# Wireless backhaul – introduction and evolution

## Wireless Networks

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Dr. Mikael Coldrey, Principal Researcher
Ericsson Research, Sweden

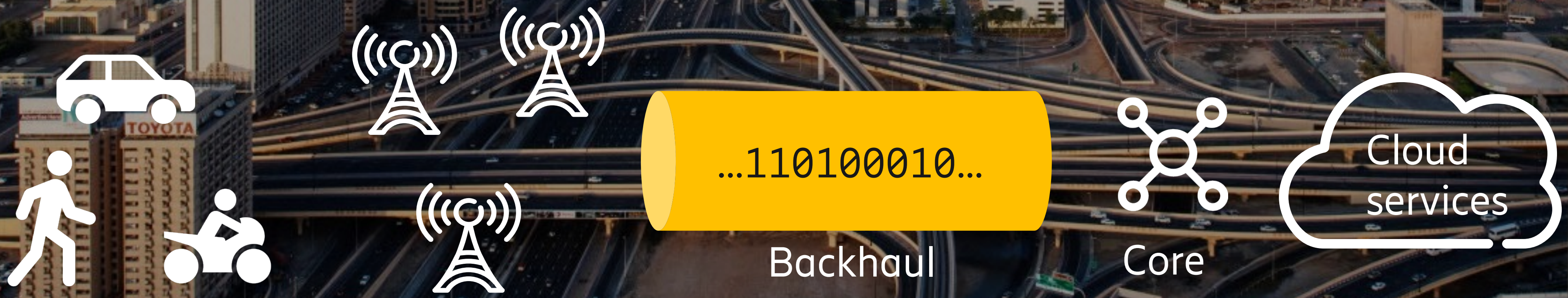
# Content

- Introduction to backhaul
- Wireless backhaul usage and forecasts
- Spectrum & licensing
- Technology and evolution
  - Some selected topics
  - MIMO
- Key takeaways

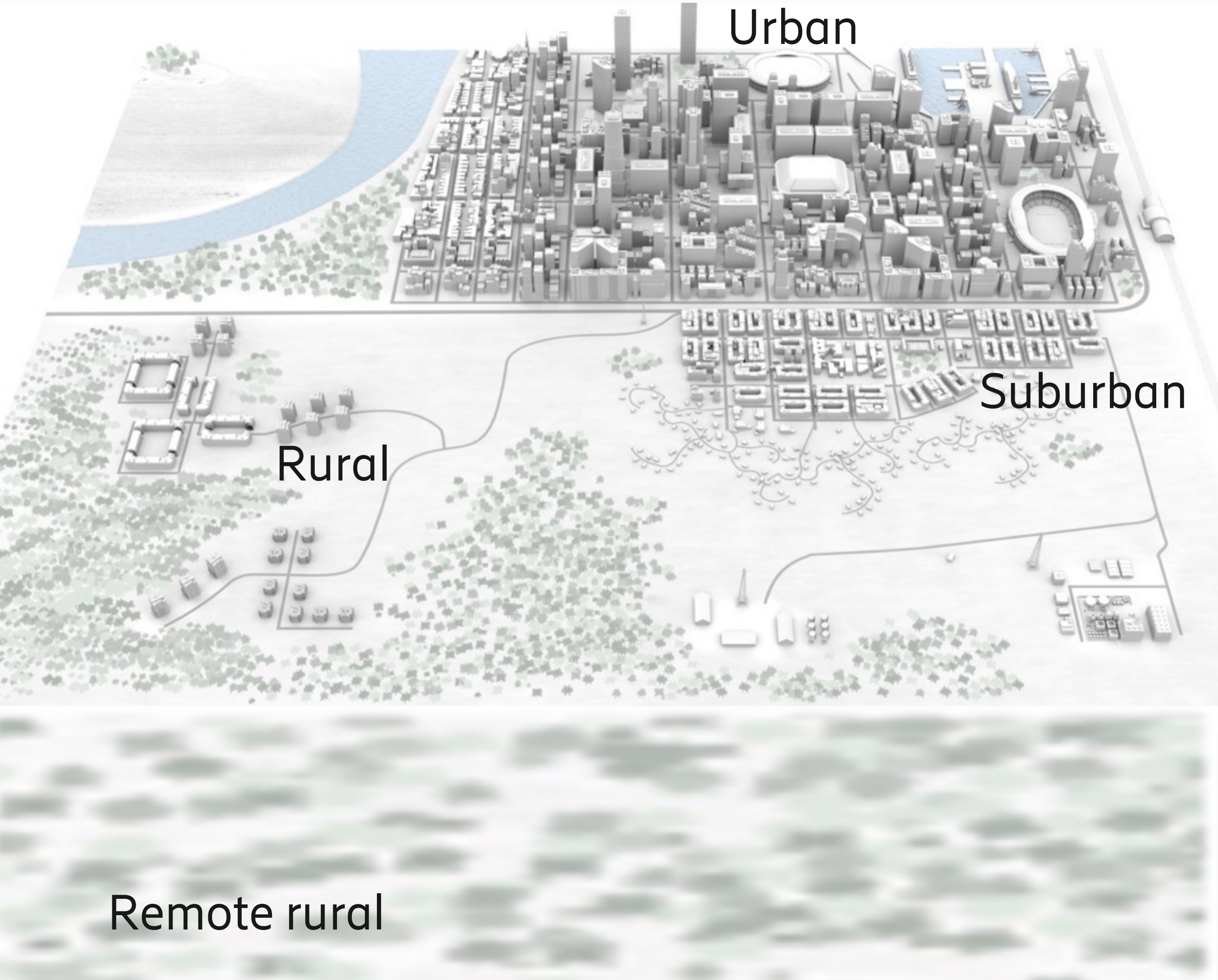
# Introduction

# Wireless Transport (backhaul)

*Backhaul is the connection between radio base station sites and the core network*



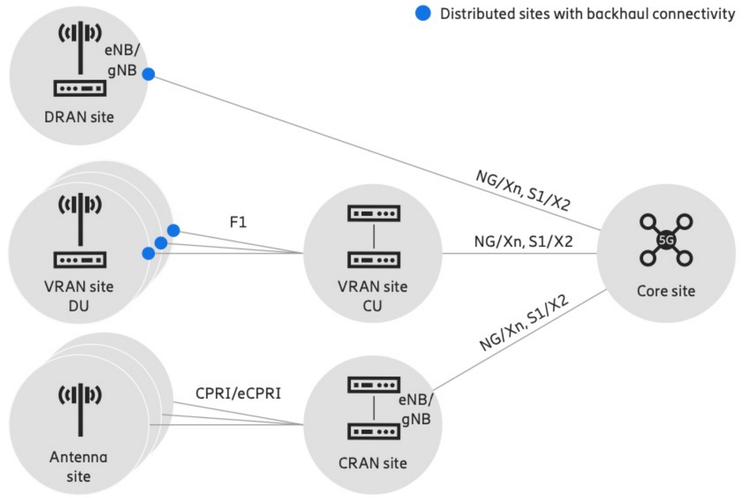
# Site deployments




# Wireless backhaul usage and forecasts

# Backhaul capacity forecast

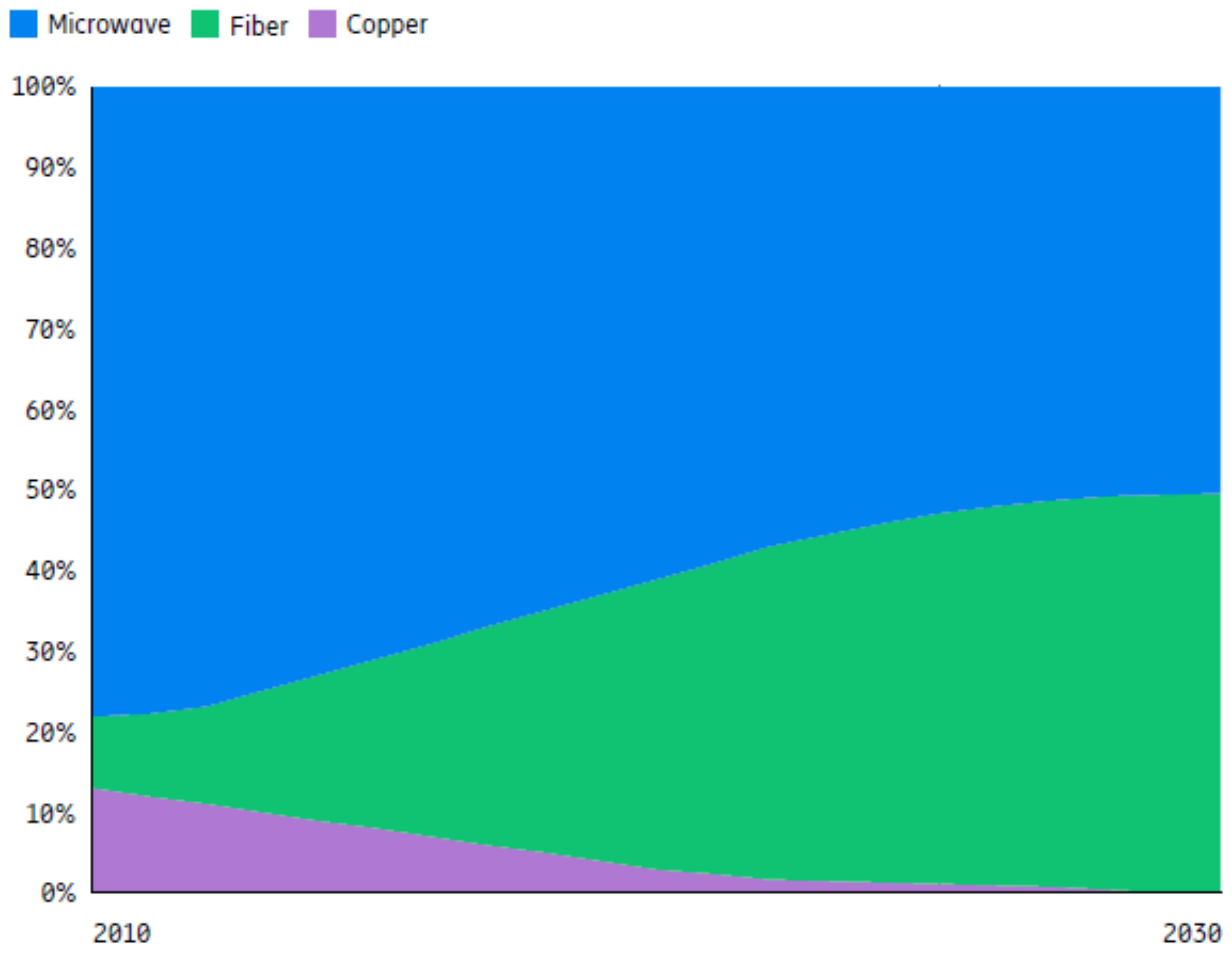
| | | 2022 | 2025 | 2027 |
|---|---|---|---|---|
| 3G/4G and selective 5G | Urban | 450 Mbps – 3 Gbps | 3 Gbps – 10 Gbps | 3 Gbps – 15 Gbps |
| | Suburban | 200 Mbps – 1 Gbps | 500 Mbps – 3 Gbps | 700 Mbps – 5 Gbps |
| | Rural | 75 Mbps – 250 Mbps | 200 Mbps – 1 Gbps | 300 Mbps – 1 Gbps |
| 3G/4G and ubiquitous 5G | Urban | 1 Gbps – 7 Gbps | 5 Gbps – 20 Gbps | 7 Gbps – 25 Gbps |
| | Suburban | 500 Mbps – 2 Gbps | 1 Gbps – 5 Gbps | 2 Gbps – 10 Gbps |
| | Rural | 150 Mbps – 350 Mbps | 300 Mbps – 2 Gbps | 500 Mbps – 2 Gbps |




- 5G NR deployed to meet specific needs at each location using different amounts of
  - radio access spectrum
  - advanced radio features
- Very wide spans
- Microwave backhaul can already today support all these capacity scenarios

Source: Ericsson 2022

# Global backhaul media distribution up until 2030




Source: Ericsson 2023

**50%**

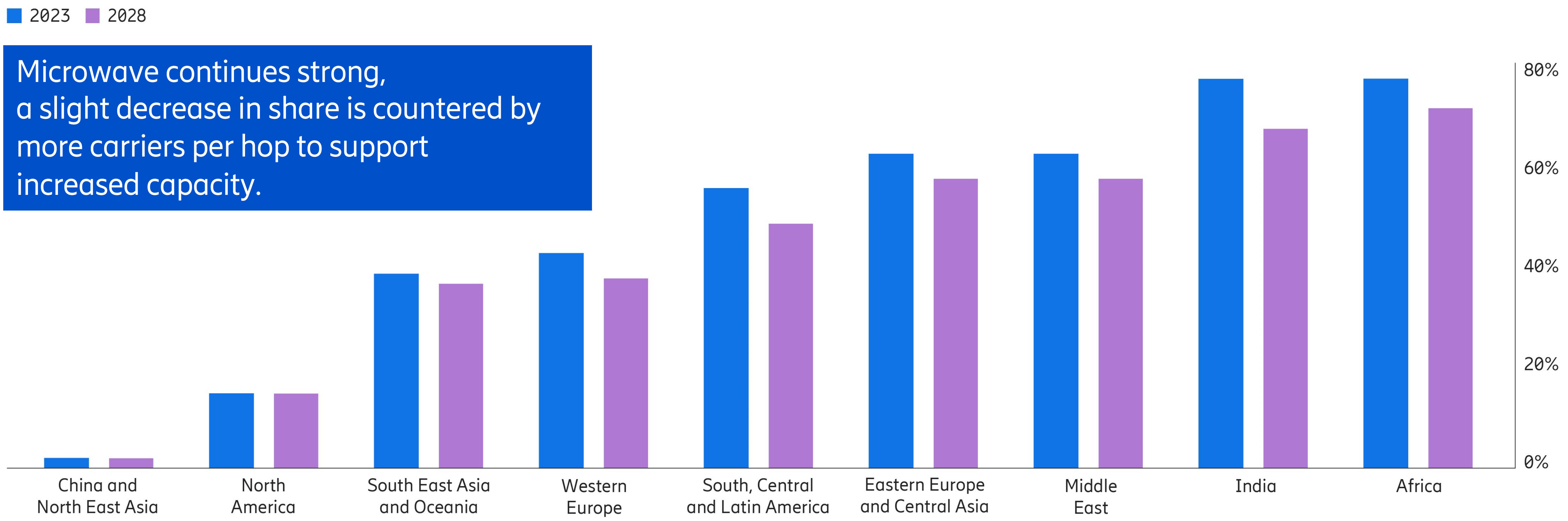
We foresee a 50/50 split between microwave and fiber for mobile backhaul by 2030*

*excluding North East Asia

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

# Regional differences in deployment of microwave backhaul 2023 and 2028

Microwave continues strong,
a slight decrease in share is countered by more carriers per hop to support increased capacity.

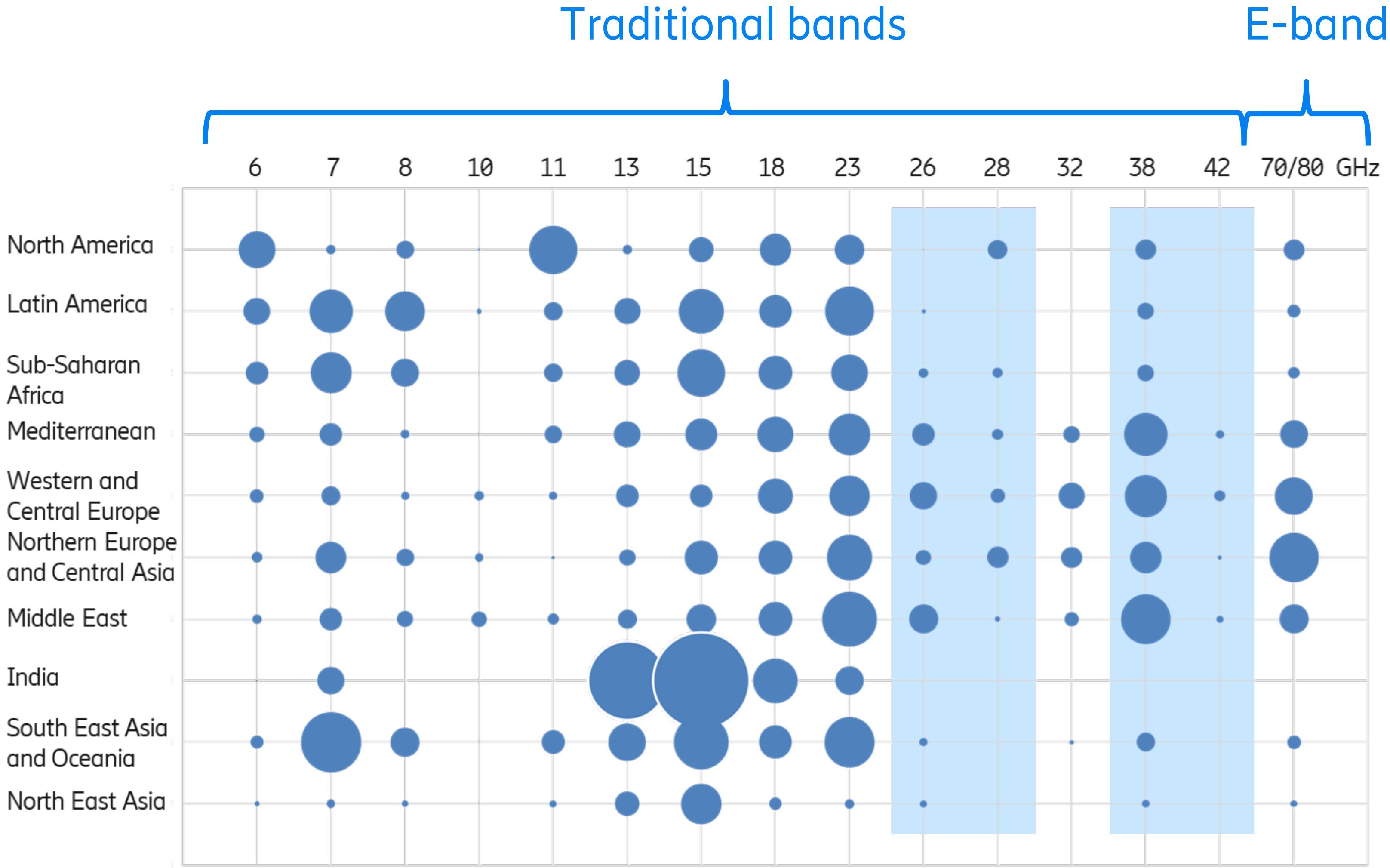



Source: Ericsson 2023

# Spectrum and licensing

# Spectrum usage

## Situation 2022




Source: Ericsson 2022

# 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)

# 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

## Backhaul licensing schemes

— Individual licensing
interference analysis in regulator's database

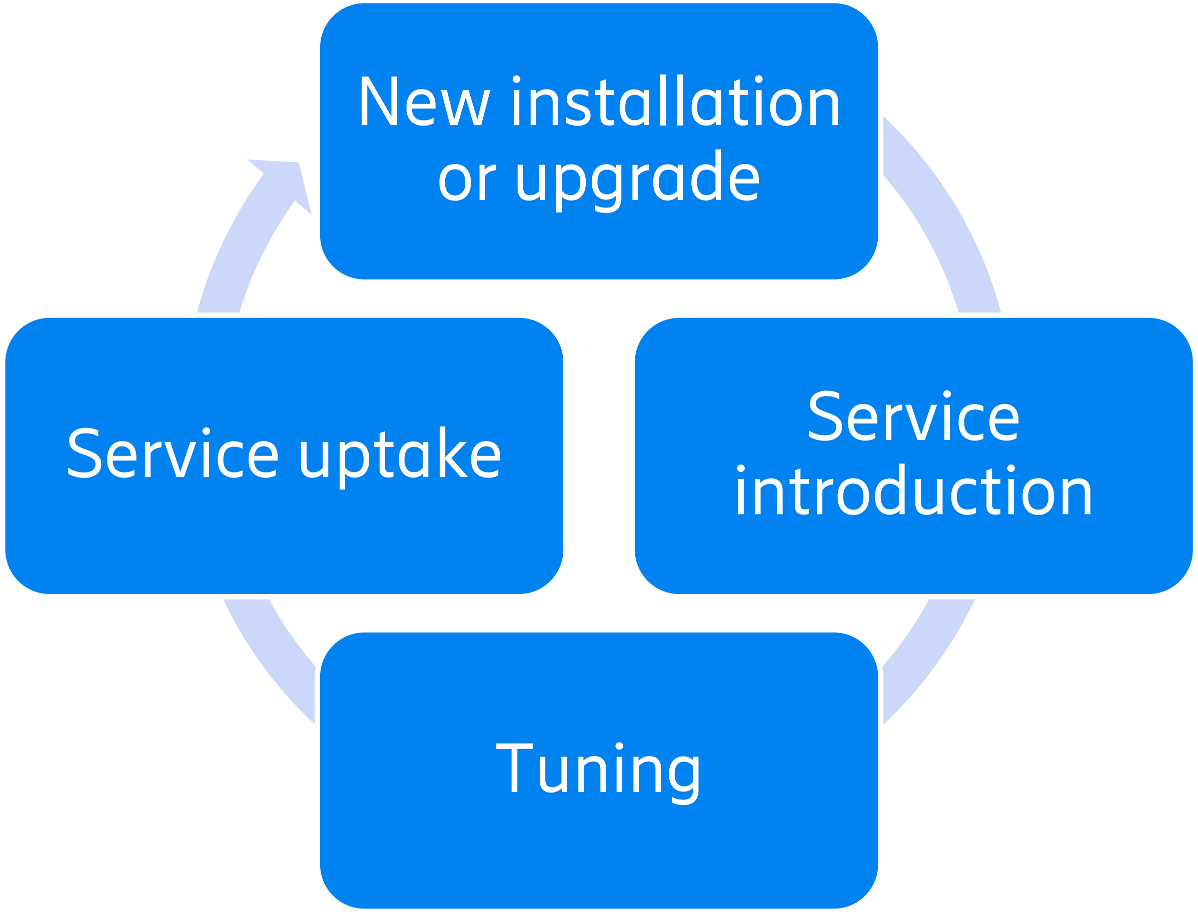
— Light licensing
"first come, first served" principle, user checks in public database and updates it, low cost

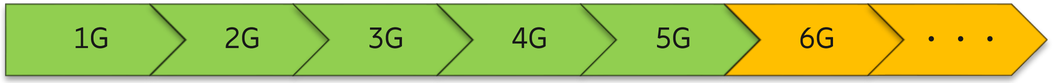
— Block licensing

— Unlicensed
e.g. 60 GHz

# Technology and evolution

# RAN and transport evolution
## Cycles




New RAN generations typically follow a 10-year cycle

Continous evolution in between generations

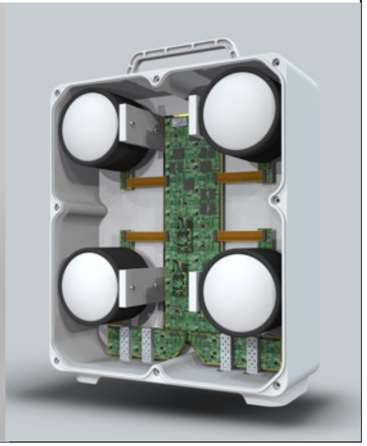
Transport evolution is driven by RAN evolution

# Short vs long haul

Short haul

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

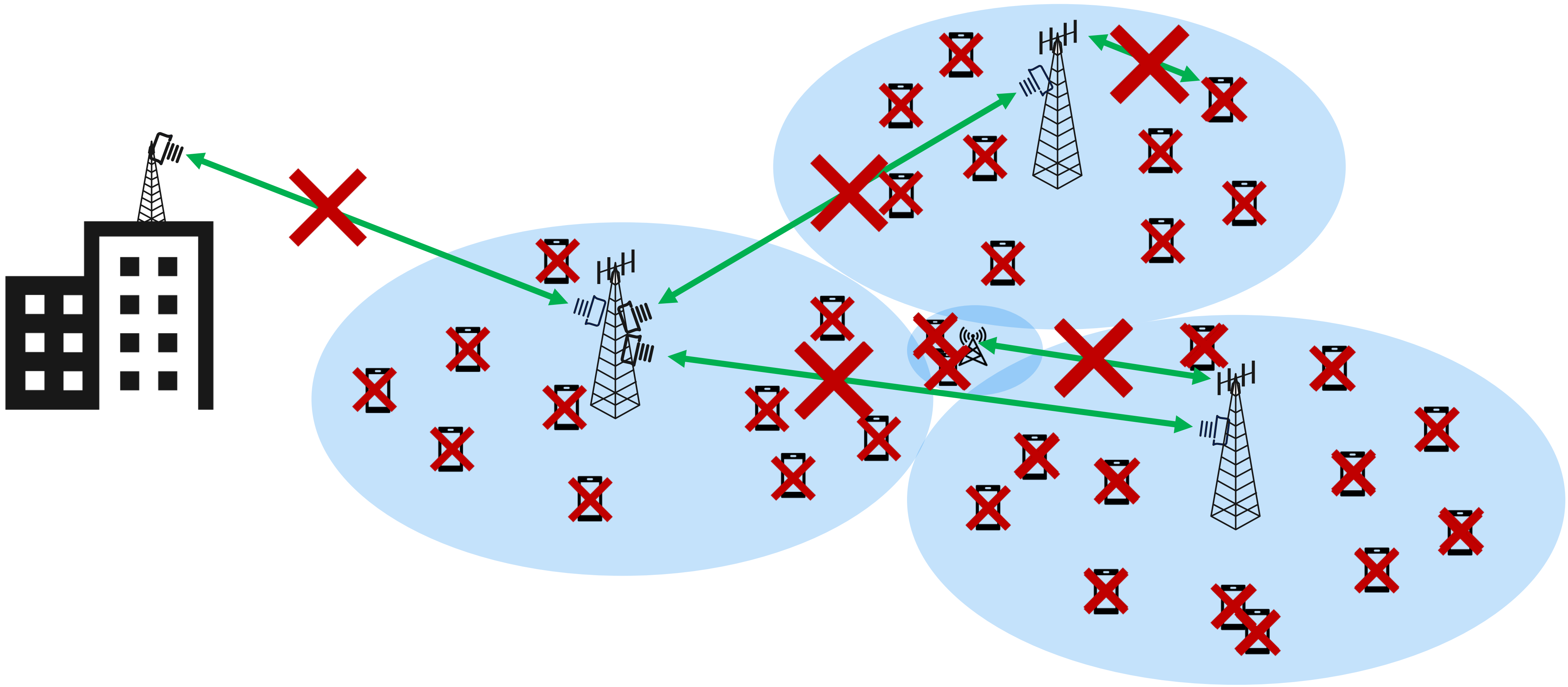
Future: beyond 100 GHz and towards 100 Gbps in E/W/D-bands



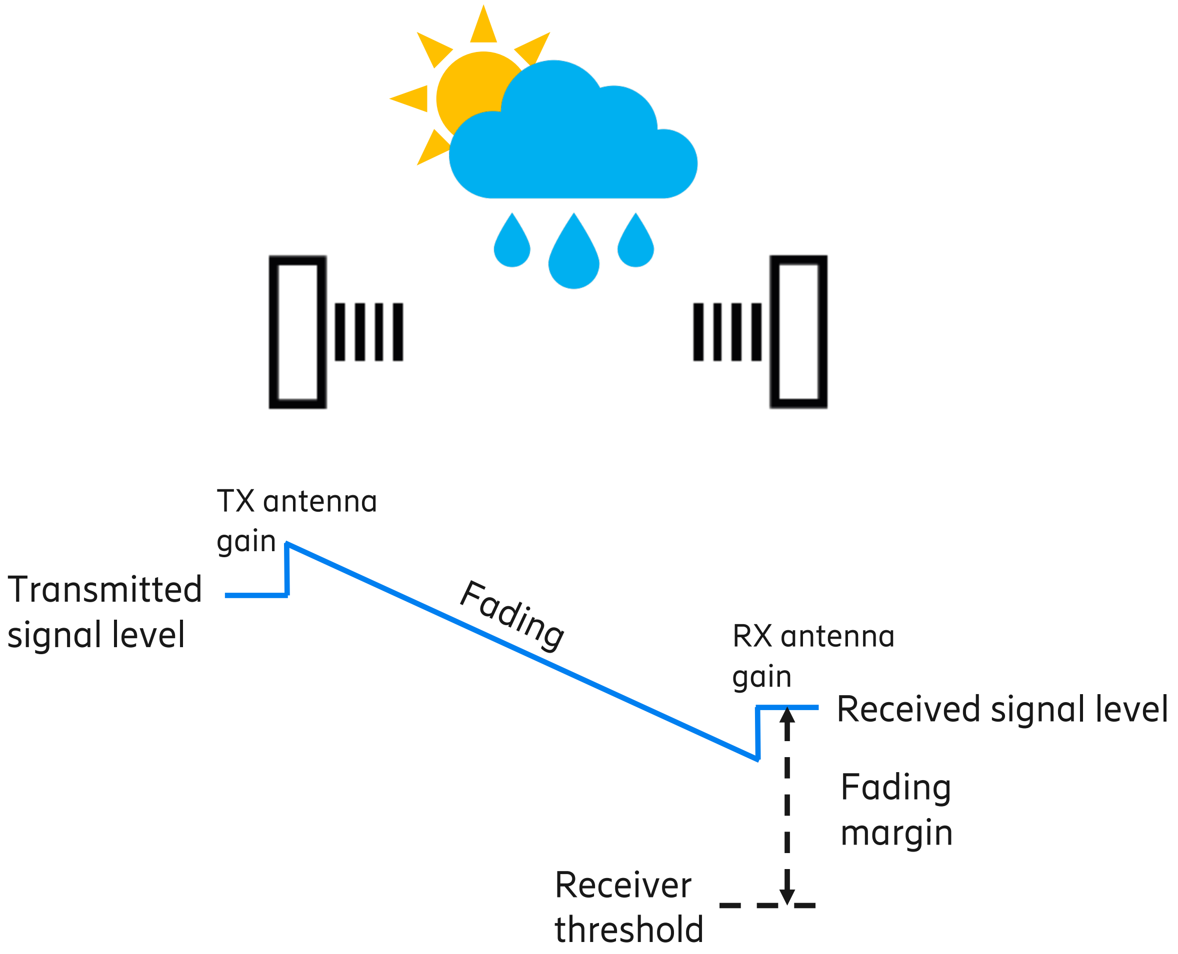
Long haul

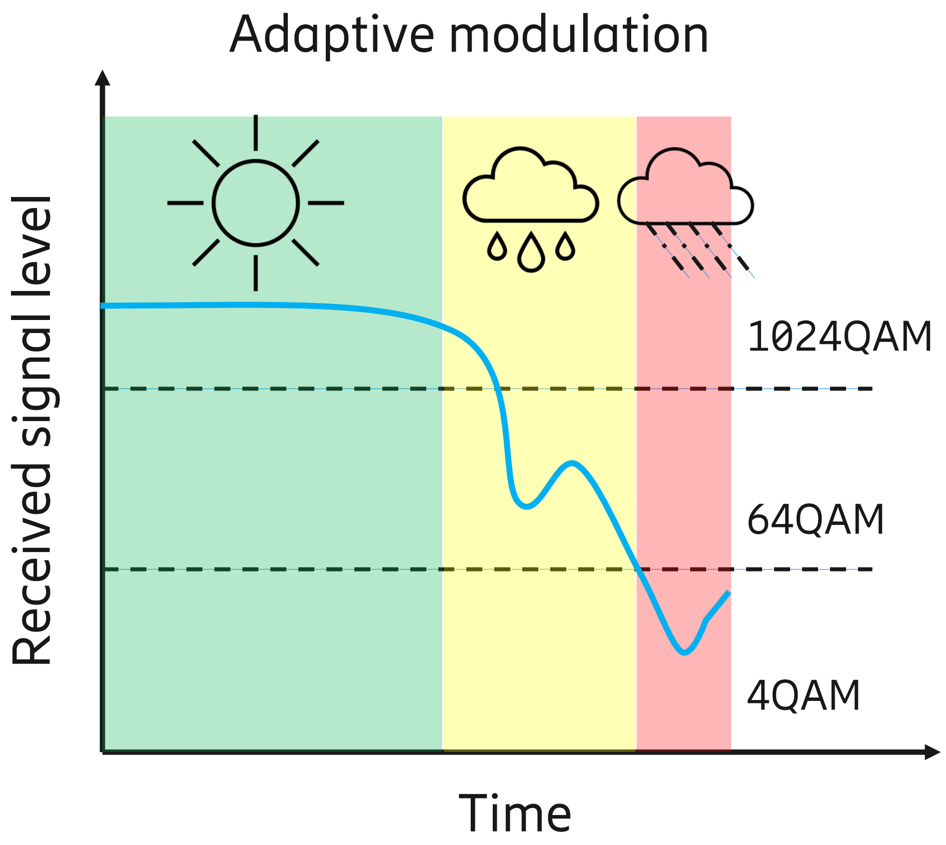
- 10 – 200 km
- 6 – 15 GHz
- < 10 Gbps

# Impact of link failure

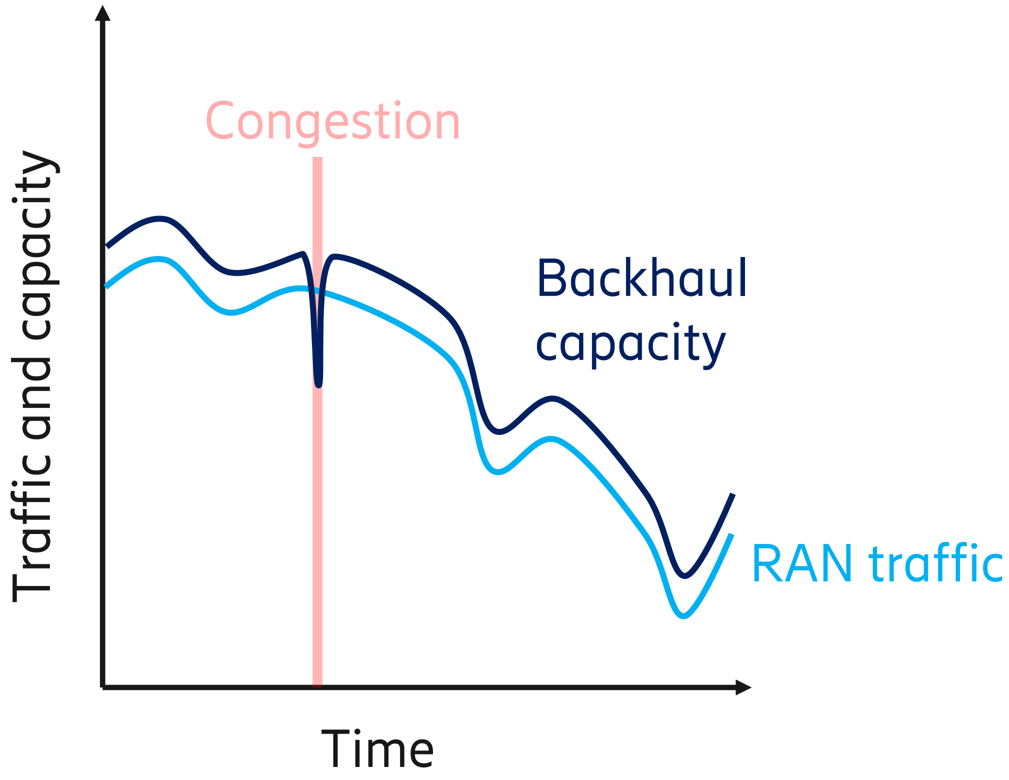


# Microwave link planning



# Backhaul dimensioning



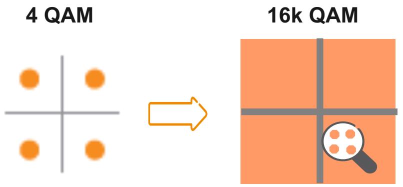

Dimension the backhaul link such that

- Probability of congestion is very small, e.g., <0.1%, <0.01%, …
- Backhaul capacity is not over-provisioned
- Different operators may have different requirements

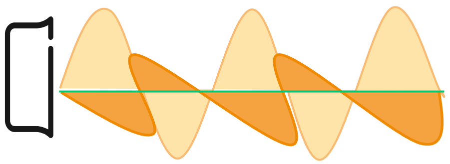
# Microwave toolbox

## Spectral Efficiency

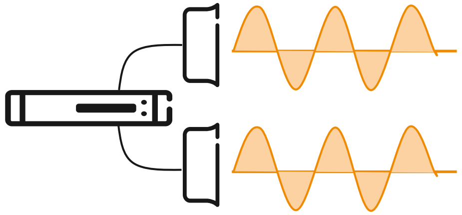
### Higher-order modulation



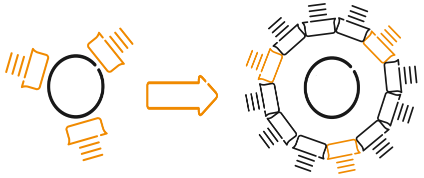

### Dual Polarization & XPIC



### MIMO



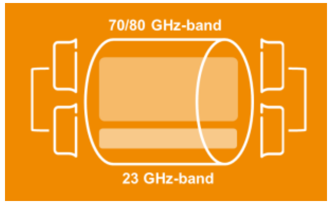
### High performance antennas



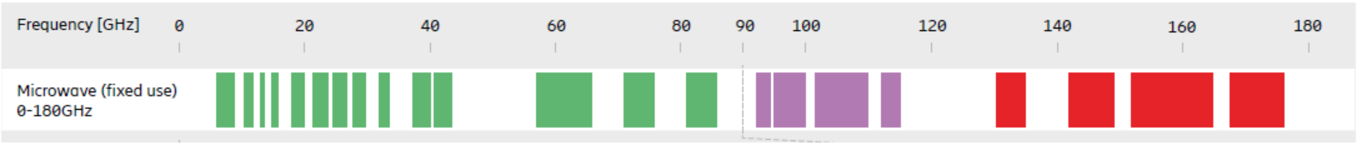
## Bandwidth

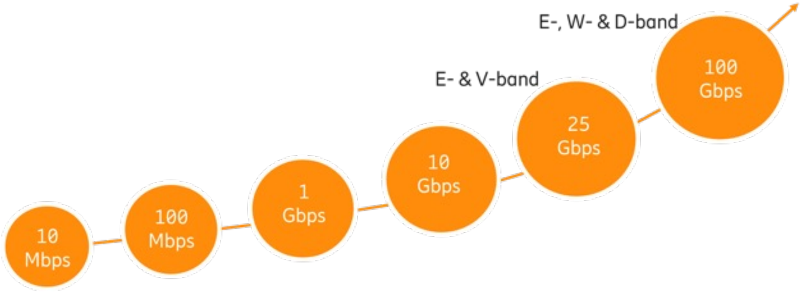
### Radio Link Bonding


### Multi-band booster




## Spectrum



# Multi-band booster

## Combining high availability and high capacity

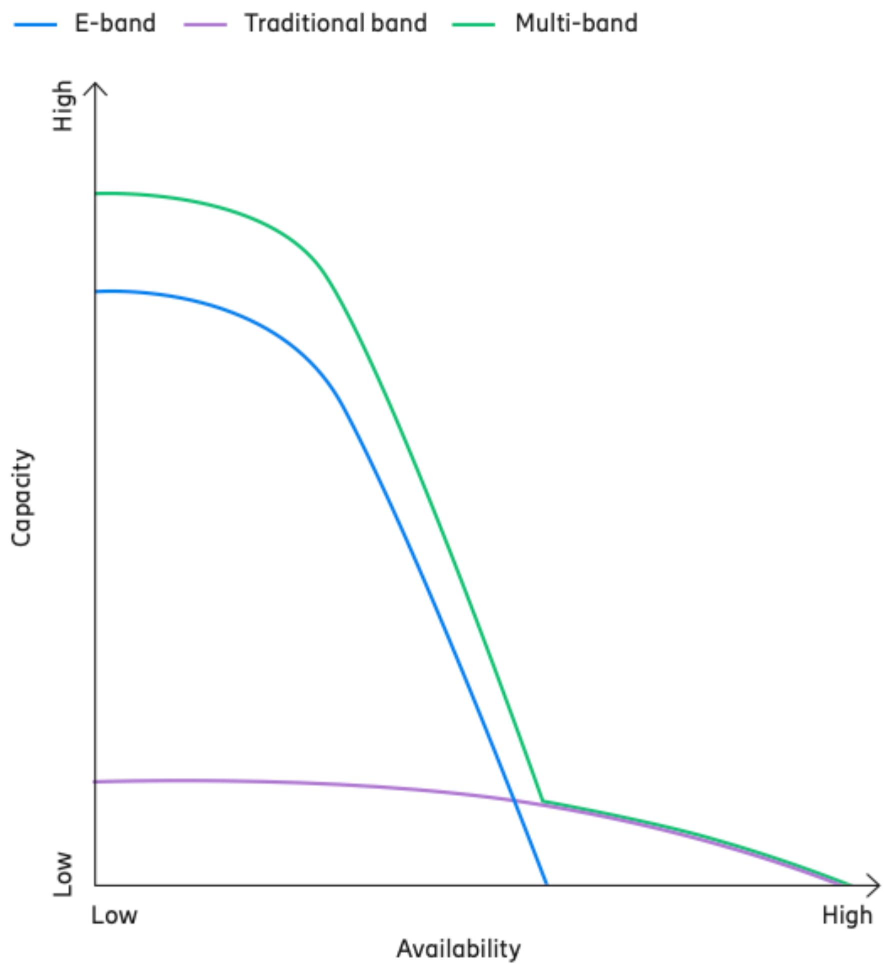
High frequencies suffer from rain fading → shorter hop length with higher frequencies

High frequencies have lower availability but wider bandwidth (higher peak rate)

Lower frequencies have higher availability but narrower bandwidth (lower peak rate)

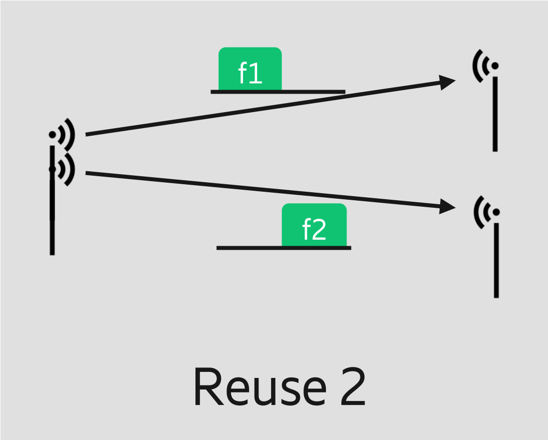
A multi-band booster solution combines the best of both

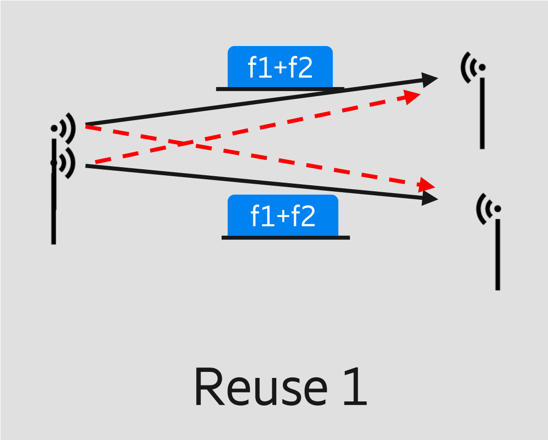
Traffic prioritization during strong fades

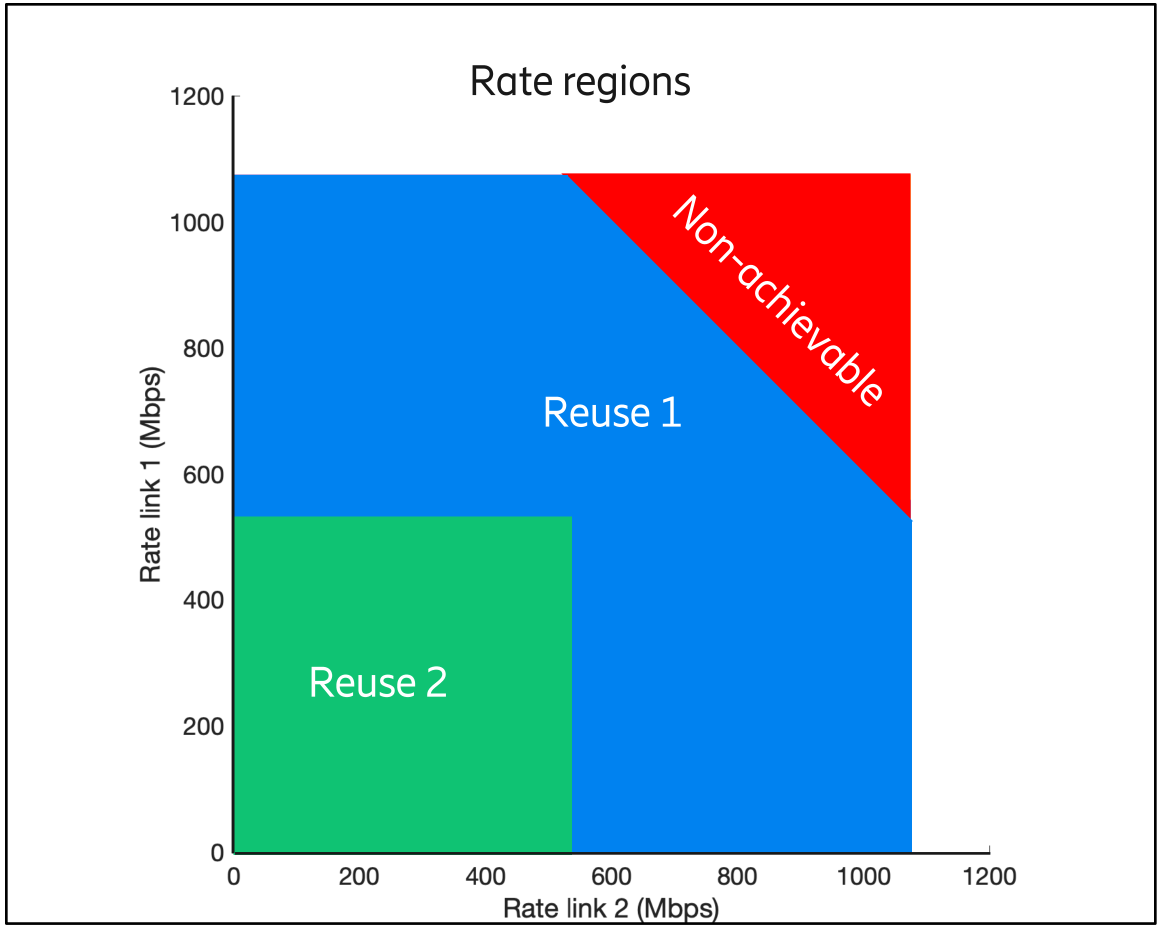


# Universal frequency reuse

## Reuse 1 vs reuse 2



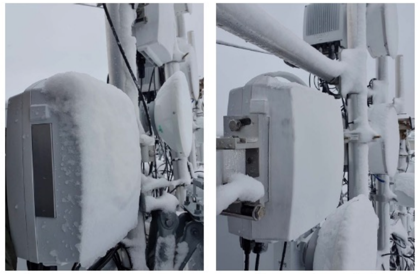




- Need for wider channels and more capacity but the spectrum is limited
- Reuse 1 has twice the peak rate of reuse 2
- The reuse 1 and non-achievable region depends on antenna isolation, interference, fading margins, etc.
- Traffic-aware power control sets the operating point in the rate region

# Antenna innovations

Innovations and new requirements are expanding the antenna palette.

Selecting the right antenna from the wide range available can yield significant increases in both capacity and spectrum efficiency



Regular antenna

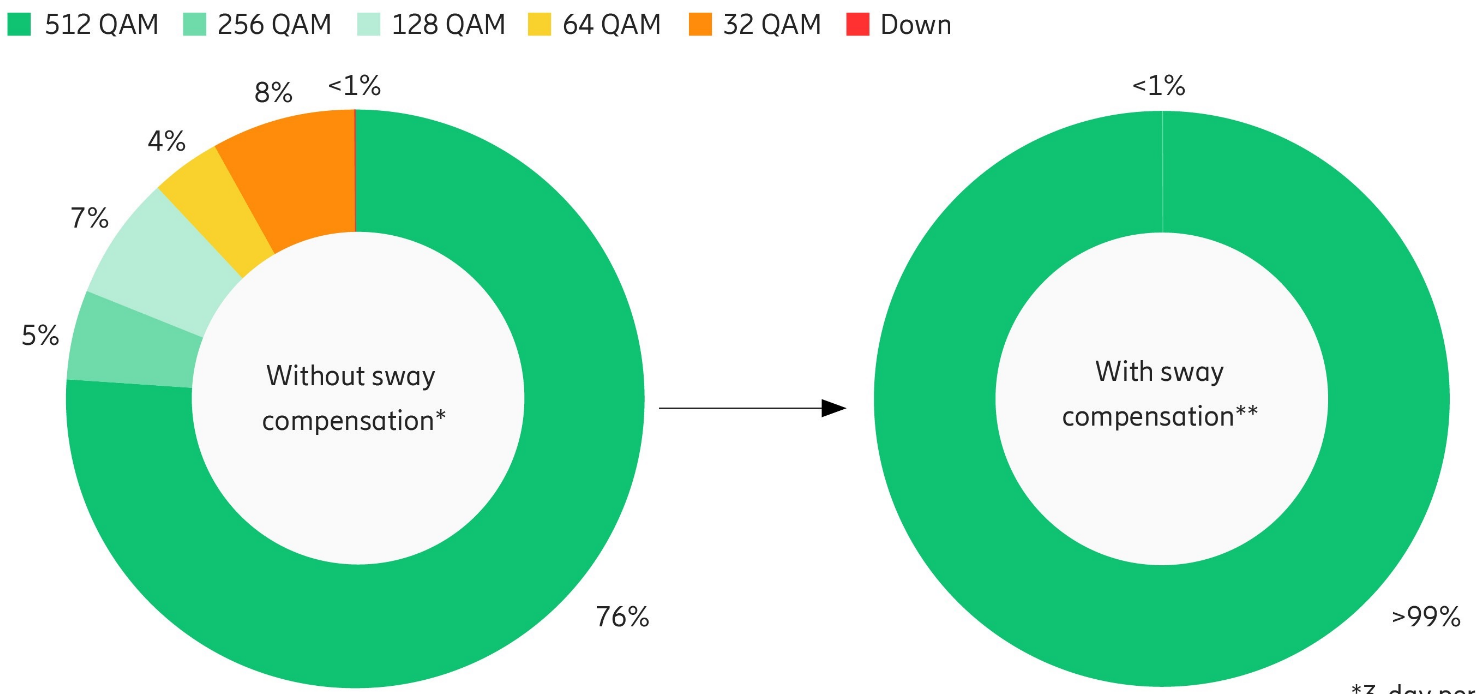
Antenna with water-repellent coated radome

Source: Ericsson 2023

Possible choices:

- Single polarized – basic option
- Dual-polarized – double capacity
- Multi-band – longer hops and higher capacities
- ETSI Class 4 – better spectrum utilization with closer hops
- Sway compensation – compensate for sway from wind or solar bending, enables larger antennas and longer hops.
- Water repellent radome - prevent snow & ice build up - allowing for smaller antennas, longer hops or higher availability

# Sway compensation antenna field trial




A sway compensation field trial was performed with a 6.7 km E-band hop in southern Europe, near the coast. A link with traffic, with a sway compensation antenna at 28 m height, was monitored.

Source: Ericsson 2023

*3-day period with solar-induced bending

**1 month with solar-induced bending, rain, wind, multipath

**+30%**

Sway compensation enables the use of 0.6.m antennas with 30% longer hops than regular 0.3 m antennas

**+80%**

Sway compensation enables the use of 0.9.m antennas with 80% longer hops than regular 0.3 m antennas

# Water repellent antennas

Regular antenna

Antenna with water-repellent coated radome

Water repellent coating on antenna:

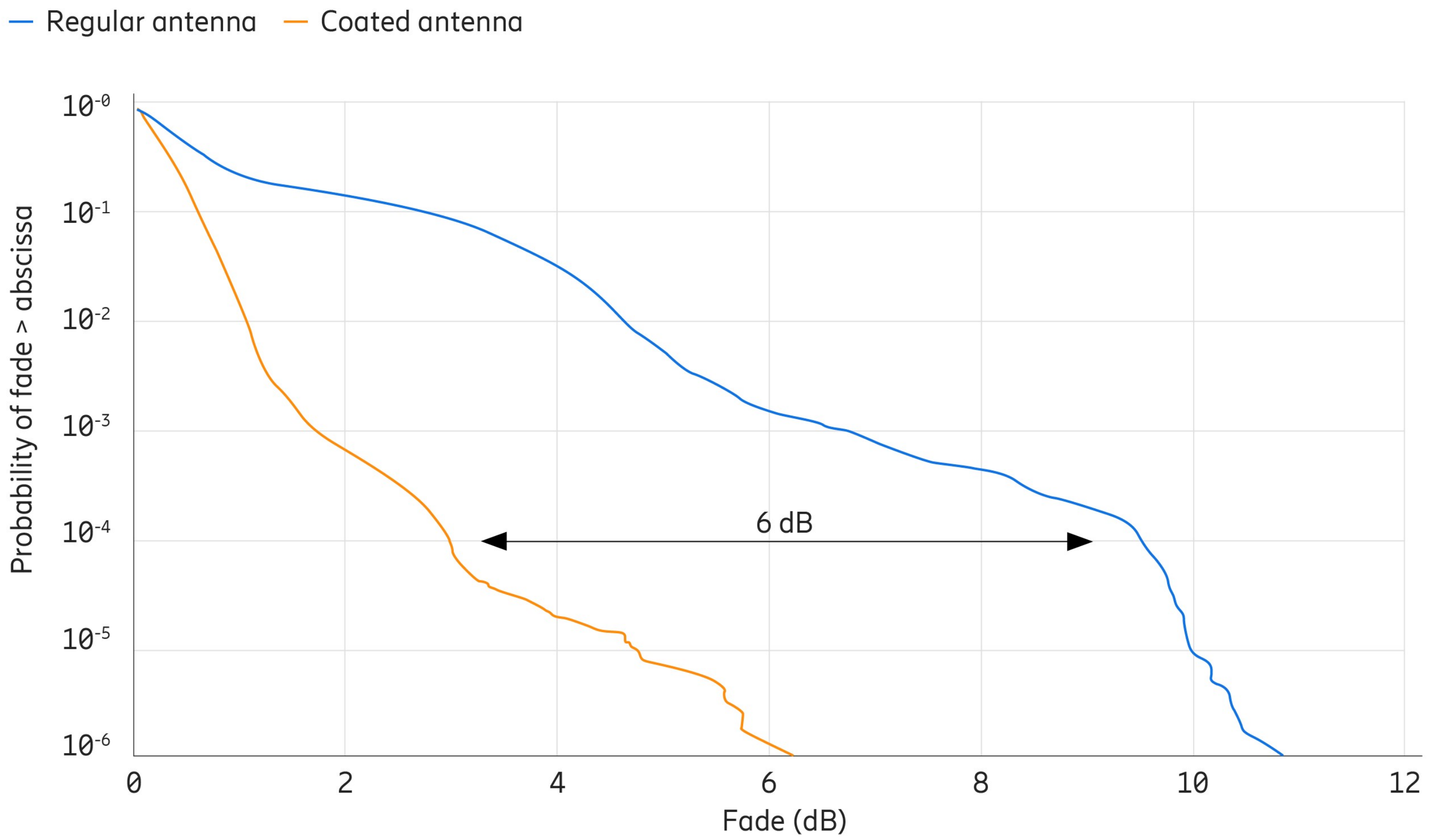
- Prevents rain, snow & ice build up
- Improves system gain performance during rain and snow
- Allows for smaller antennas, longer hops or higher availability

Wet snow sticks to the uncoated antenna

Snow slides off the antenna with water repellent coating

Source: Ericsson 2023

# Field trial with water repellent coating on E-band links – over half a year



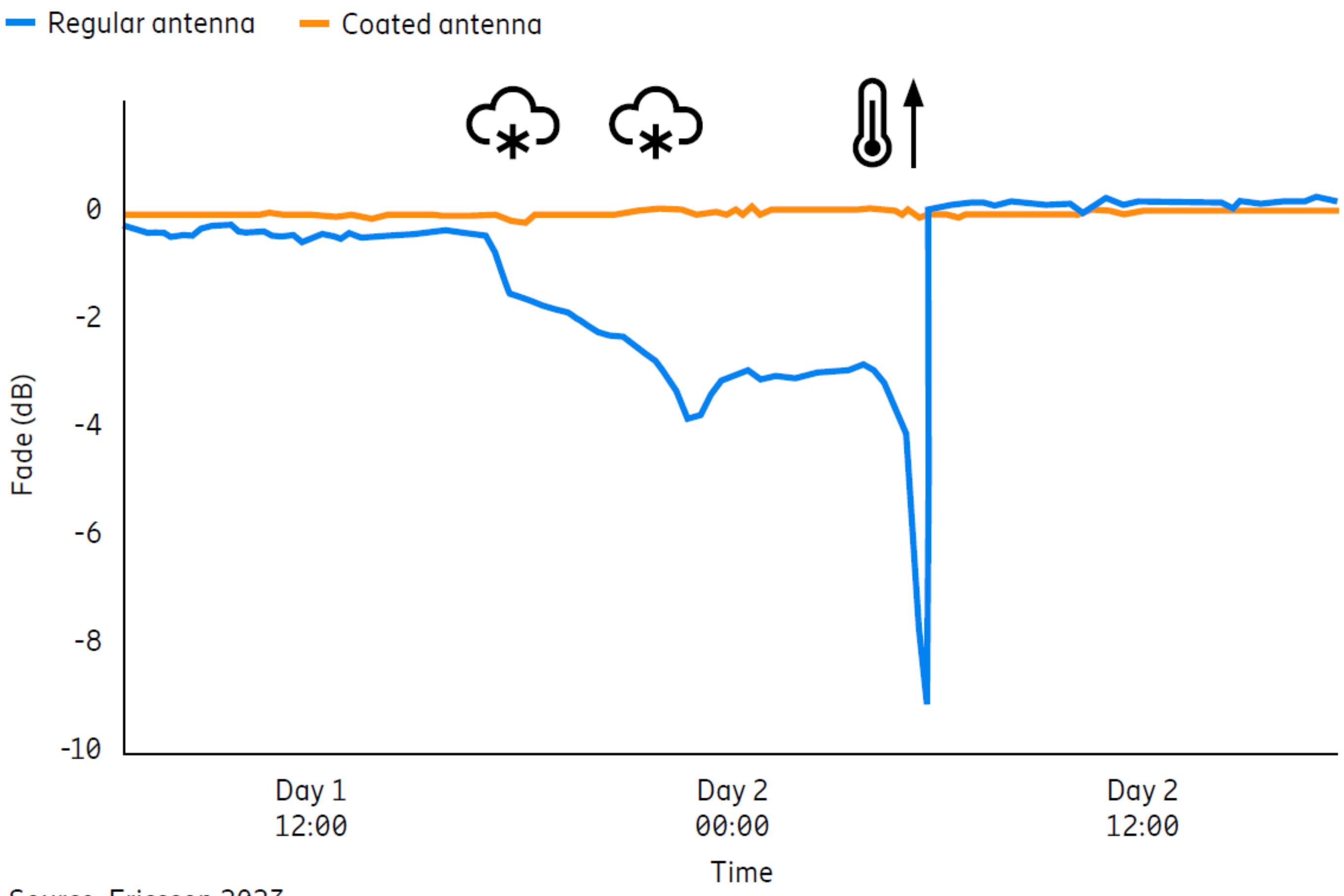

Source: Ericsson 2023

Statistics collected from December 2021 to June 2022 on a 200 m E-band hop with 2 parallel links, one with and one without water-repellent radome coating.

**6dB**

The water-repellent coating gives up to 6 dB less fading. This enables 20-30% longer hops with the same availability.

# Field trial with water-repellent coating on E-band links - in snowy conditions




Source: Ericsson 2023

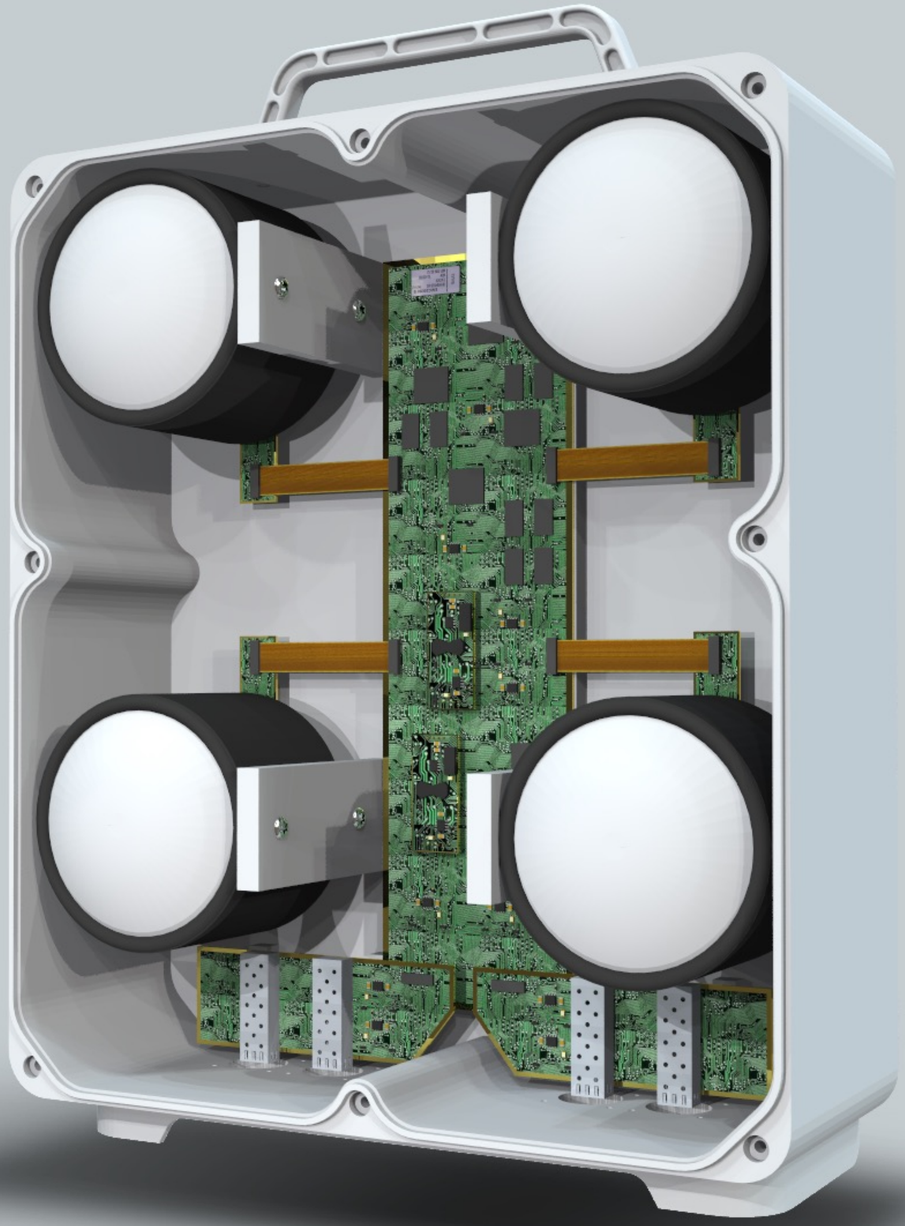
The regular uncoated link is attenuated by 4dB while the snow is dry, and by >9dB when the snow is wet.

The link with water repellent coating is unaffected

# Multi Input Multi Output – MIMO

# MIMO in microwave backhaul

Inrease spectral efficiency in band-limited channels



# History of MIMO in wireless
## Multiple Input Multiple Output

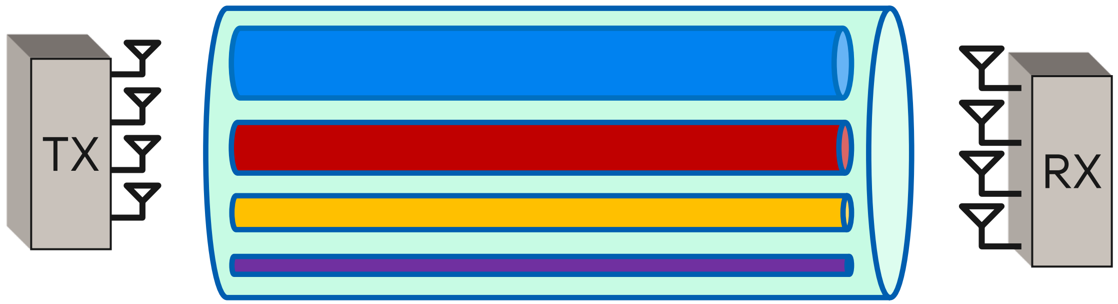
Receive antenna diversity in 1920's

Spatial Division Multiple Access (SDMA) in 1980's

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

# Multi-stream transmission

- MIMO is multi-stream transmission → one big data pipe consisting of multiple smaller data pipes
- Dual polarized transmission can also be seen as a MIMO system
- Combine spatial MIMO with dual polarized MIMO for higher order MIMO
- The different streams may have different capacities depending on
  - Antenna separation: optimal vs suboptimal
  - Propagation conditions
  - Choice of DSP
- In optimal conditions, all streams have equal capacity and NxN MIMO has N x SISO capacity




# Propagation

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

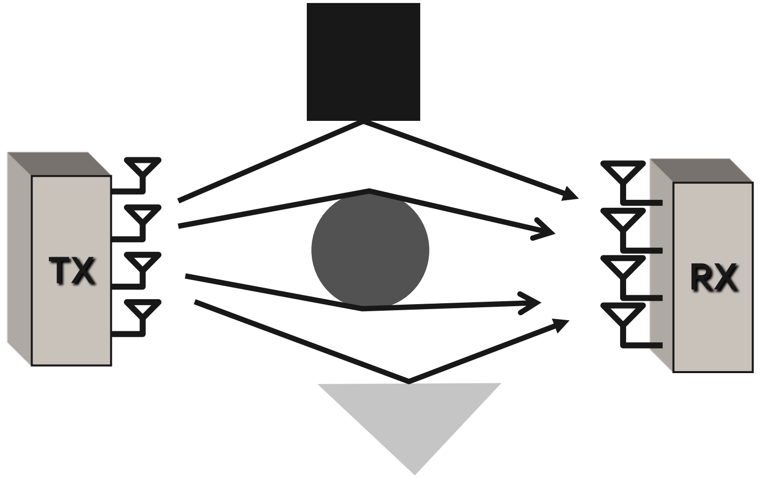
**MIMO in 3GPP/Wi-Fi**

0.5-10 wavelengths in antenna separation

Exploit multipath propagation

LOS is not good for MIMO → correlated channels

Multipath usually implies high path loss → low Signal-to-Noise Ratio (SNR)



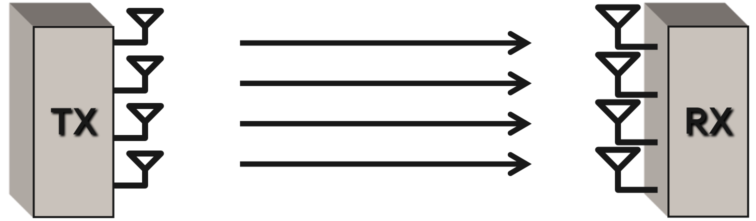

**MIMO in microwave**

100-1000 wavelengths in antenna separation

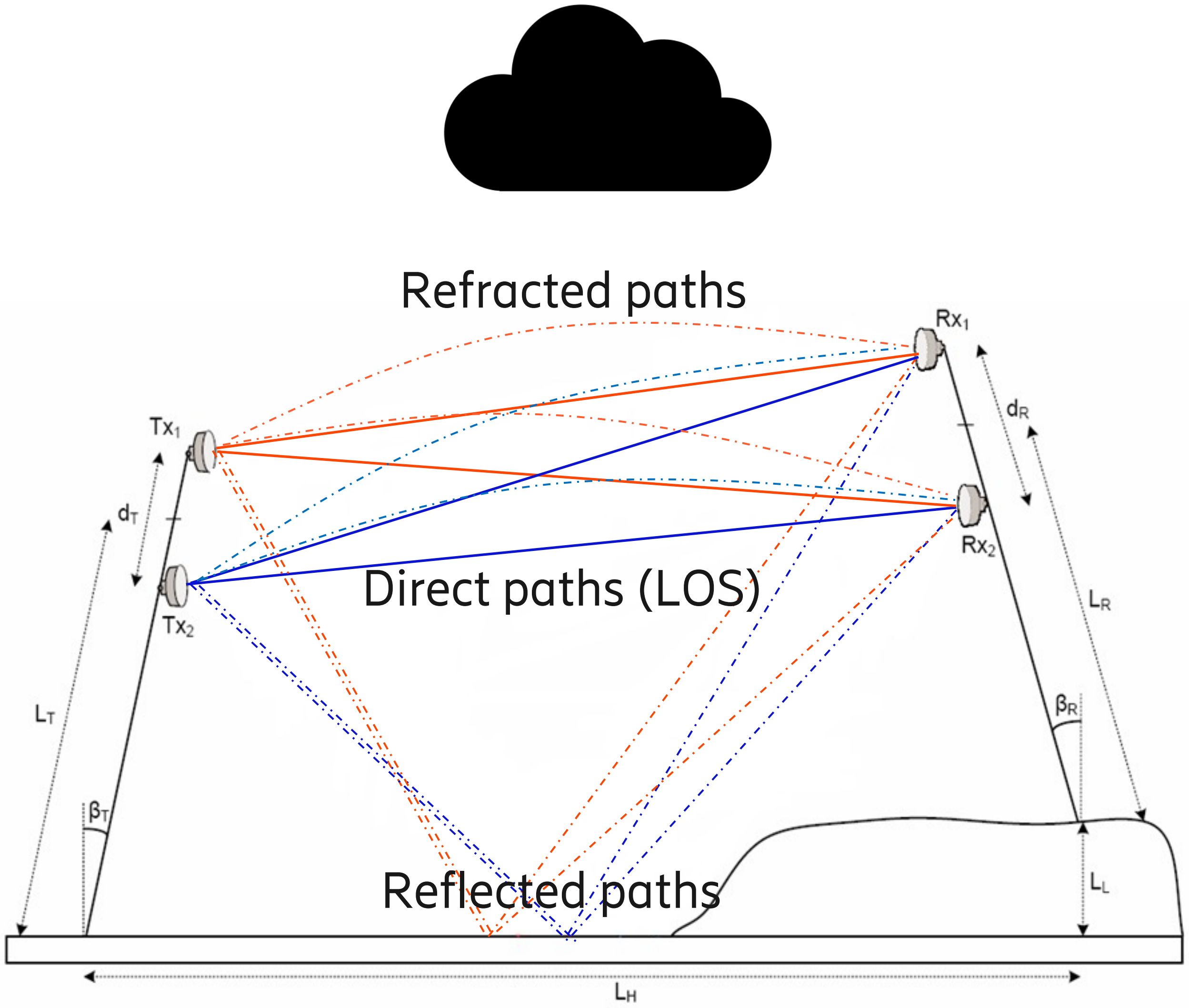
Exploit LOS propagation

Exploit antenna/channel orthogonality → large antenna separations in wavelengths

LOS implies low path loss → high SNR

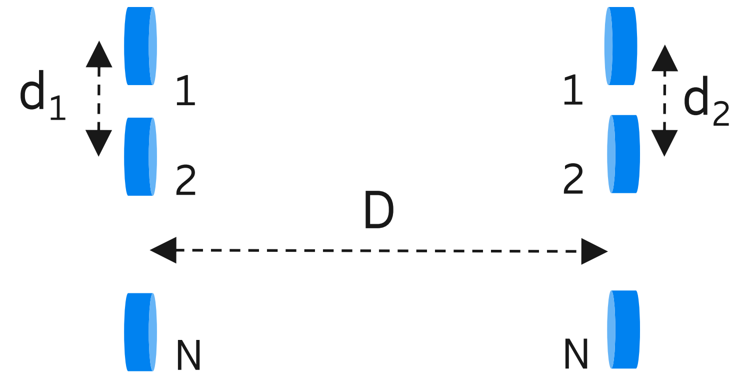


# MIMO propagation in wireless transport




# Optimal MIMO design

- 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?
  - Reduced performance

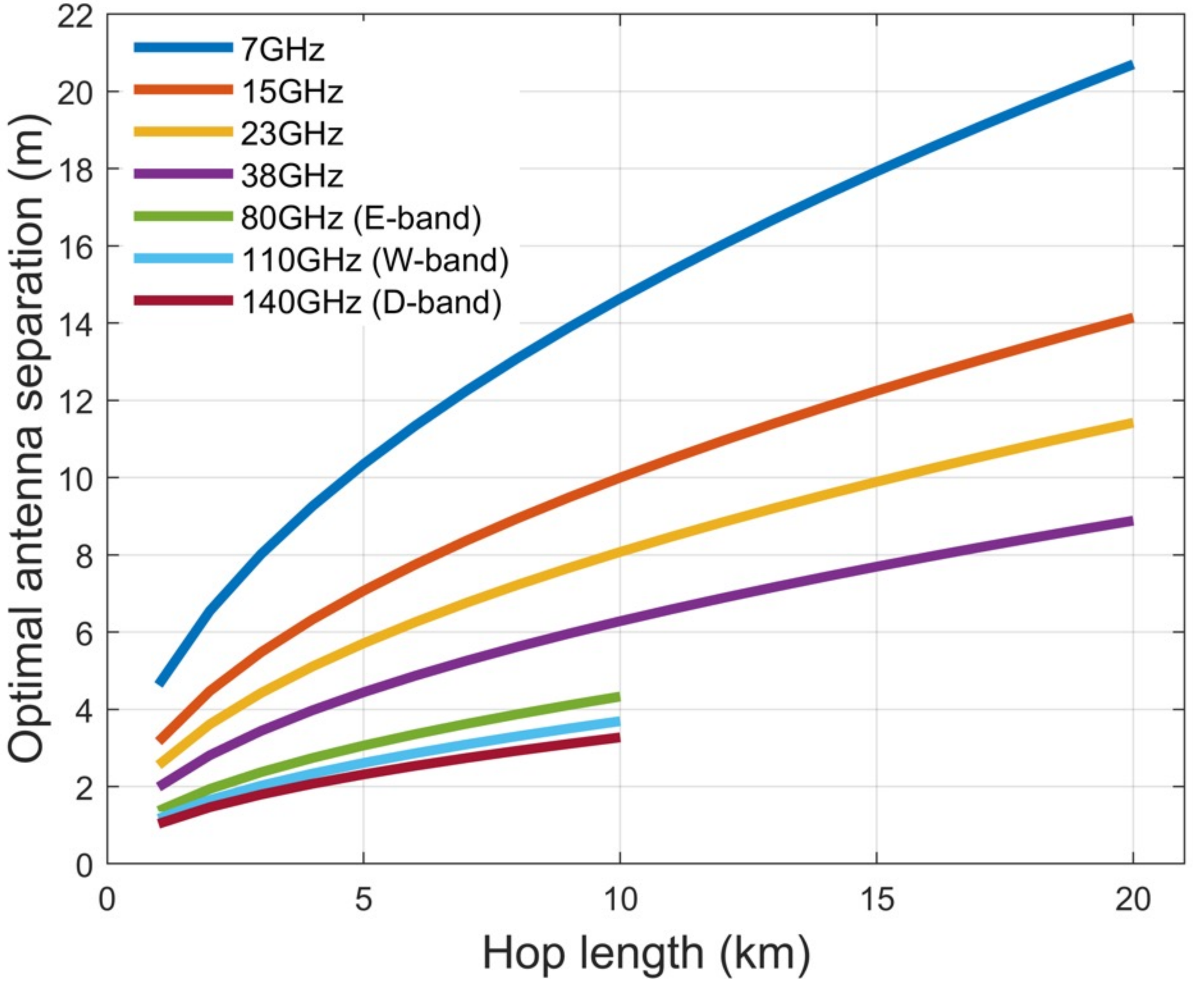


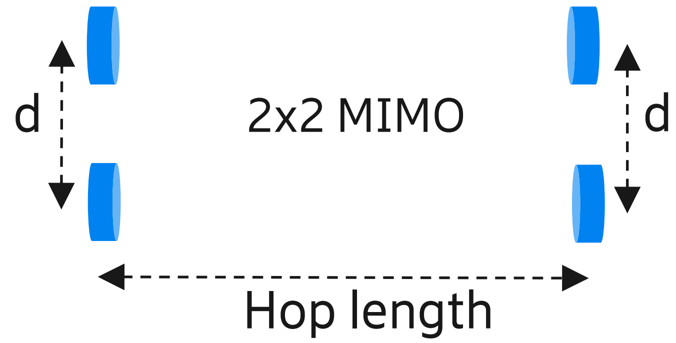

Some analysis gives optimal antenna separation in the symmetric NxN case:

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

$d_1$ and $d_2$ are antenna separations
D is hop length
$\lambda$ 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

# D-band example

## Reaching 100 Gbps

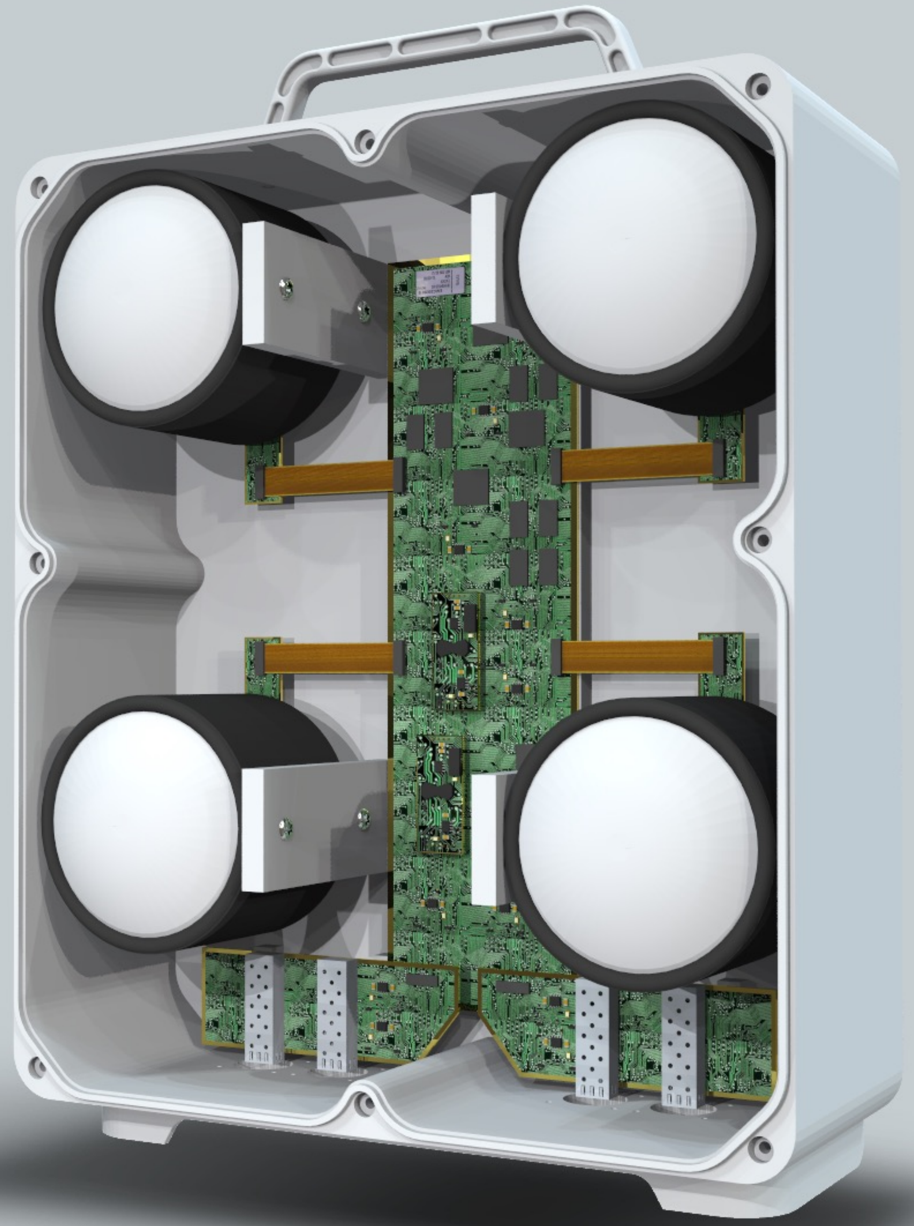
8 x 8 MIMO

2.25 Gbaud (2.5 GHz channel spacing)

64 QAM

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

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



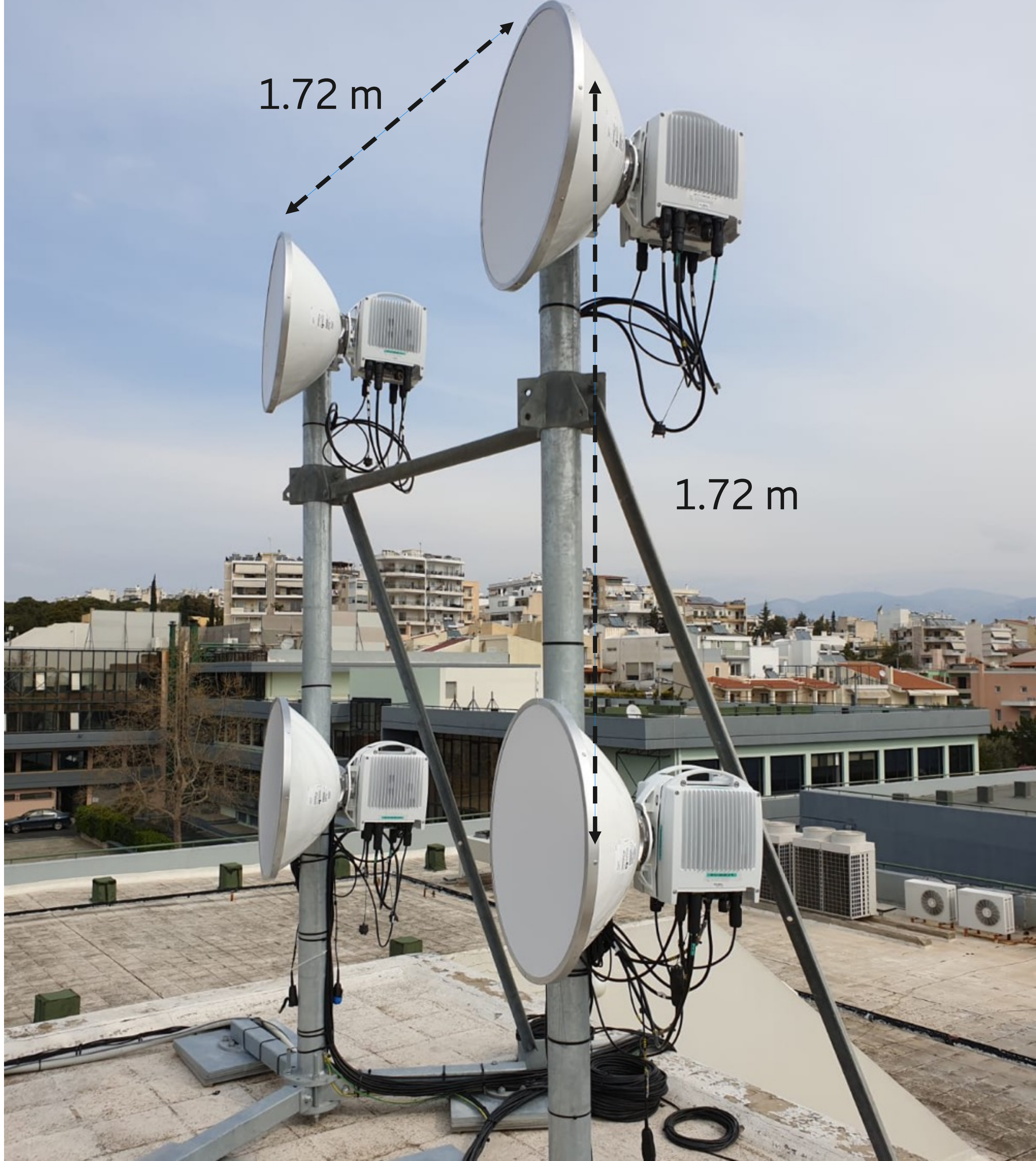

100 Gbps trial
E-band
1.5 km
E-band

# 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

- Choice of backhaul is usually a mix of fiber and microwave
  - Large regional variations
- Wireless transport enables fast, flexible and cost-efficient mobile network deployments → 50% of all sites globally are connected with microwave backhaul
- Radio access evolution drives wireless transport evolution:
  - Spectrum (move to higher frequencies and wider bandwidths)
  - Technology (more spectral efficient wireless backhaul, e.g., MIMO, higher frequency reuse)
  - Beyond 100 GHz and towards 100 Gbps research is ongoing to support beyond 5G and 6G systems