz (E-band) backhaul

## United Kingdom
8% of all hops
1.2 km average distance



## France
4% of all hops
2 km average distance

## Poland
20% of all hops
2.8 km average distance



## Czech republic
20% of all hops
1.6km average distance

# Backhaul spectrum licensing schemes

## Radio access spectrum is block licensed

- Individual use in a *geographic area*, very expensive (auctioning)

## Backhaul spectrum is mostly point-to-point licensed

- Individual use between *geographic points* A and B

## Licensing schemes

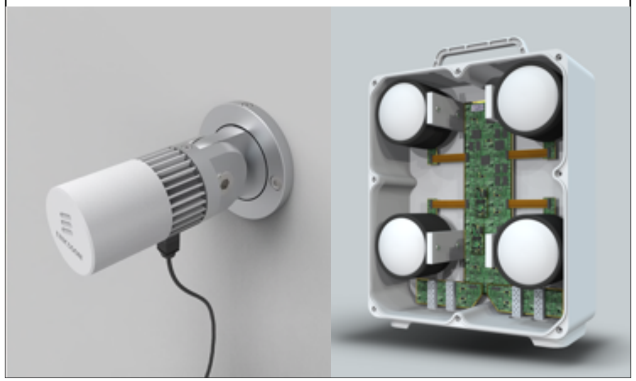
- Individual licensing
  interference analysis in regulator's database
- Light licensing
  "first come, first served" principle, user checks in public database and updates it, low cost
- Block licensing
  e.g. 28 GHz (transitioned to 5G in US)
- License exempt
  e.g. 2.4, 5.8, 60 GHz

# Short vs long haul

Short haul

- Up to 10-20 km
- 15 – 42 GHz, 60, 70/80 GHz
- < 25 Gbps

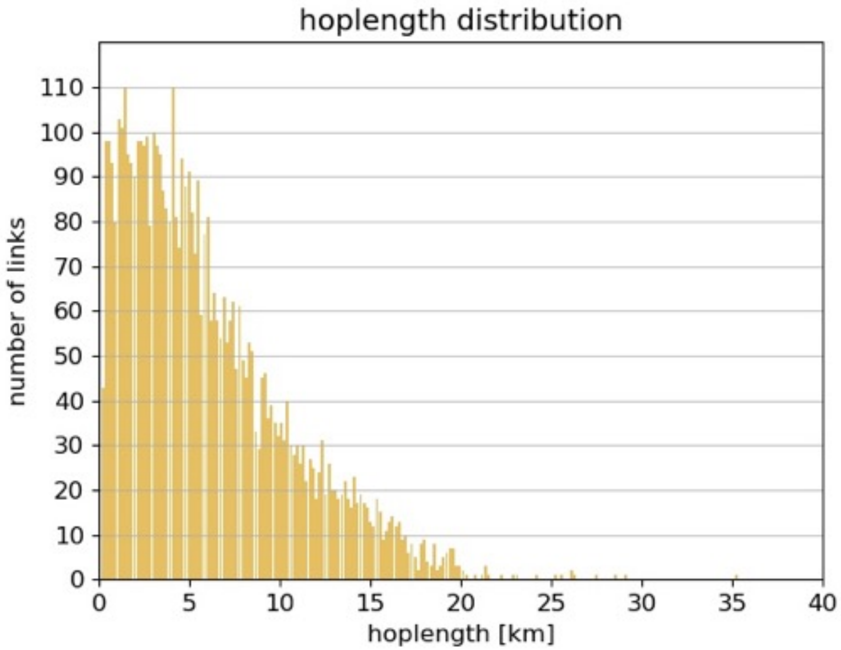
Future: beyond 100 GHz and towards 100 Gbps in E/W/D-bands

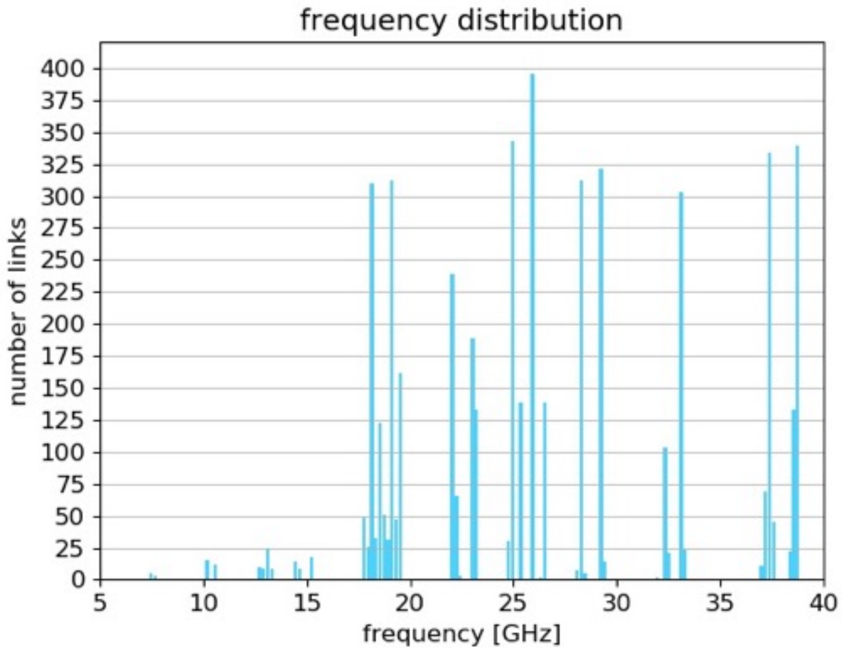


Long haul

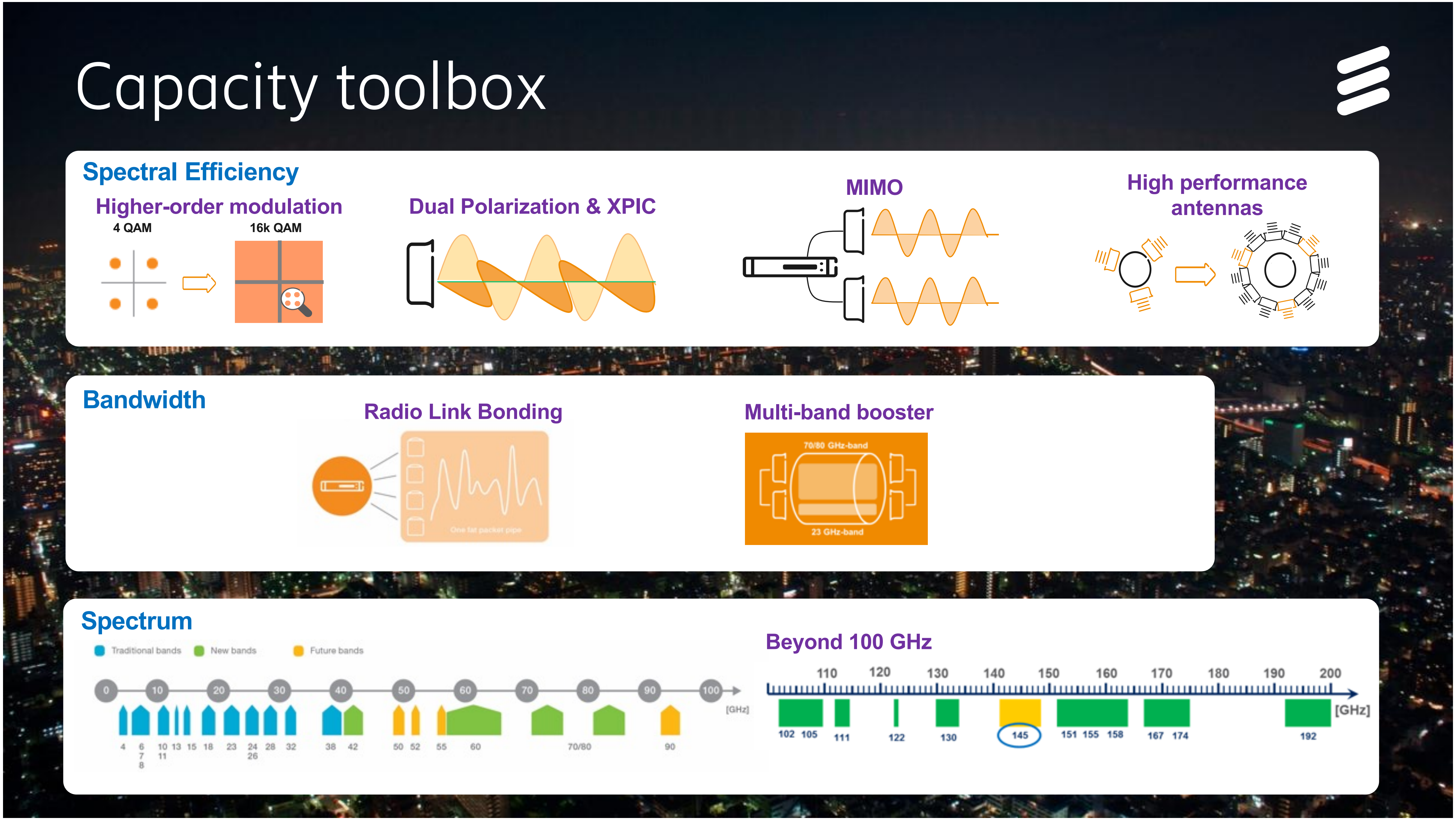
- 10 – 200 km
- 6 – 15 GHz
- < 10 Gbps

# Hop length statistics



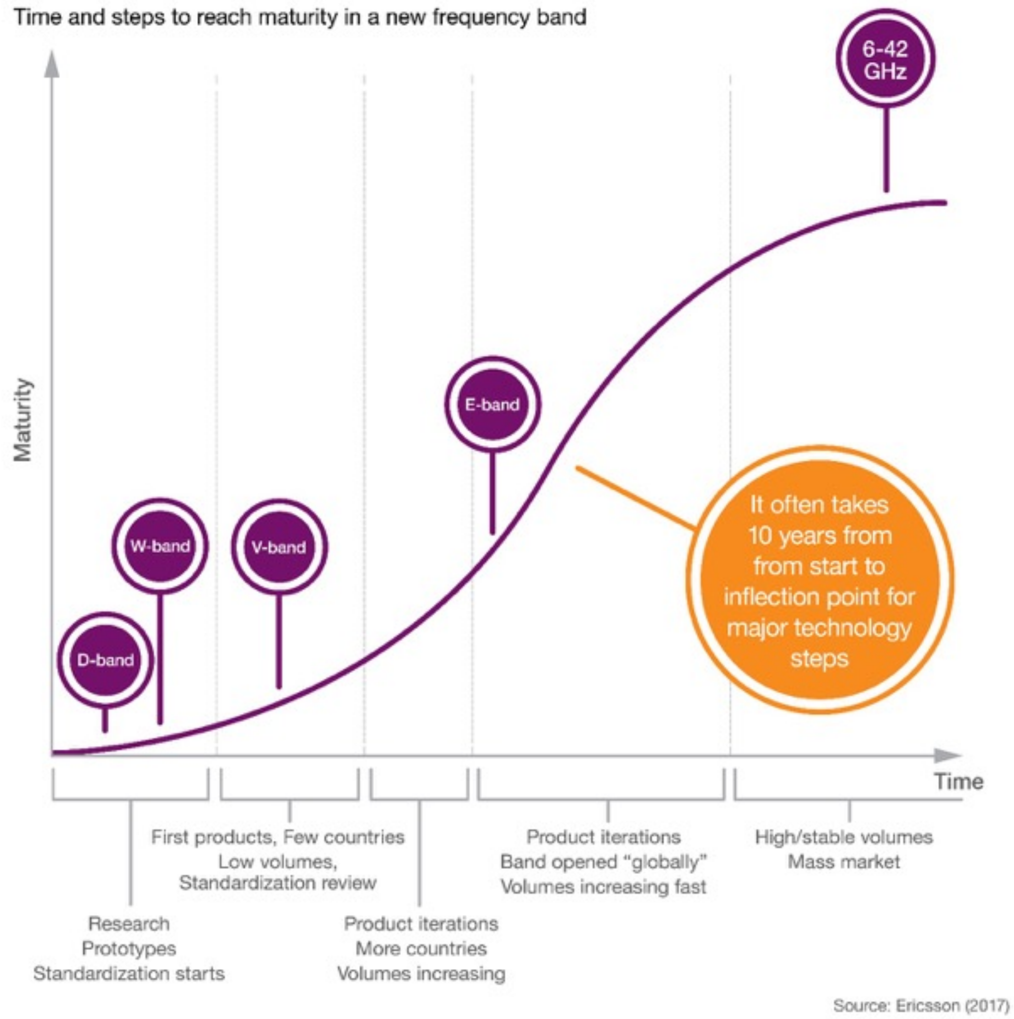

Currently 5052 hops in Sweden, Denmark and Germany in two different networks


Capacity toolbox
Spectral Efficiency
Higher-order modulation
4 QAM
16k QAM
Dual Polarization & XPIC
MIMO
High performance antennas
Bandwidth
Radio Link Bonding
Multi-band booster
70/80 GHz-band
23 GHz-band
Spectrum
Traditional bands
New bands
Future bands
0 10 20 30 40 50 60 70 80 90 100
[GHz]
4 6 7 8 10 11 13 15 18 23 24 26 28 32 38 42 50 52 55 60 70/80 90
Beyond 100 GHz
110 120 130 140 150 160 170 180 190 200
[GHz]
102 105 111 122 130 145 151 155 158 167 174 192

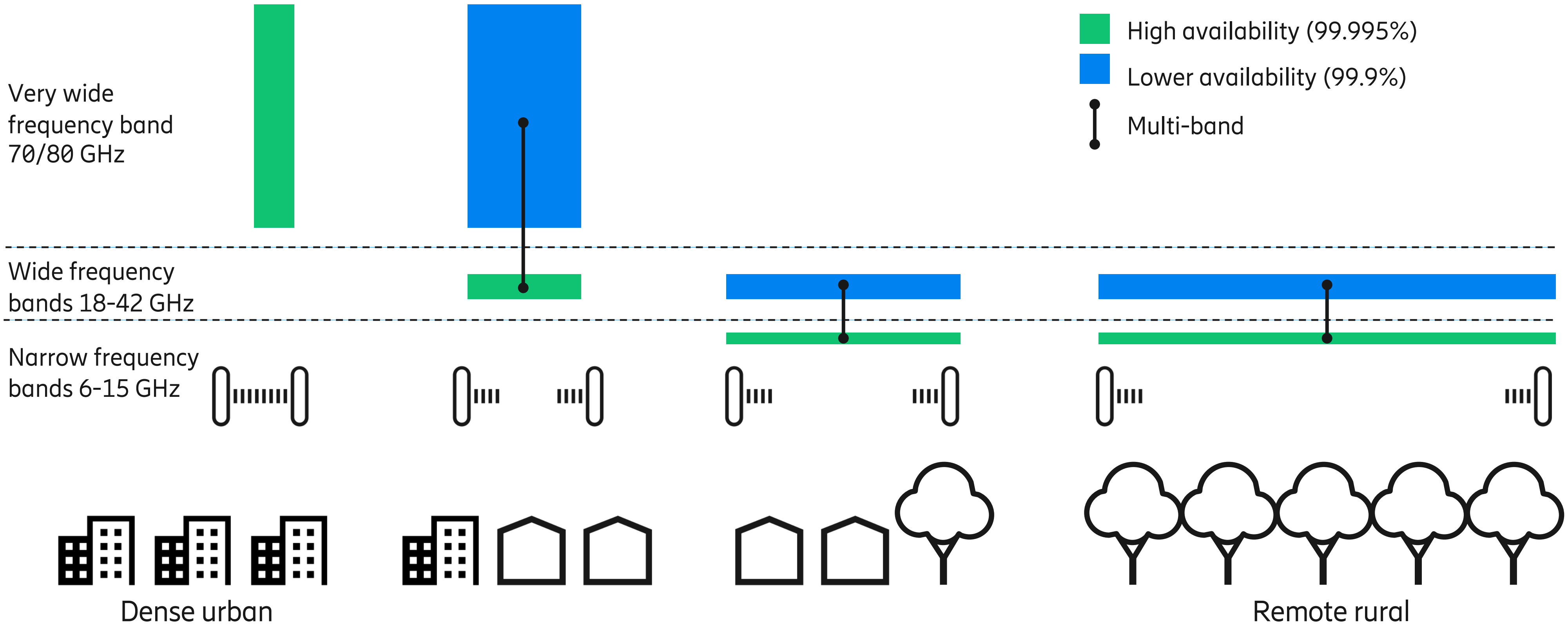
# W- & D-band

5

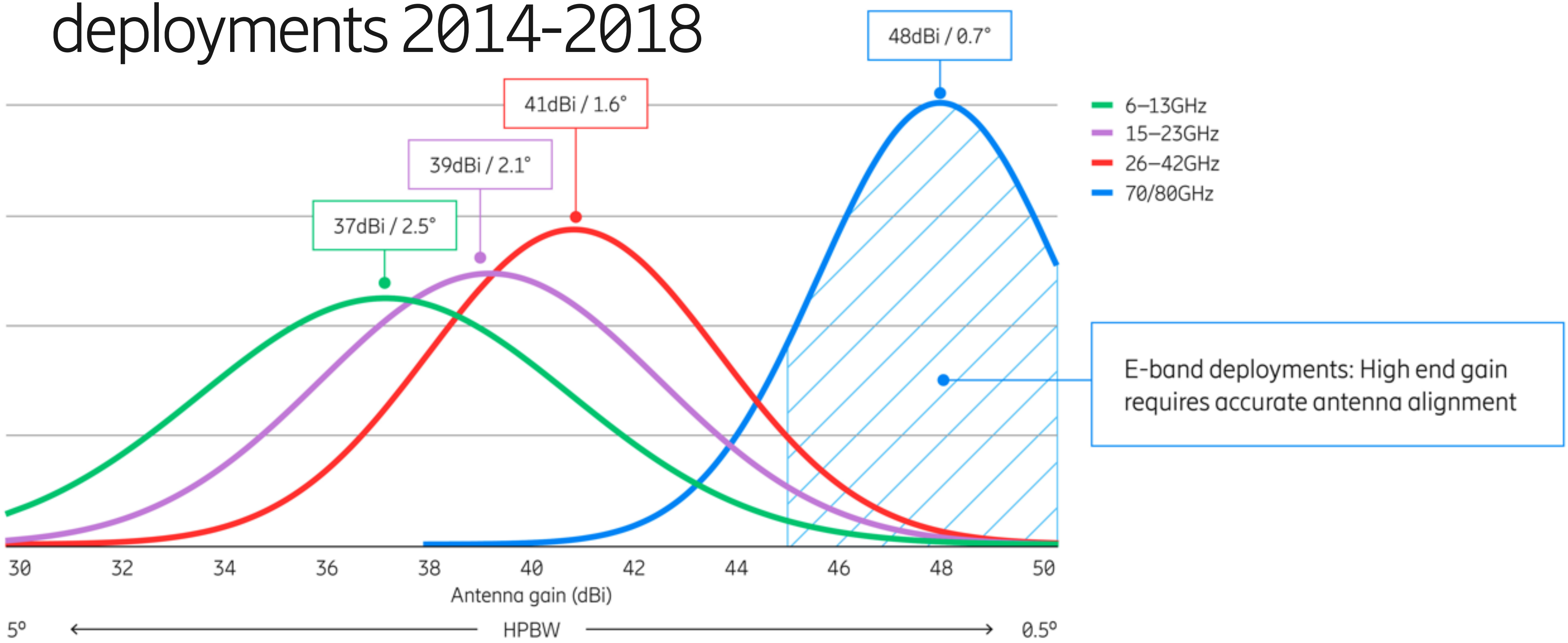
- Total amount of spectrum for W- and D-band is ~50 GHz – 5x more spectrum than E-band
- No significant use until 2025
- Approx 10 years for D-band to mature
- W-band will have a shorter journey due to its closeness to E-band



# Multi-band booster – combining different frequencies



# Antenna gain distribution per frequency range, deployments 2014-2018




Source: Ericsson (2019)

7

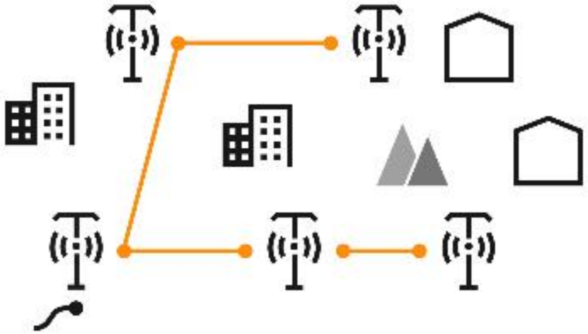
# Integrated Access and Backhaul (IAB)
## 5G NR self-backhauling

Extend coverage for 5G NR mmWave

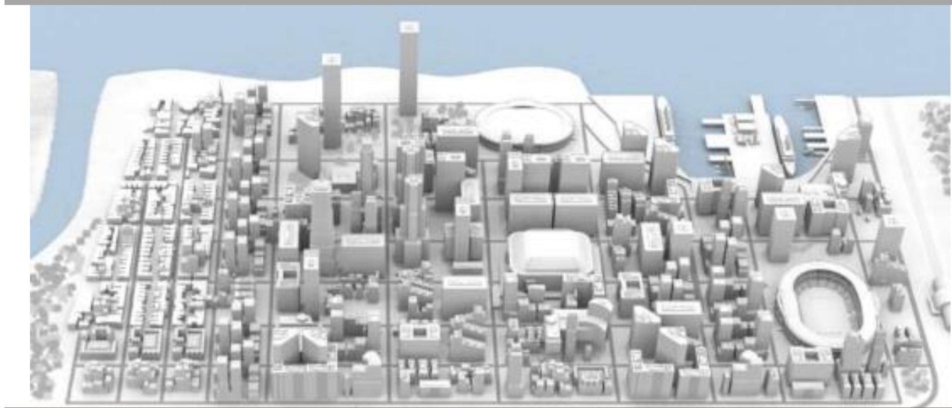
Street level sites

In-band IAB – access and backhaul in same band

In 3GPP Release 16 & 17 (ongoing)



Above the clutter - Rooftop & tower sites

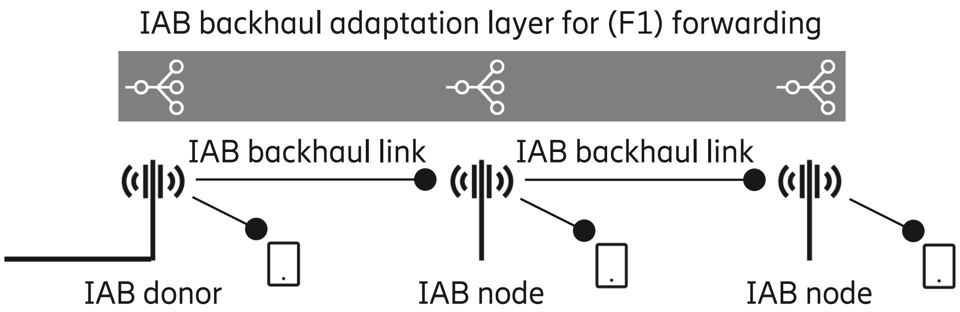


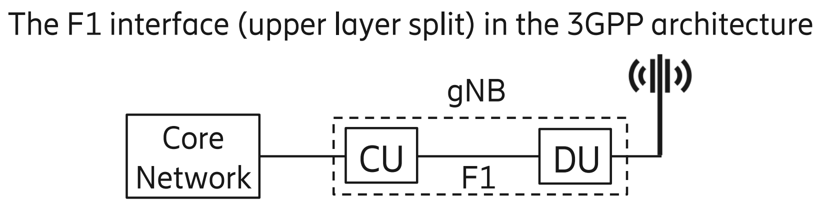
In the clutter – street level sites on wall, pole & strand

# 5G NR – IAB characteristics

Backhaul as an embedded 5G NR feature

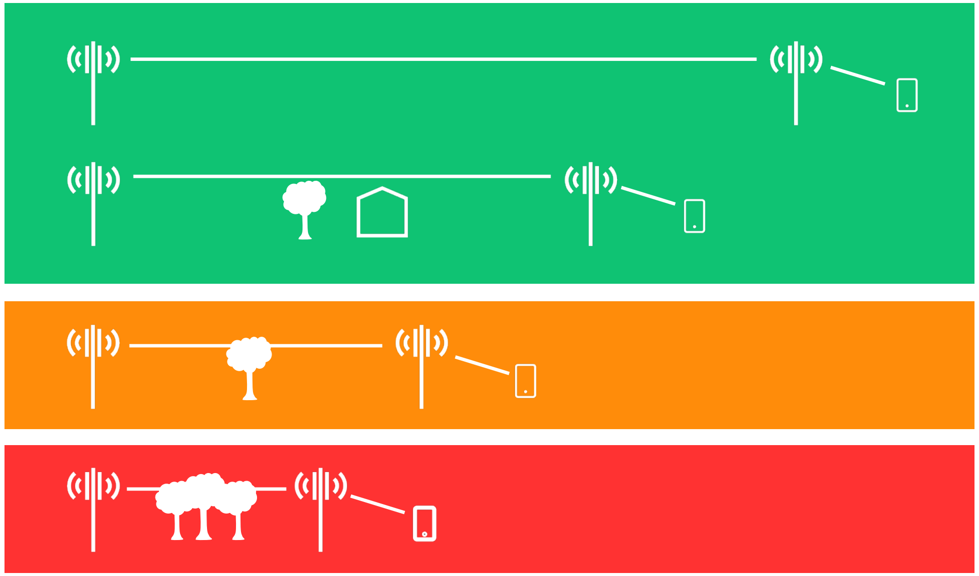
In 3GPP Release 16 & 17 (ongoing)



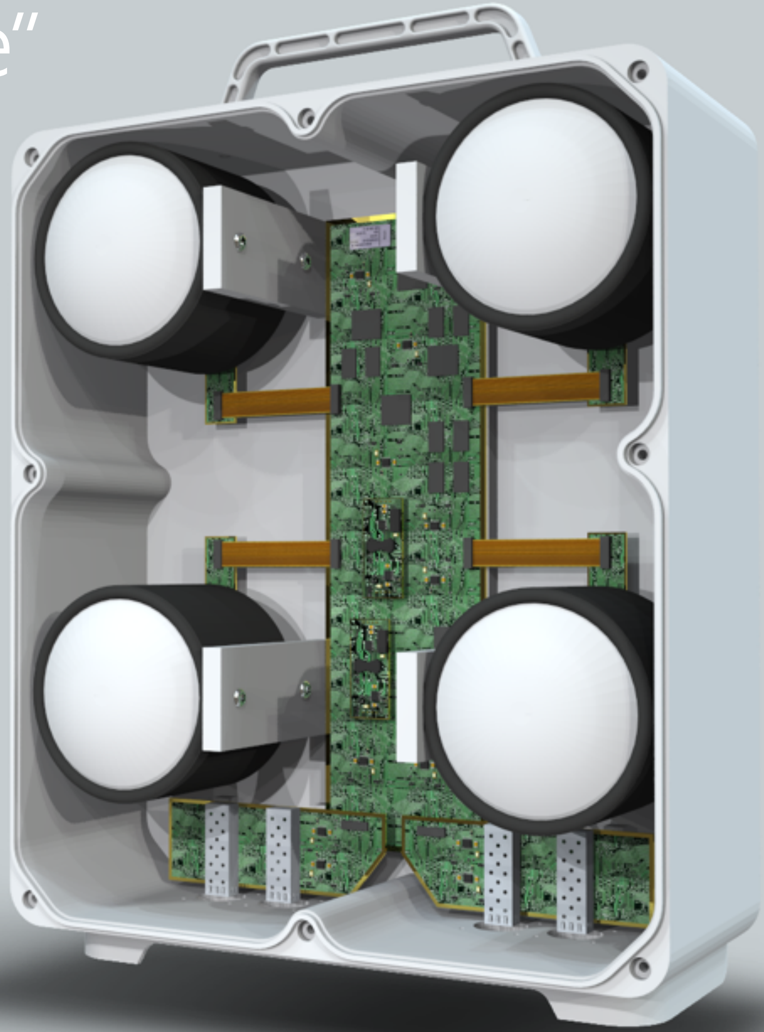




Typically a few hundred meters distance

Up to about a kilometer for line-of-sight



# MIMO "deep dive"



Introduction

Principles of MIMO

Considerations when deploying MIMO

Breaking through 100 Gbps

Final remarks

Q & A

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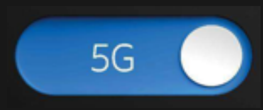
# Driving forces

x5

Total mobile data traffic is expected to increase five times by 2024




In 2024, 25 percent of mobile data traffic will be carried by 5G networks

More spectrum in RAN

Limited backhaul spectrum

Calls for even more spectral efficient wireless backhaul !

# History of MIMO in wireless

## Multiple Input Multiple Output

Receive antenna diversity in 1920's

Spatial Division Multiple Access (SDMA) in 1980's

MIMO theory by Bell Labs in 1990's
Multiple streams over the same bandwidth

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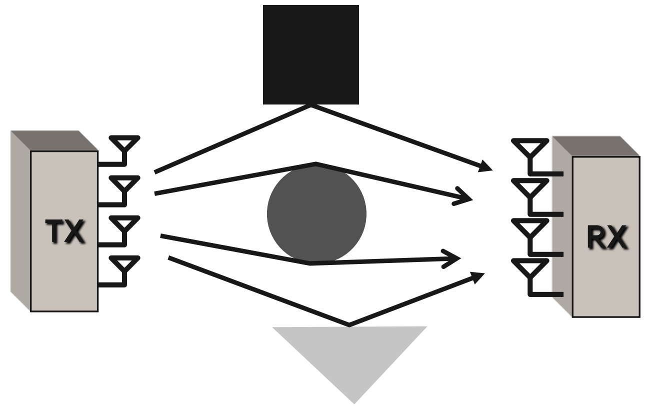
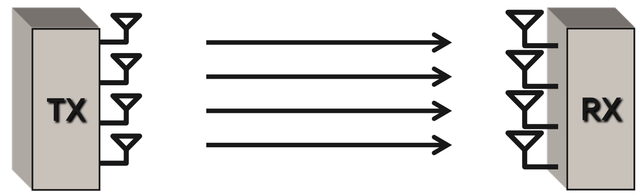
# Propagation

## multipath vs line-of-sight (LOS)

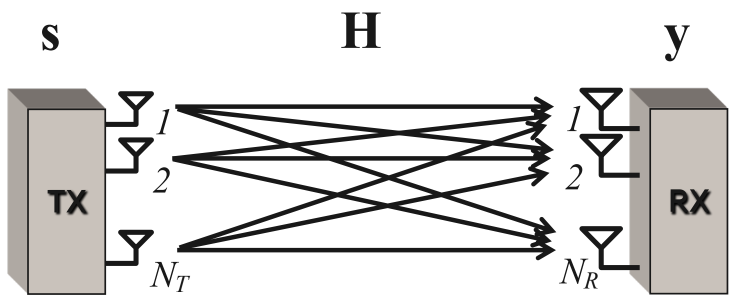
| | |
|---|---|
| **MIMO in 3GPP/Wi-Fi**<br>0.5-10 wavelengths in antenna separation | Exploit multipath propagation<br><br>LOS is not good for MIMO → correlated channels<br><br>Multipath usually implies high path loss → low Signal-to-Noise Ratio (SNR) |
| **MIMO in microwave**<br>100-1000 wavelengths in antenna separation | Exploit LOS propagation<br><br>Exploit antenna/channel orthogonality → large antenna separations in wavelengths<br><br>LOS implies low path loss → high SNR |



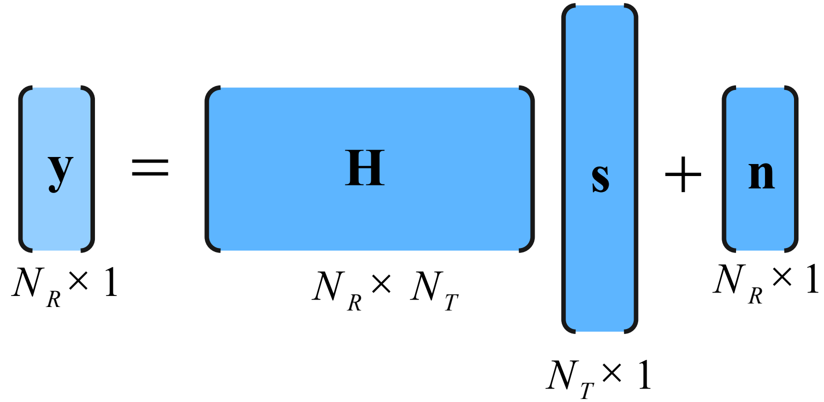



# The MIMO channel matrix

- The matrix $\mathbf{H}$ represents the propagation channels between all Tx and Rx antennas
- In microwave, the system is typically symmetric, i.e. $N_R = N_T$
- The received signal is mixed up by the MIMO channel




- Knowledge of the MIMO channel matrix provides
  - Signal reconstruction at Rx
  - Precoding at Tx
  - Analysis of MIMO channel (performance)
    - function of antenna deployment, frequency, hop length, etc.



# Analysis of MIMO channel matrix


— A very useful tool from linear algebra is the Singular Value Decomposition (SVD) of a matrix which diagonalizes any matrix

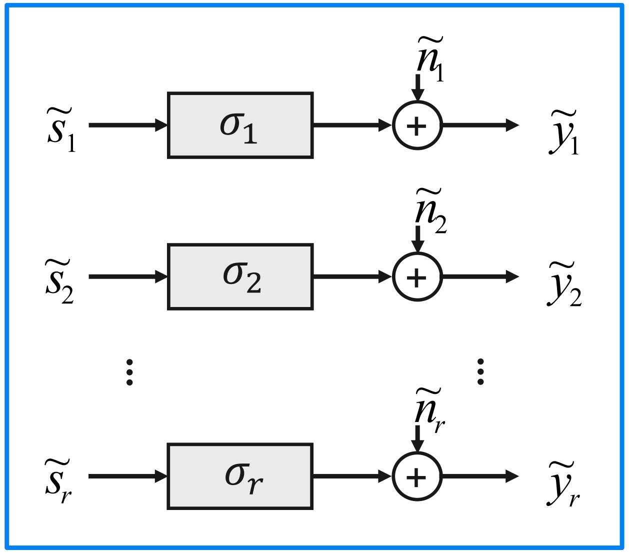
$\boldsymbol{H} = \boldsymbol{U}\,\boldsymbol{\Sigma}\,\boldsymbol{V}^H$ $\boldsymbol{U}$ and $\boldsymbol{V}$ are unitary and $\boldsymbol{\Sigma} = diag(\sigma_1, \sigma_2, \dots)$ contains the singular values

— The SVD can be used to transform the MIMO channel to parallel Single-Input Single-Output (SISO) channels

**Parallel SISO channels!**

$$\tilde{y}_i = \sigma_i\, \tilde{s}_i + \tilde{n}_i,\;\; i = 1 \dots r$$

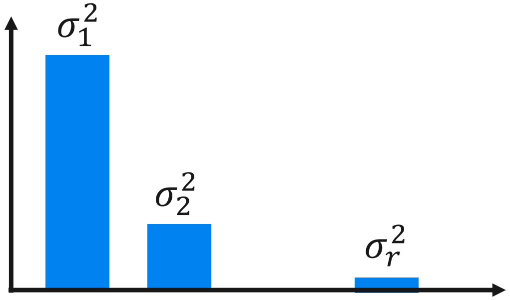
$$C_{MIMO} = \sum_{i=1}^{r} C_{SISO}(i) \quad \text{bps/Hz}$$



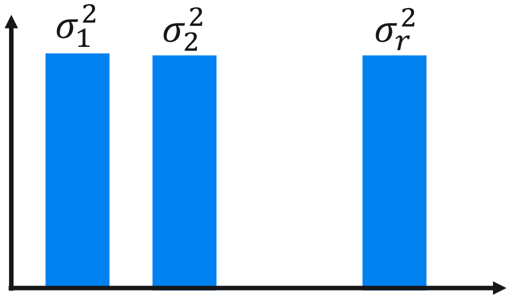
# MIMO is like multiple SISO channels

$$C_{MIMO} = \sum_{i=1}^{r} \log_2(1 + \rho\, \sigma_i^2) \quad \text{bps/Hz}$$

- The singular values tell us how good these SISO channels are
  - They are related to the SNRs of the SISO channels
- So how do they typically look?
- In a multipath MIMO propagation channel they may vary a lot

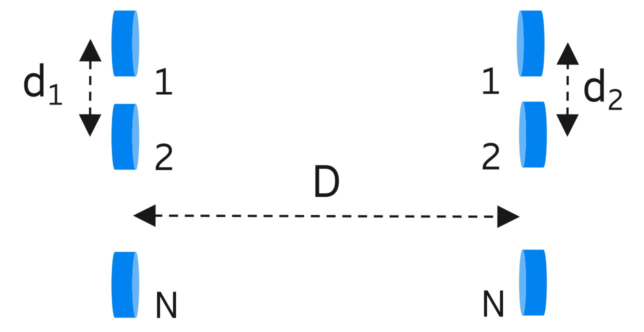



- However, in a properly designed LOS MIMO propagation channel they may all be equal
  - Equal singular values maximize the MIMO capacity !!



# How to design for equal singular values?

- Analytical expressions exist for uniform arrays
- Some important observations about the optimal antenna separation
  - It depends on wavelength (frequency)
  - It depends on hop length
  - It depends on the number of antennas
    - a site installation constraint
- What happens for suboptimal antenna spacings?
  - The singular values become unequal
  - Translates to a loss in SNR (loss in system gain)
  - Depending on implementation the SNR loss may be the same or different for all data streams

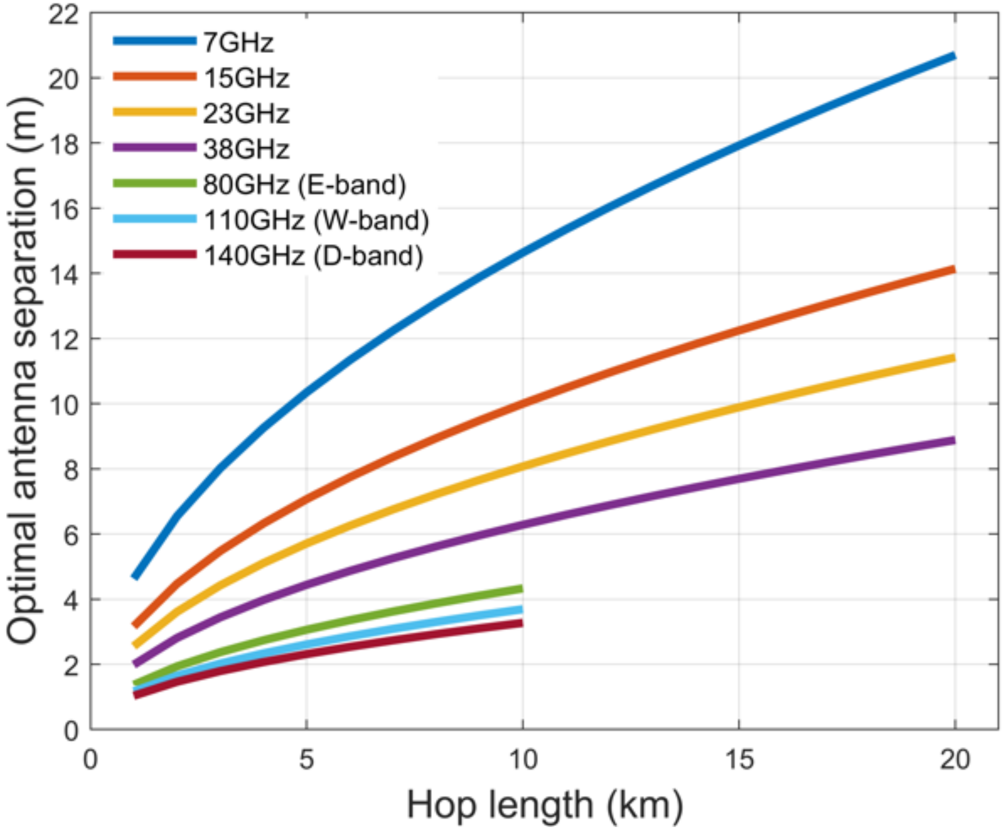


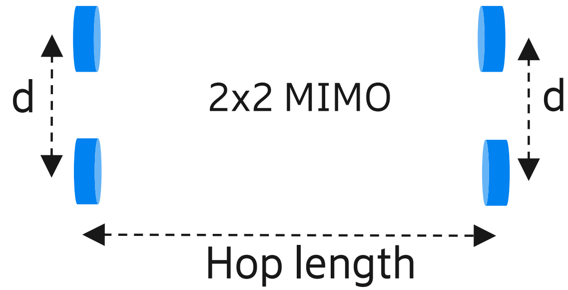

Some analysis gives optimal antenna separation in the symmetric NxN case:

$$d_1 d_2 = \frac{D\,\lambda}{N}$$

$d_1$ and $d_2$ are antenna separations
D is hop length
λ is wavelength
N is number of antennas

# Optimal antenna separation




Example 1: 2x2 MIMO system covering 20 km at 15 GHz would need 14 m antenna separation for optimum performance

Example 2: 2x2 MIMO system covering 1 km at 140 GHz would need 0.5 m antenna separation for optimum performance

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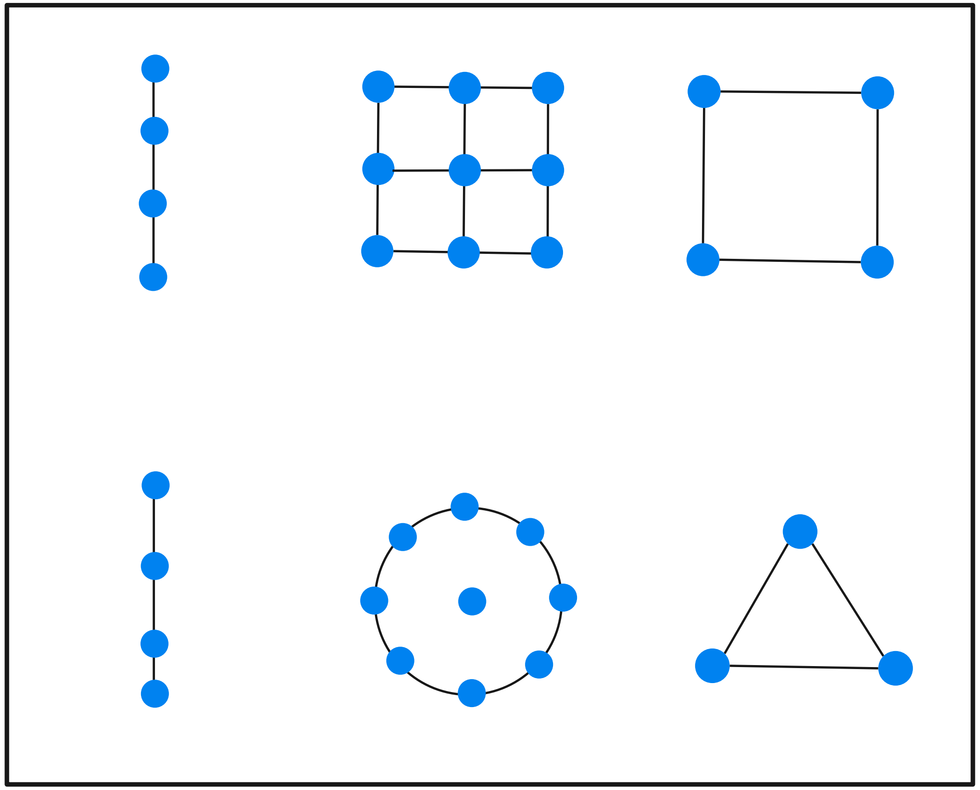
# Antenna arrangements

Possible antenna arrangements

- Linear arrays
- Planar arrays
- Regular arrays
- Irregular arrays

The “optimal” antenna placement depends on

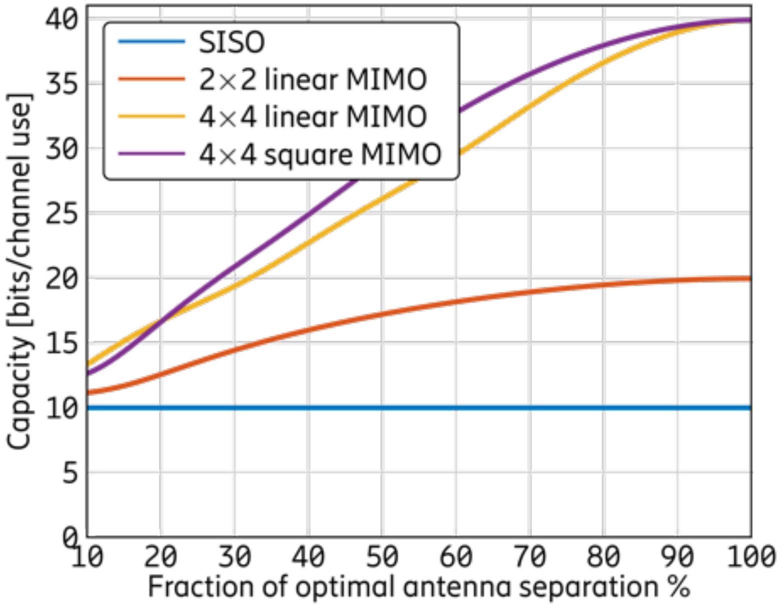
- Frequency
- Hop length
- Antenna arrangement
- Site constraints



# Suboptimal antenna separation

## capacity and singular values

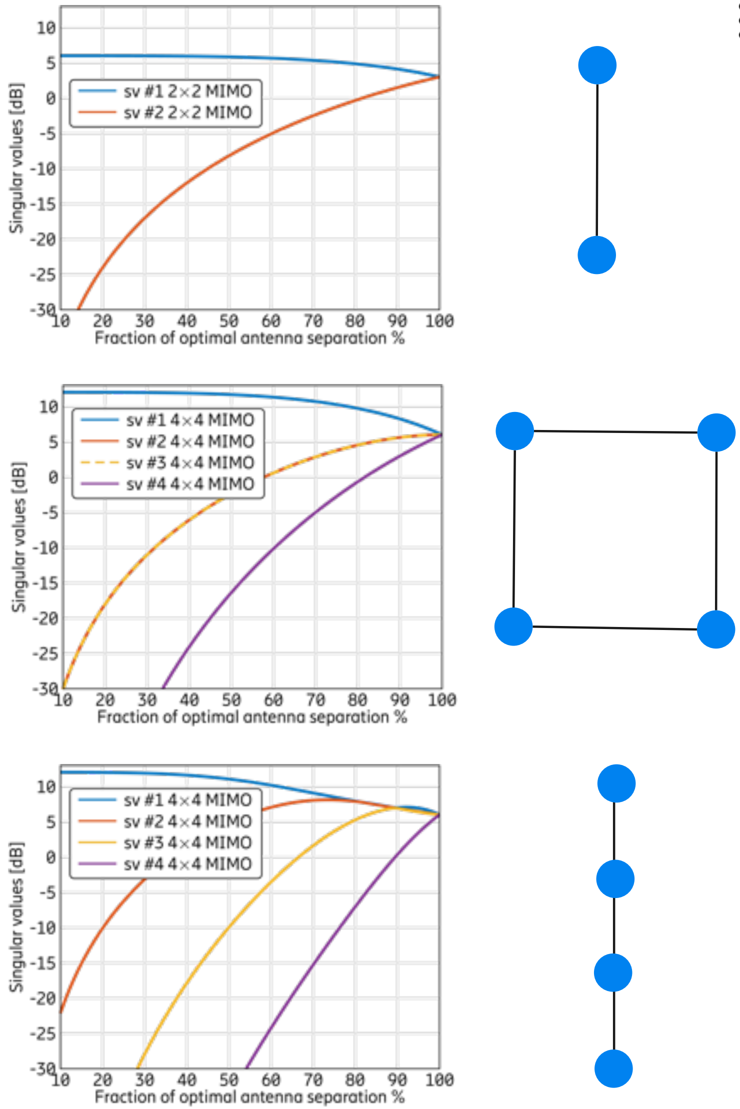
Spectral efficiency




— Optimal capacity is attained at optimal antenna separation (100%)

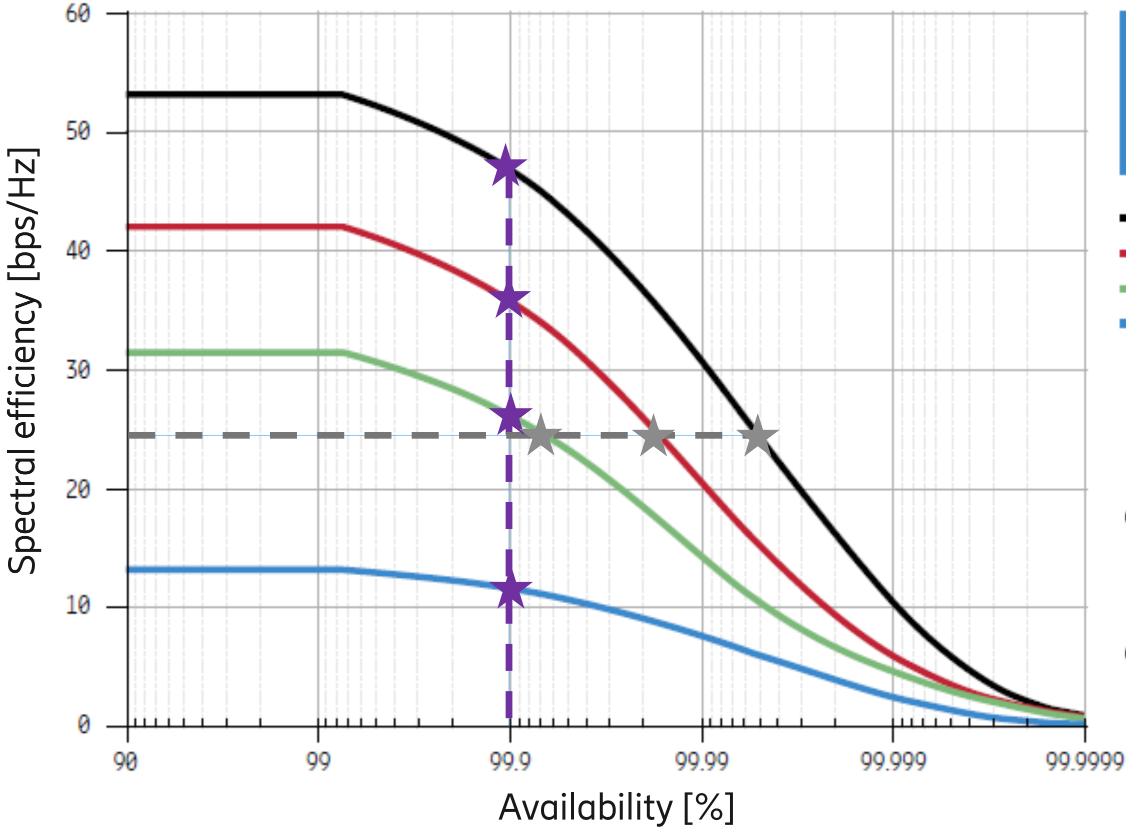
— Huge gains over SISO also at 50% separation

Singular values

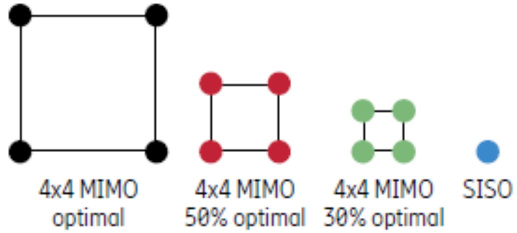


# Suboptimal antenna separation

## capacity vs availability trade-off




Sub-optimal antenna separation is a trade-off between MIMO capacity and availability.



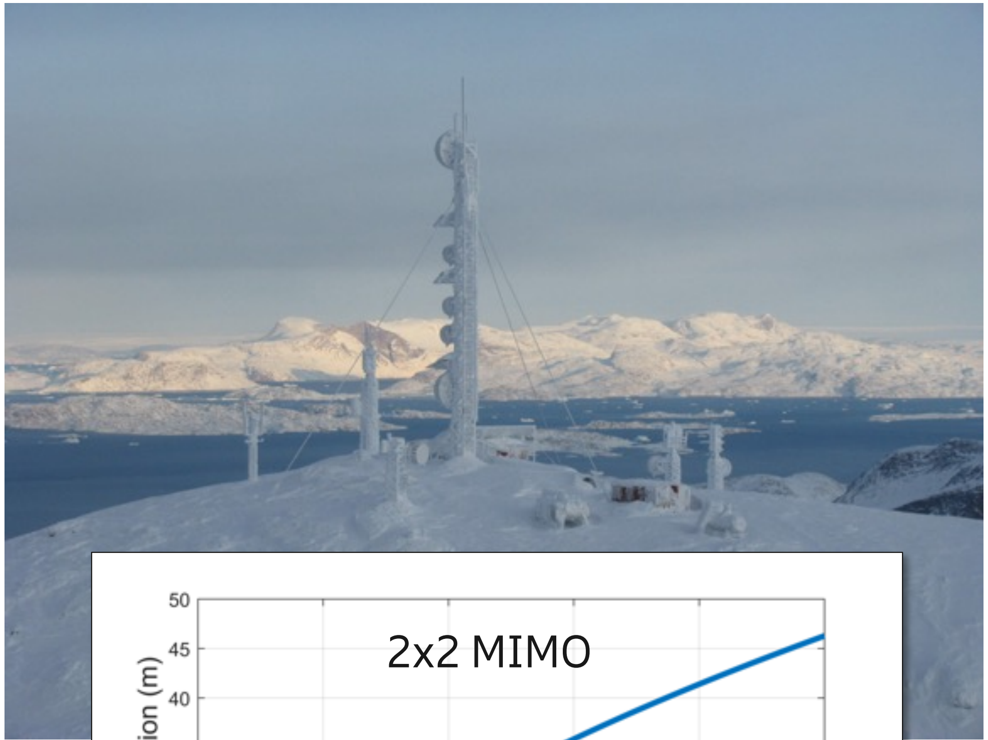
# MIMO in long haul

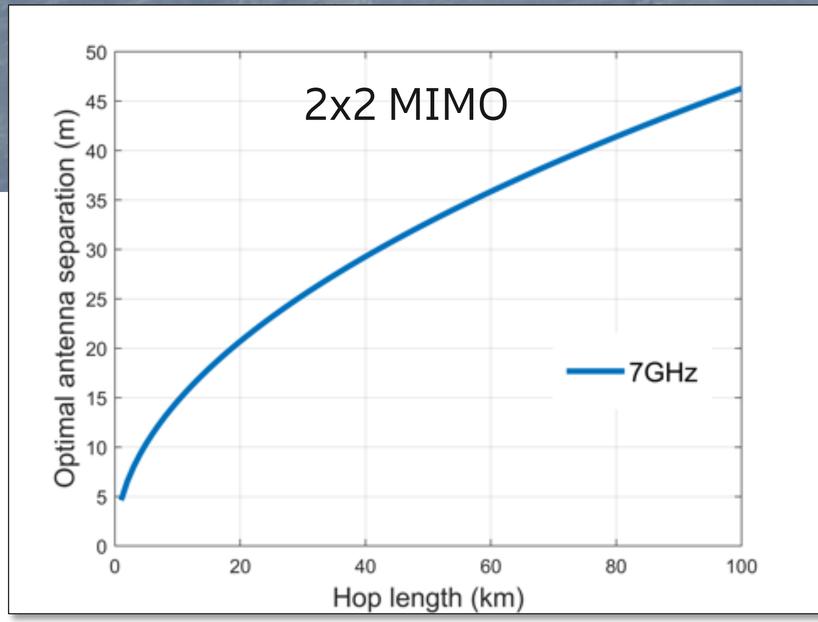
- Rule of thumb antenna separation for spatial diversity systems is ~200 wavelengths
  - Example
    - 8.6 m at 7 GHz

- Example of 2x2 MIMO deployment at 7 GHz
  - If 8.6 m (100% of optimal) separation is used → 3.5 km hop
  - If 8.6 m (50% of optimal) separation is used → 13.8 km hop

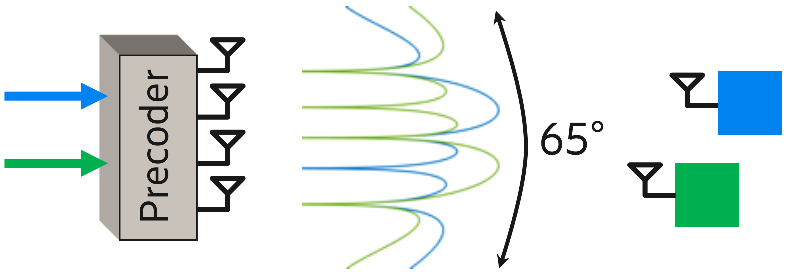
- However, up to 15-20 m spatial diversity deployments exist

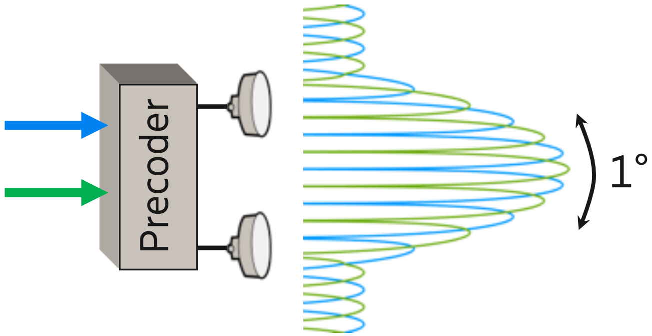
- If 15 m is 50% of optimal separation → 42 km hop
- If 20 m is 50% of optimal separation → 75 km hop





# Precoding in MIMO systems



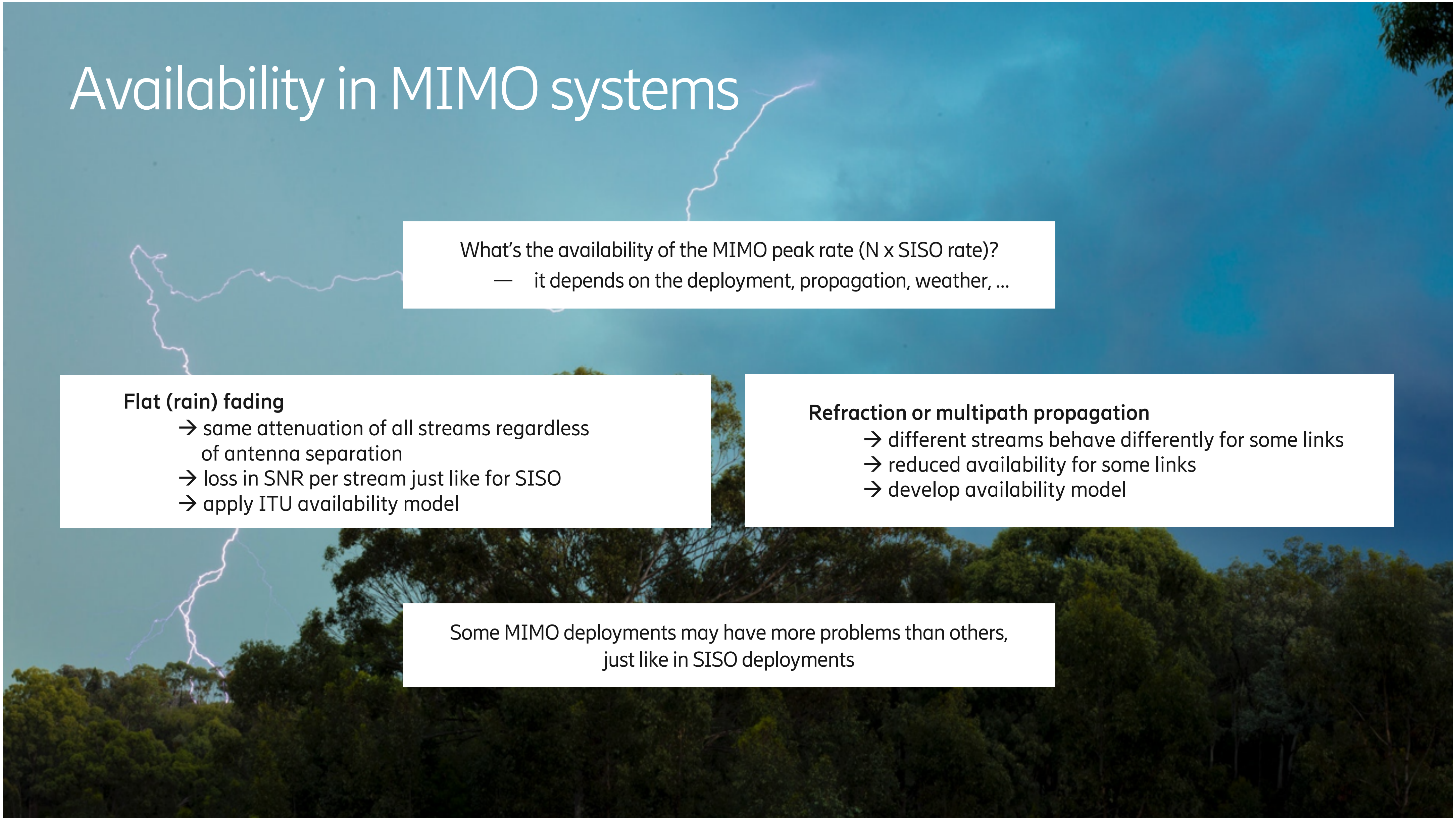




- Precoding is a generalization of beamforming
  - Transmit data to a "user" while minimizing interference to other "users"
- Requirements
  - channel knowledge at Tx...
  - phase synchronized transmitters...

- Dynamic digital implementation (analog and hybrid is possible too)
  - Orbital Angular Momentum (OAM) is like a static analog precoder
  - The SVD (the linear algebra exercise) gives us a digital precoder
  - There's alternative digital precoders

- When and why use precoding in microwave systems?
  - Little or no benefit for optimally deployed MIMO systems
  - For suboptimal antenna separations precoding gives improved
    - availability
    - capacity

?



# Availability in MIMO systems

What's the availability of the MIMO peak rate (N x SISO rate)?

— it depends on the deployment, propagation, weather, ...

**Flat (rain) fading**

→ same attenuation of all streams regardless of antenna separation
→ loss in SNR per stream just like for SISO
→ apply ITU availability model

**Refraction or multipath propagation**

→ different streams behave differently for some links
→ reduced availability for some links
→ develop availability model

Some MIMO deployments may have more problems than others, just like in SISO deployments

Introduction

Principles of MIMO

Considerations when deploying MIMO

**Breaking through 100 Gbps**

Final remarks

Q & A

# D-band example

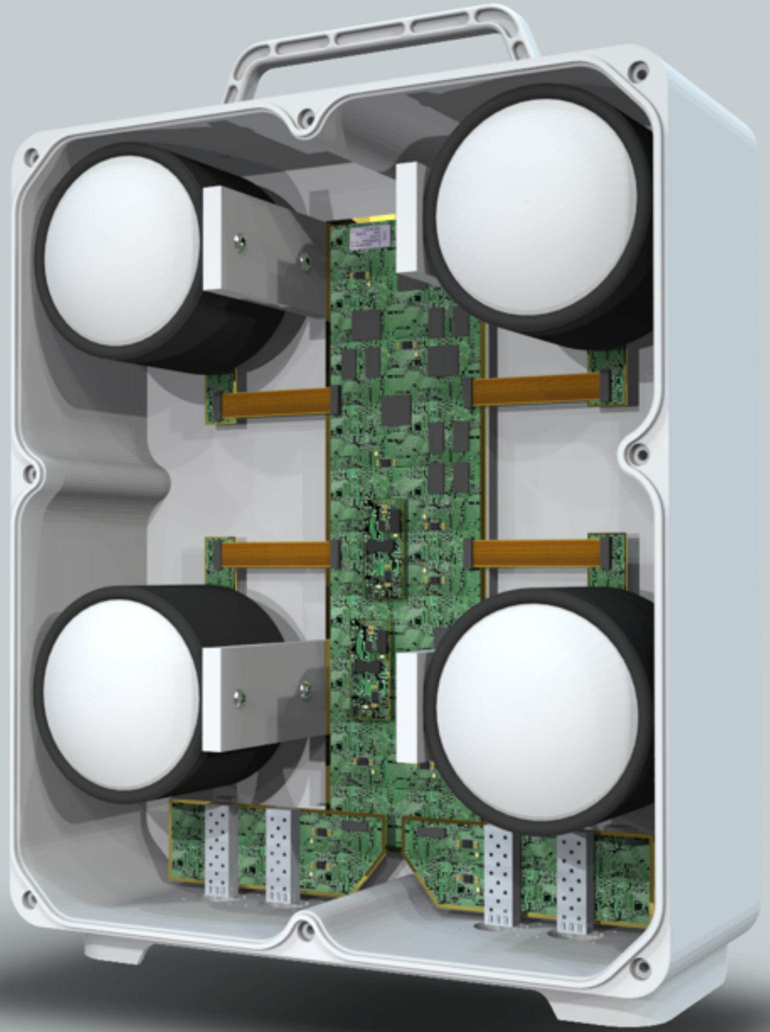
8 x 8 MIMO

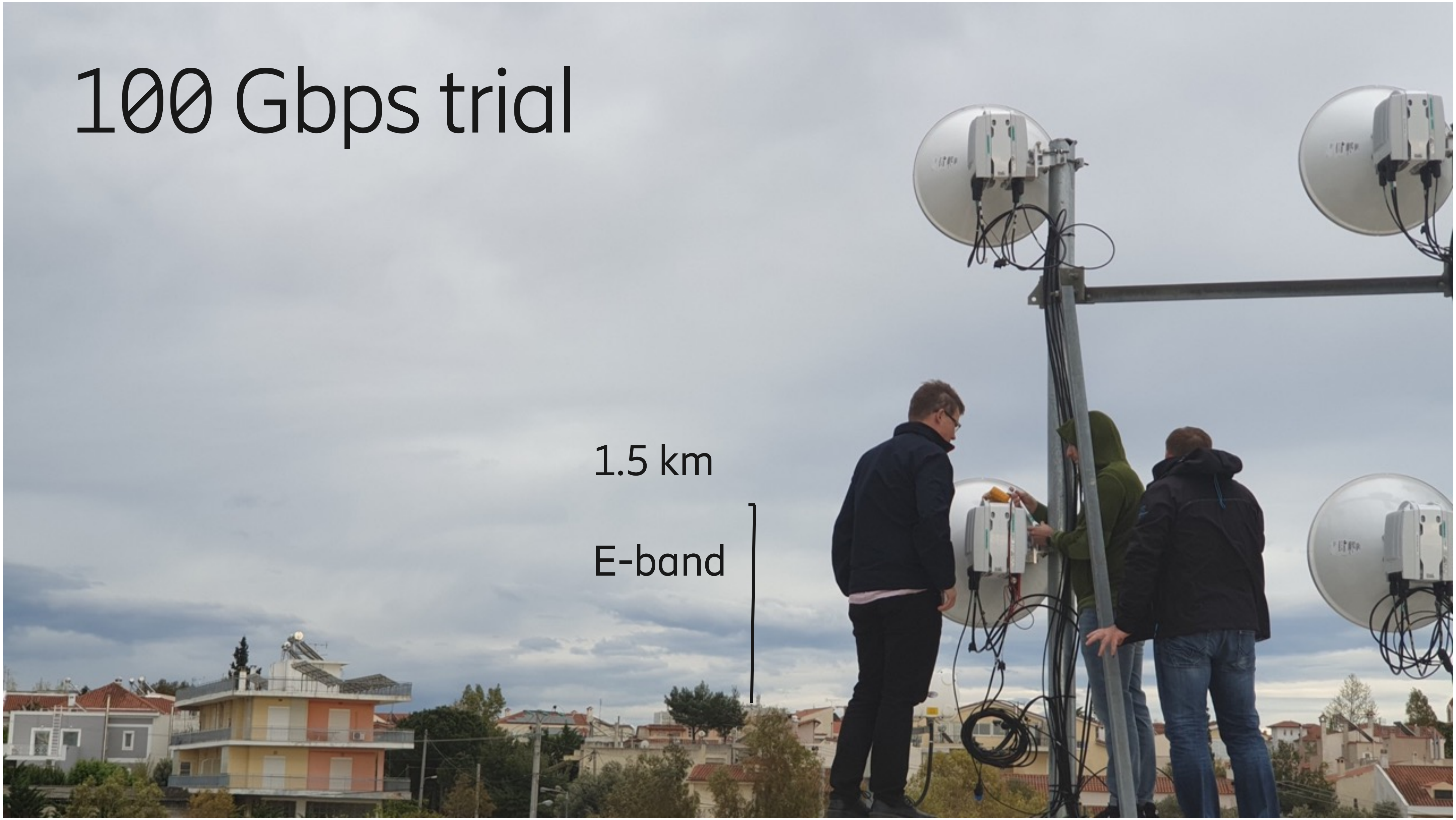
2.25 Gbaud (2.5 GHz channel spacing)

64 QAM

→ $8 \times 2.25e^{9} \times 6 = 108$ Gbps

Hop length: 50 m (100%) to 550 m (30%)



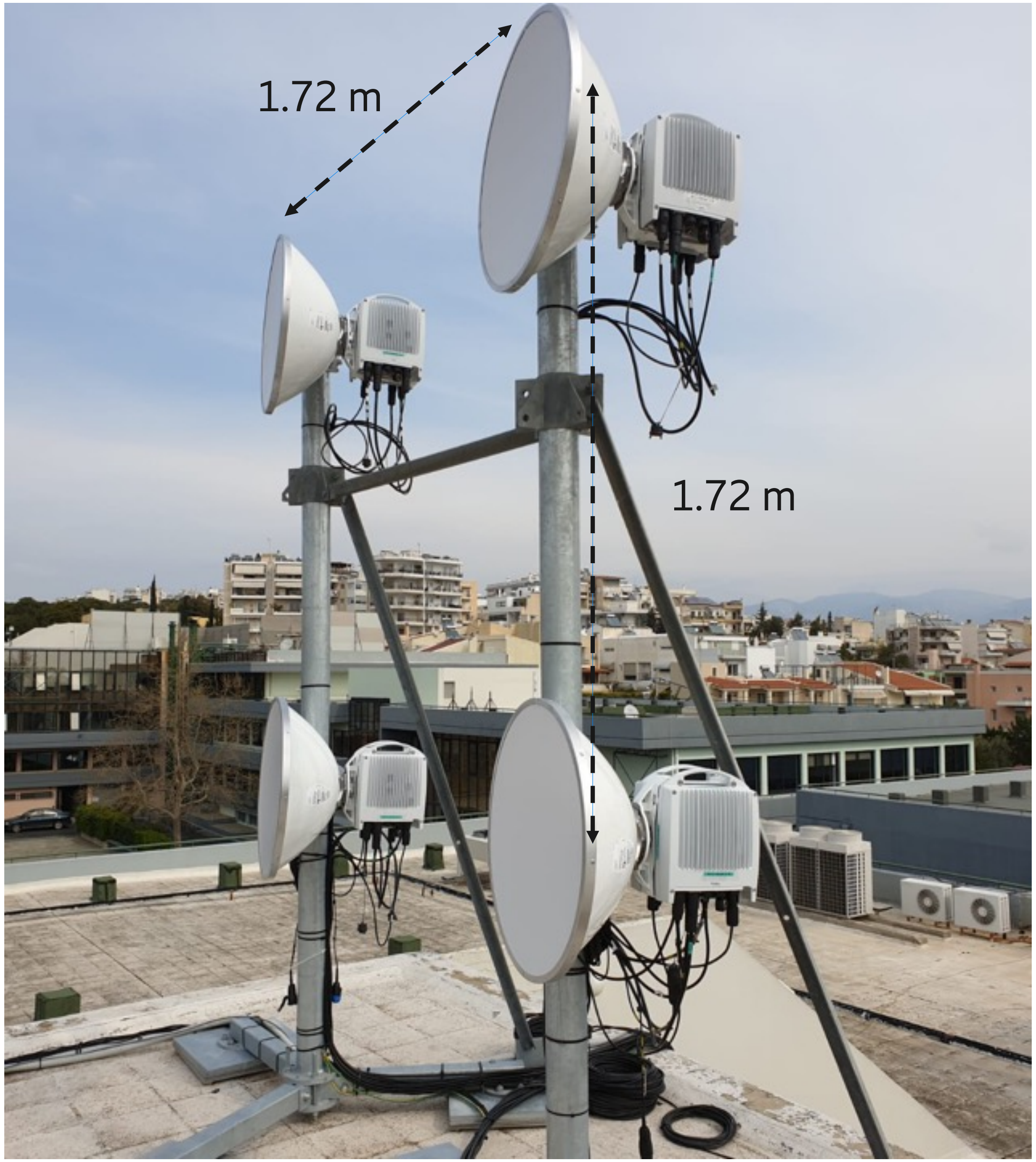

100 Gbps trial
1.5 km
E-band

# 8x8 MIMO setup

1.5 km hop length
8 E-band radios
18 dBm max output power per radio

2.25 Gbaud (2.5 GHz channel )
128 QAM (7 bits/symbol)
→ 8 x 7 x 2.25e9 = 126 Gbps

100 Gbps with 99.995% availability
125 Gbps with 99.99% availability



# Key takeaways

— Wireless transport enables fast, flexible and cost-efficient mobile network deployments → 40% of all sites globally are connected with wireless backhaul

— Radio access evolution drives transport evolution:

  — Spectrum (move to higher frequencies and wider bandwidths)

  — Technology (more spectral efficient wireless backhaul, e.g. MIMO, higher order modulation)

  — Beyond 100 GHz and towards 100 Gbps research is ongoing