CMP4204
Wireless Technologies

Lecture 12

Cellular Mobile

5G New Radio (NR)

CISSP®

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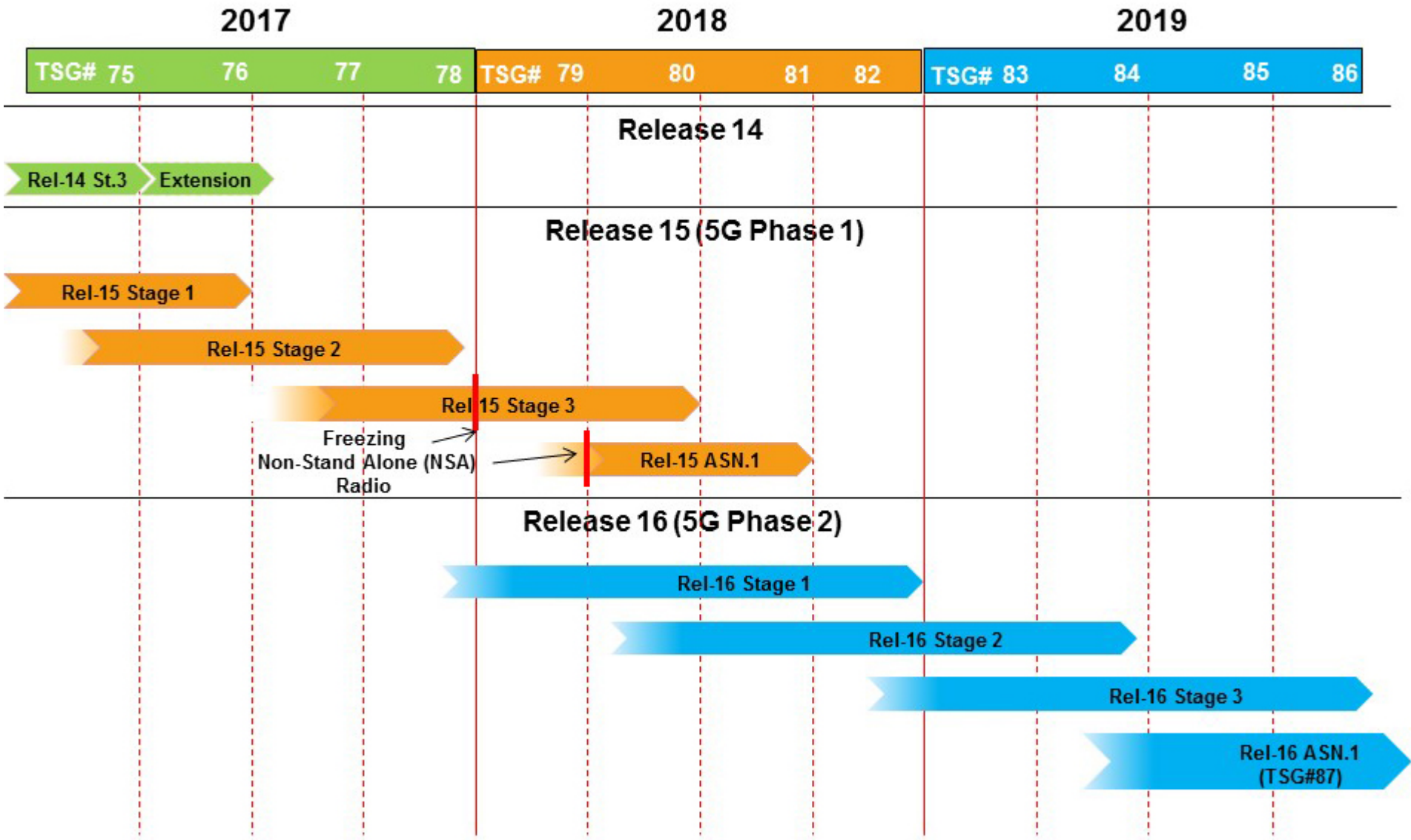
5G NR

- Standard set to:
  - Significantly increased data rates to support large populations.
  - 1 Gb/s simultaneously to many subscribers in proximity.
  - Massive numbers of simultaneous connections to support IoT
  - Enhanced spectral efficiency compared to 4G.
  - Improvements in coverage.
  - Improved signal efficiency.
  - Reduced latency.

5G


2017
2018
2019
TSG# 75
76
77
78
TSG# 79
80
81
82
TSG# 83
84
85
86
Release 14
Rel-14 St.3
Extension
Release 15 (5G Phase 1)
Rel-15 Stage 1
Rel-15 Stage 2
Rel-15 Stage 3
Freezing
Non-Stand Alone (NSA)
Radio
Rel-15 ASN.1
Release 16 (5G Phase 2)
Rel-16 Stage 1
Rel-16 Stage 2
Rel-16 Stage 3
Rel-16 ASN.1
(TSG#87)

5G use cases

- **enhanced Mobile BroadBand (eMBB)**
  - Essentially a fibre-like experience over a wireless radio link
    - Multi Gbps peak rates for DL and UL.
- **massive Machine Type Comms (mMTC)**
  - connectivity for millions of devices.
- **Ultra Reliable Low Latency Comms (URLLC)**
  - Highly available, reliable and low latency service.

enhanced mobile broadband (eMBB)

- Performance compared to 4G
  - 10X throughput
  - 10X decrease in end-to-end latency
  - 10X connection density
  - 3X spectrum efficiency
  - 100X traffic capacity
  - 100X network efficiency

massive Machine Type Comms (mMTC)

- Device 2 Device (D2D) communication
  - Transmitting relatively low volumes.
  - Non-delay-sensitive data
    - Low bandwidth and not latency-critical.
  - Low-cost devices.
  - Extended battery life.

Ultra Reliable Low Latency Comms (URLLC)

- Solution for emerging mission-critical applications such as industrial Internet, smart grids, infrastructure protection, eHealth, public safety and Intelligent Transportation Systems (ITS).
  - Latency
    - Time delay between data being generated and transmitted from a device like a sensor and it being correctly received by another device like an actuator.
  - Reliability
    - Provide a high level of certainty that a message is correctly delivered to the receiver within a latency bound.
  - Availability
    - System endurance against outage scenarios.

Ultra Reliable Low Latency Comms (URLLC)

• Factory automation	< 1 ms
• Motion control	< 1 ms
• Remote control	5 - 100 ms
• Intelligent transport systems	5 ms
• Smart grid	3 – 5 ms
• Tactile Internet	1 ms

(19 Mar 2018 – Smile Communications 4G network)

Latencies in 4G LTE

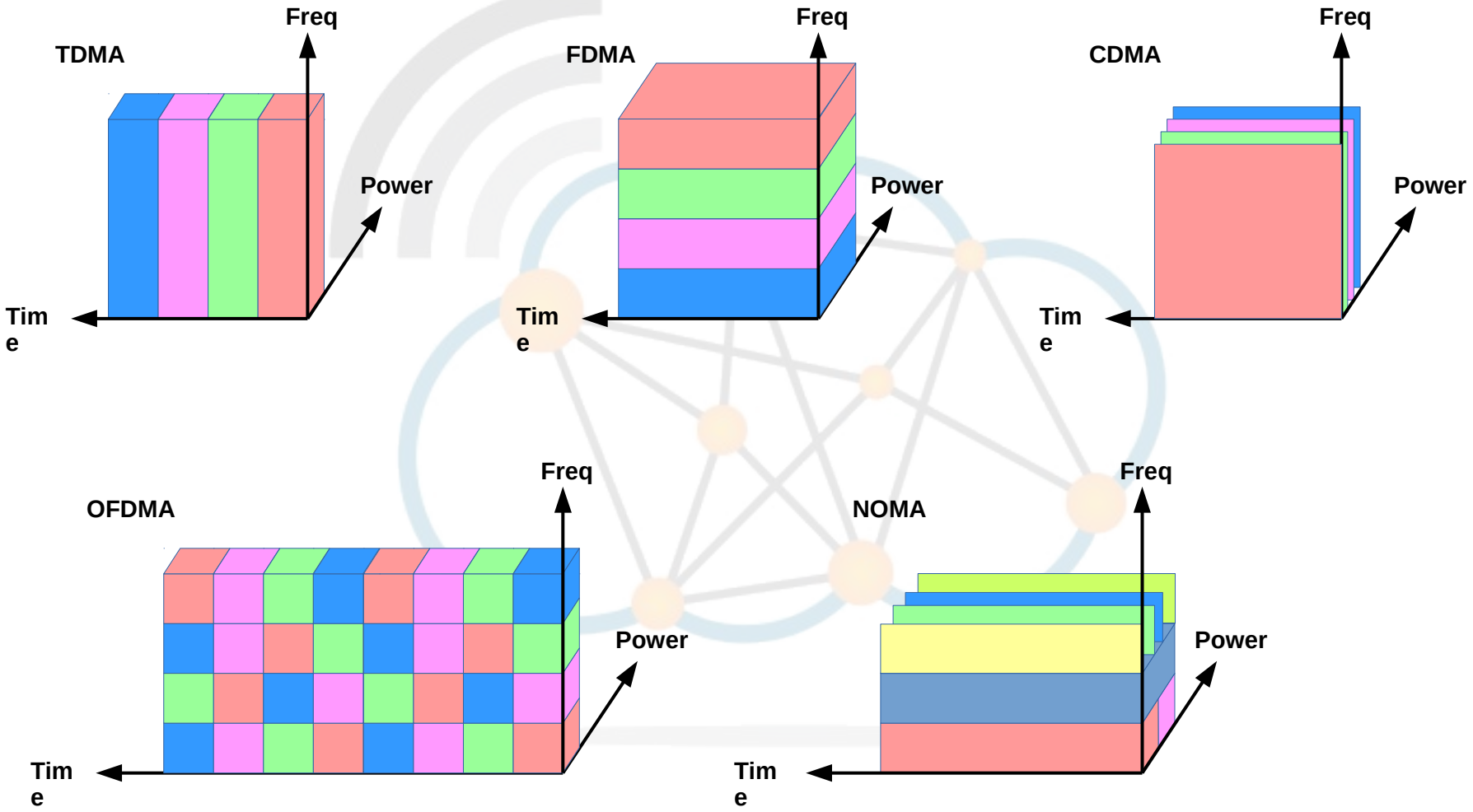
- Best 10%: 21 - 43 ms
- Median: 33 - 75 ms
- Worst 10%: 47 - 200 ms

~ $ **ping 8.8.8.8**
PING 8.8.8.8 (8.8.8.8) 56(84) bytes of data.
64 bytes from 8.8.8.8: icmp_seq=1 ttl=46 time=207 ms
64 bytes from 8.8.8.8: icmp_seq=2 ttl=46 time=204 ms
64 bytes from 8.8.8.8: icmp_seq=3 ttl=46 time=214 ms
64 bytes from 8.8.8.8: icmp_seq=4 ttl=46 time=203 ms

5G Modulation

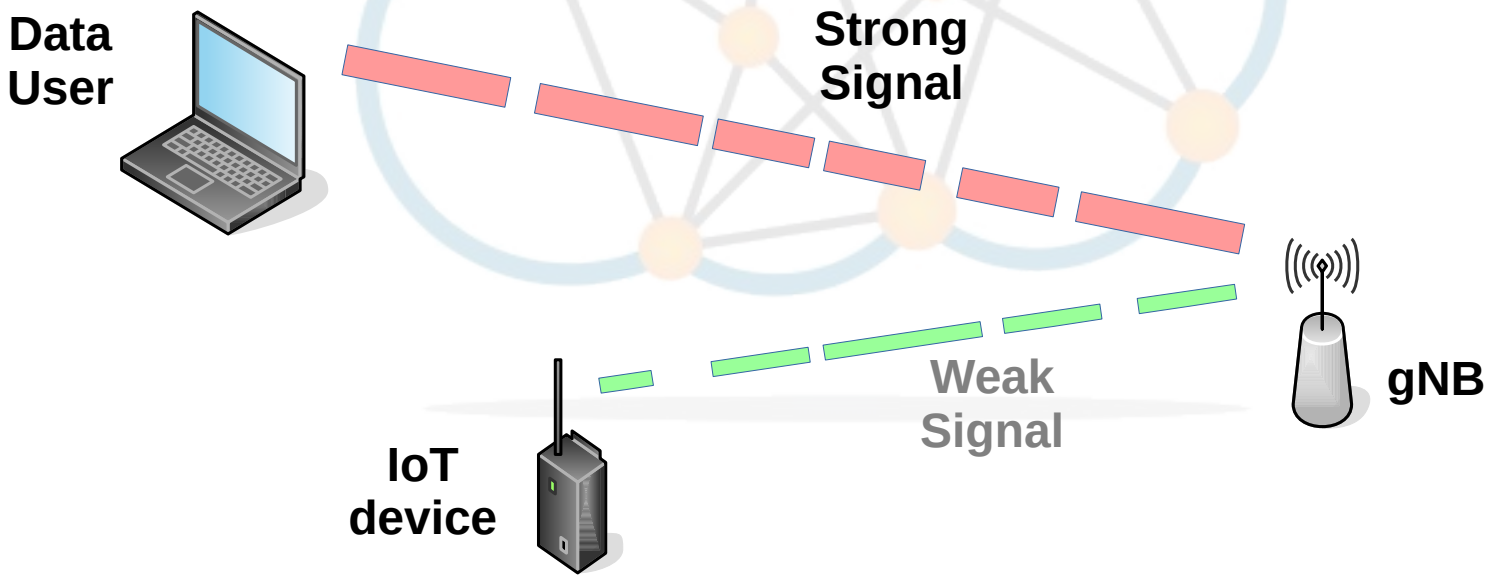
- LTE/LTE-A many interactive processes between eNB and UE before data is transmitted.
- OK for long time continuous sessions
  - Signalling overhead averaged over time is less.
- In mMTC, used in IoT,
  - The device TX a small amount of data over a short period of time
  - There are millions of such IoT devices.
- LTE/LTE-A , the signalling overhead is too high and access efficiency becomes low.

Non-Orthogonal Multiple Access (NOMA)

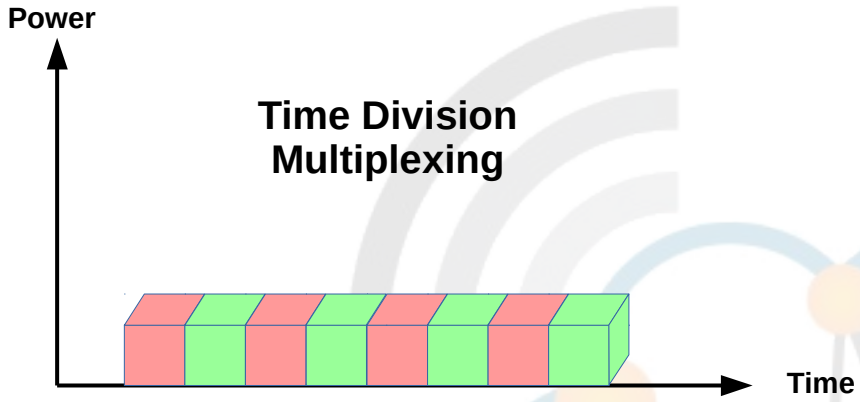


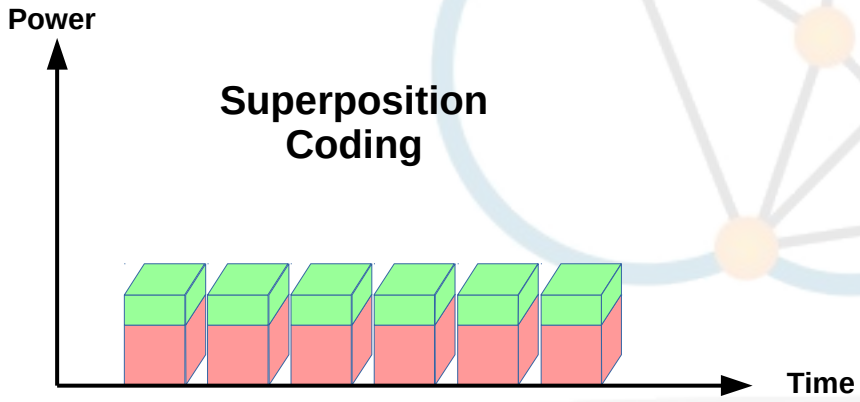
Non-Orthogonal Multiple Access (NOMA)

- NOMA will address the (M2M) requirements.
- Shares time & freq resources among users.
- NOMA = OFDM + superposition + Successive Interference Cancellation (SIC).



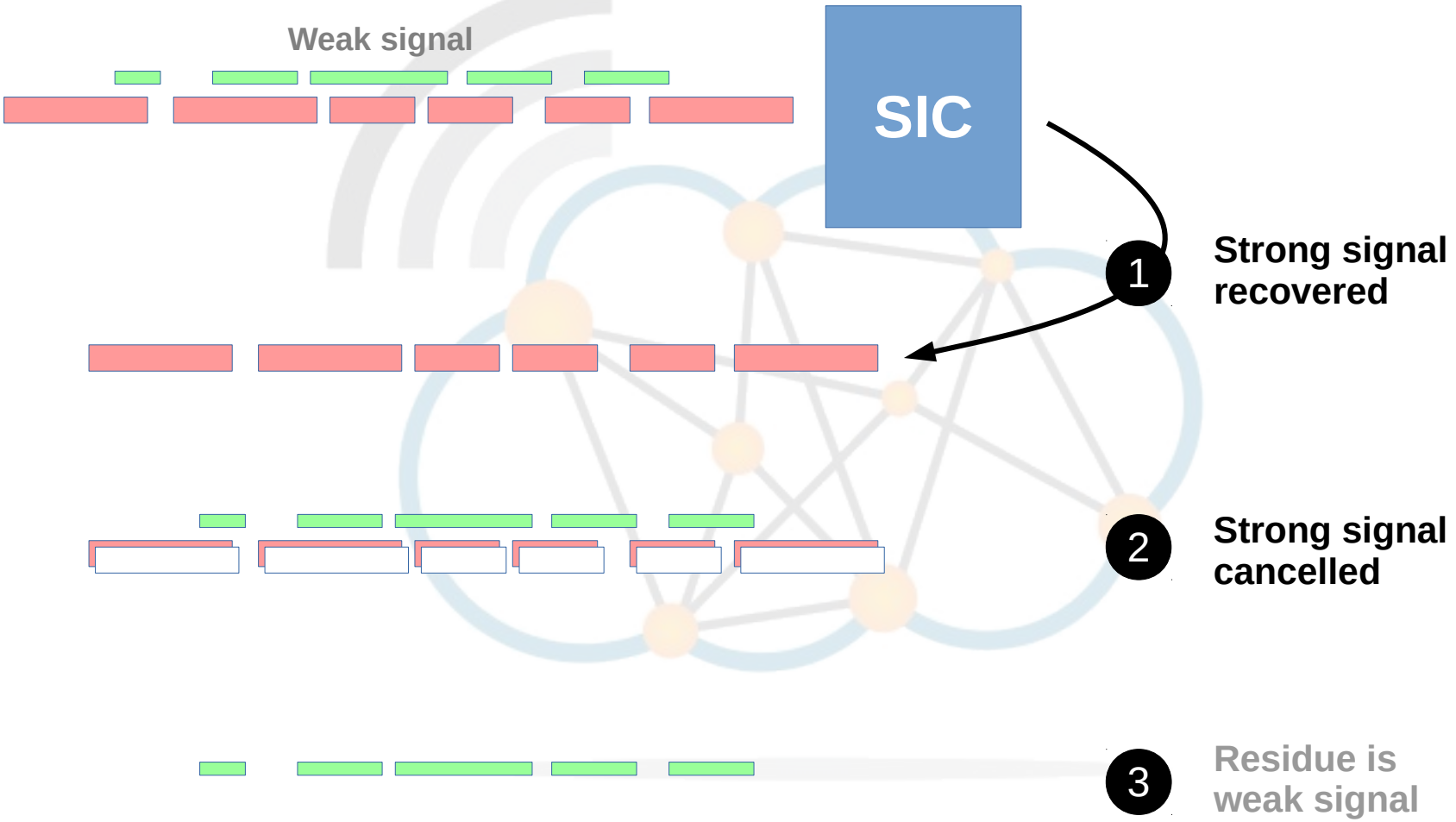
Superposition Coding





- Weak and strong signals transmitted together.
- Superposition coded.

Successive Interference Cancellation (SIC)



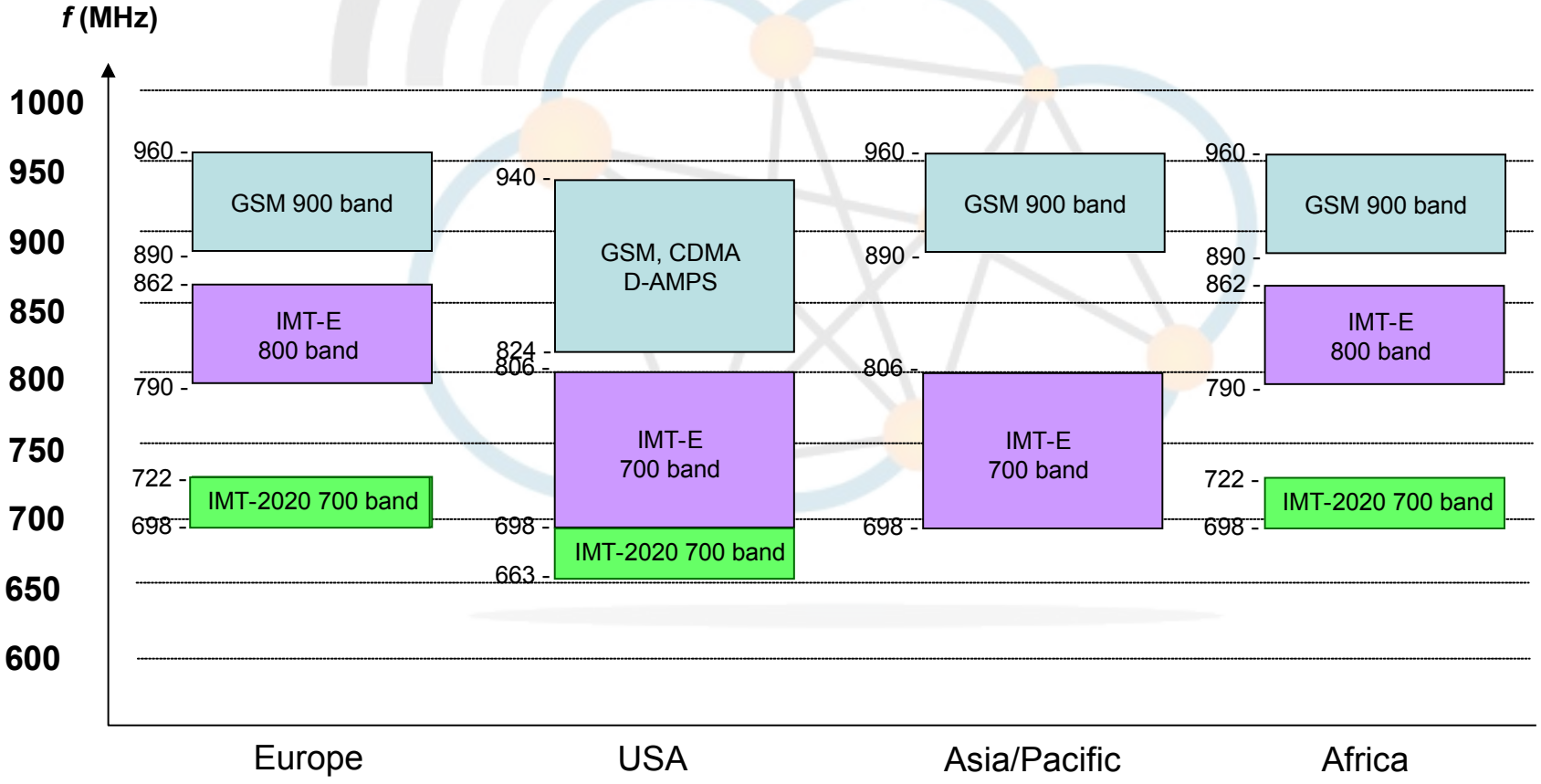
Successive Interference Cancellation (SIC)

- Physical layer capability that allows a receiver to decode packets that arrive simultaneously.
- Receiver receives two or more signals concurrently
  - In today's systems only the strongest signal is decoded.
- SIC
  - Decodes the strongest signal bits
  - Reconstructs the strongest signal
  - Subtracts (cancelled) the strongest signal from the combined signal
  - Bits of the weaker signal is decoded from this residue.

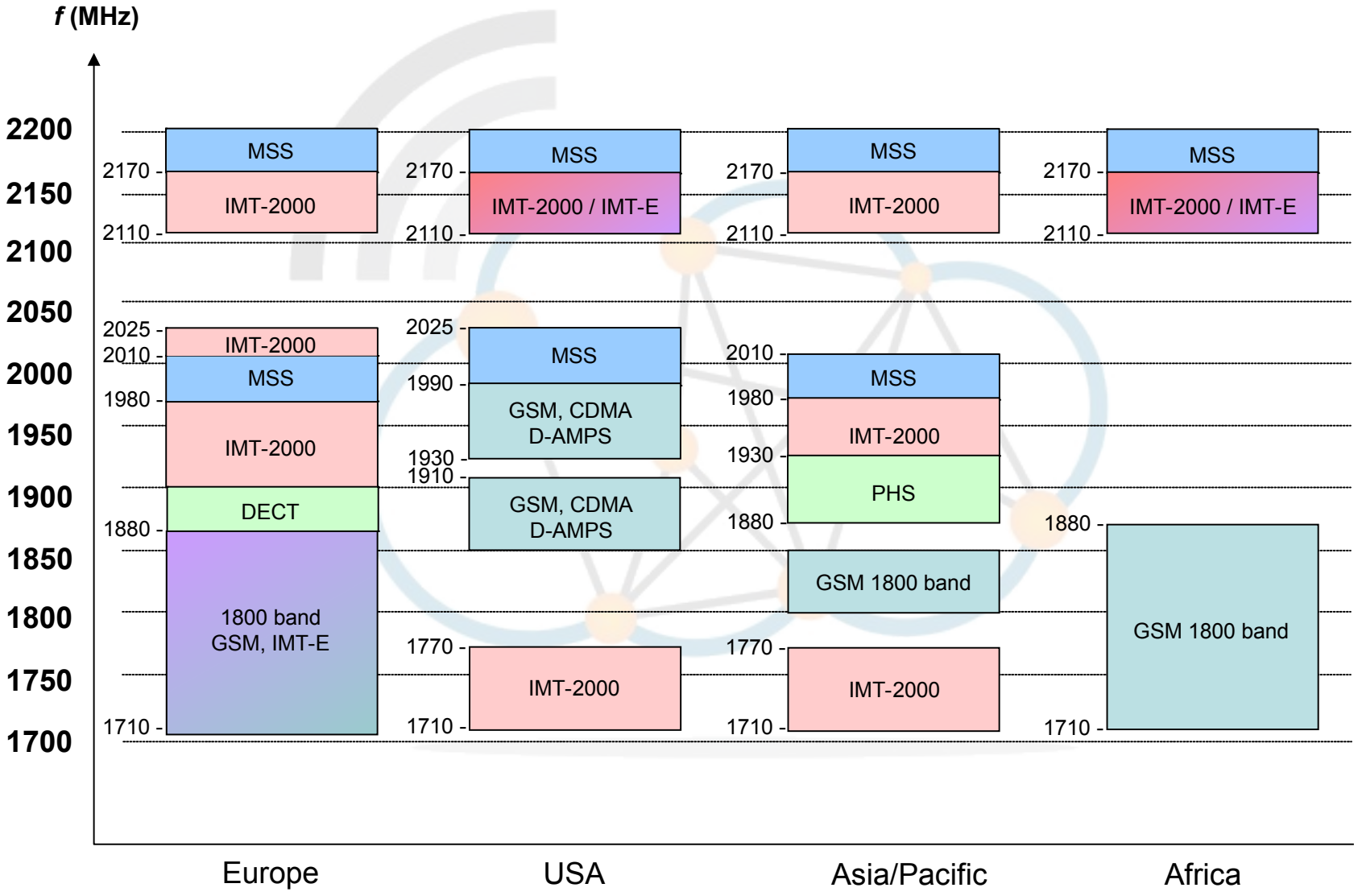
The 5G Spectrum conundrum

- Mobile generations 1G ➞ 4G
  - Assigned new frequency bands
  - Wider spectral bandwidth per channel
    - 1G up to 30 kHz
    - 2G up to 200 kHz
    - 3G up to 5 MHz
    - 4G up to 20 MHz
  - What about 5G
    - Very little room for larger channel bandwidths and new frequency bands
    - Higher frequency bands would begin to overlap with K-band satellite transmissions.

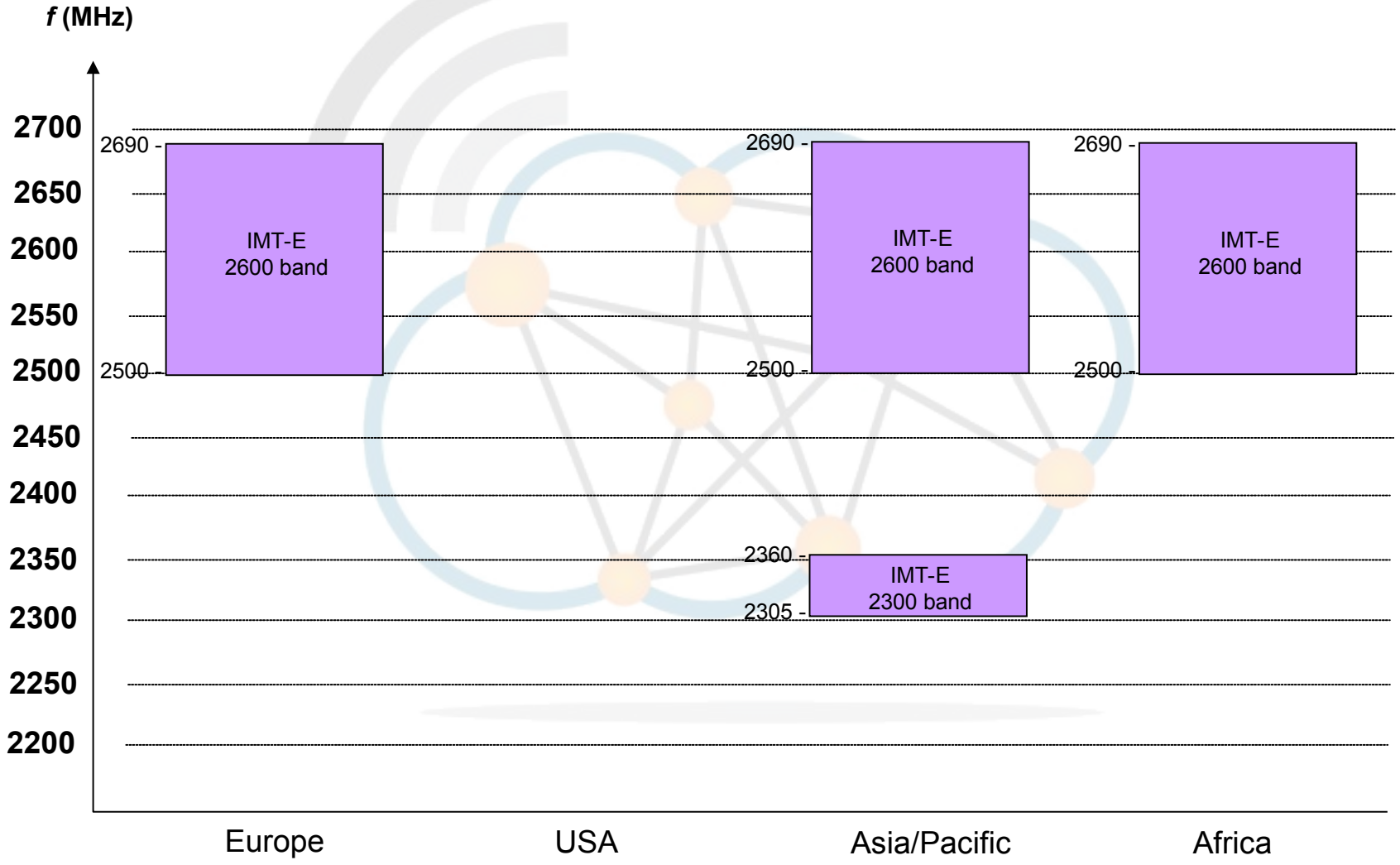
IMT-2000/IMT-Adv/IMT2020 – > 1 GHz



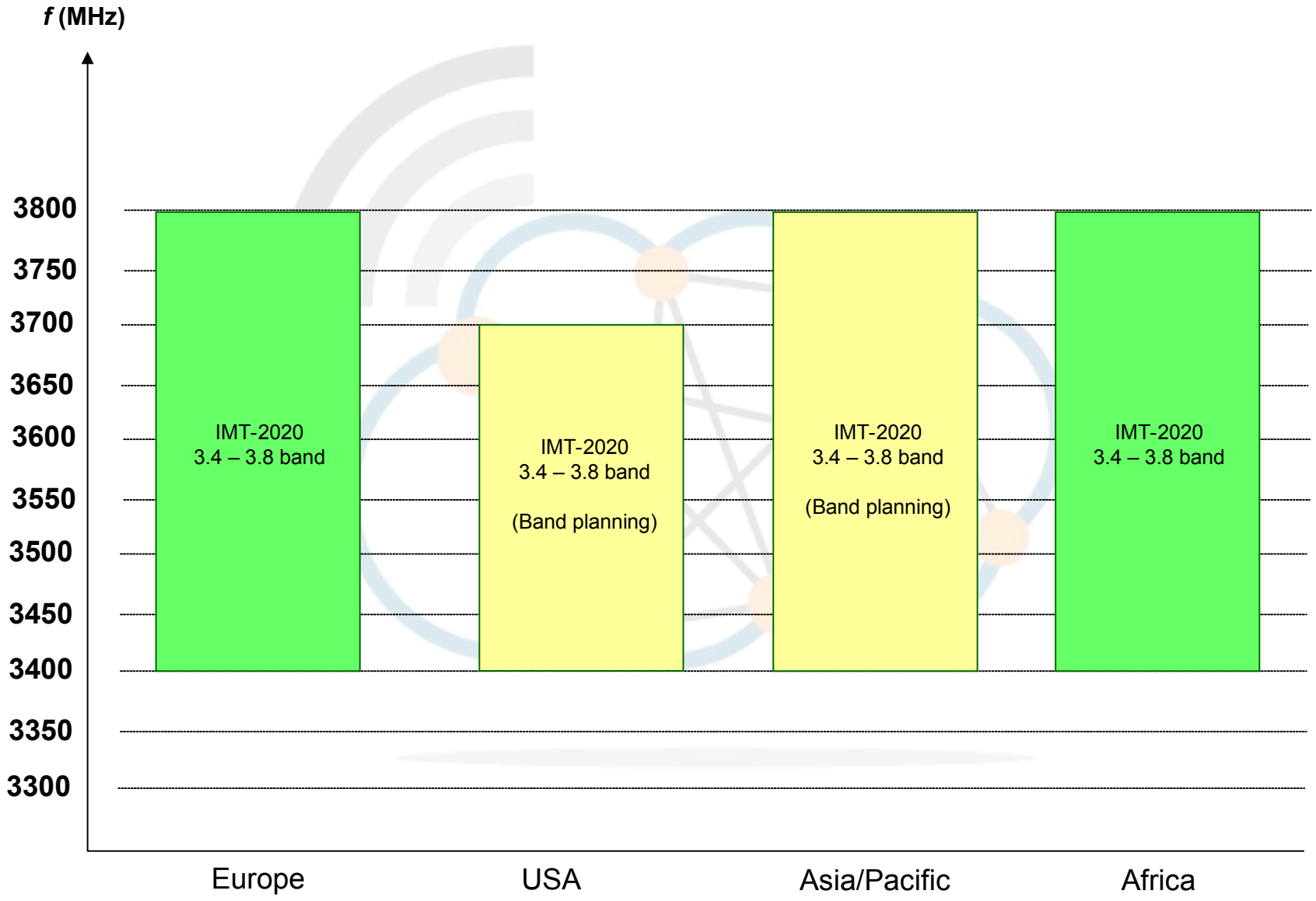
IMT-2000/IMT-E – Spectrum 1 <> 2 GHz



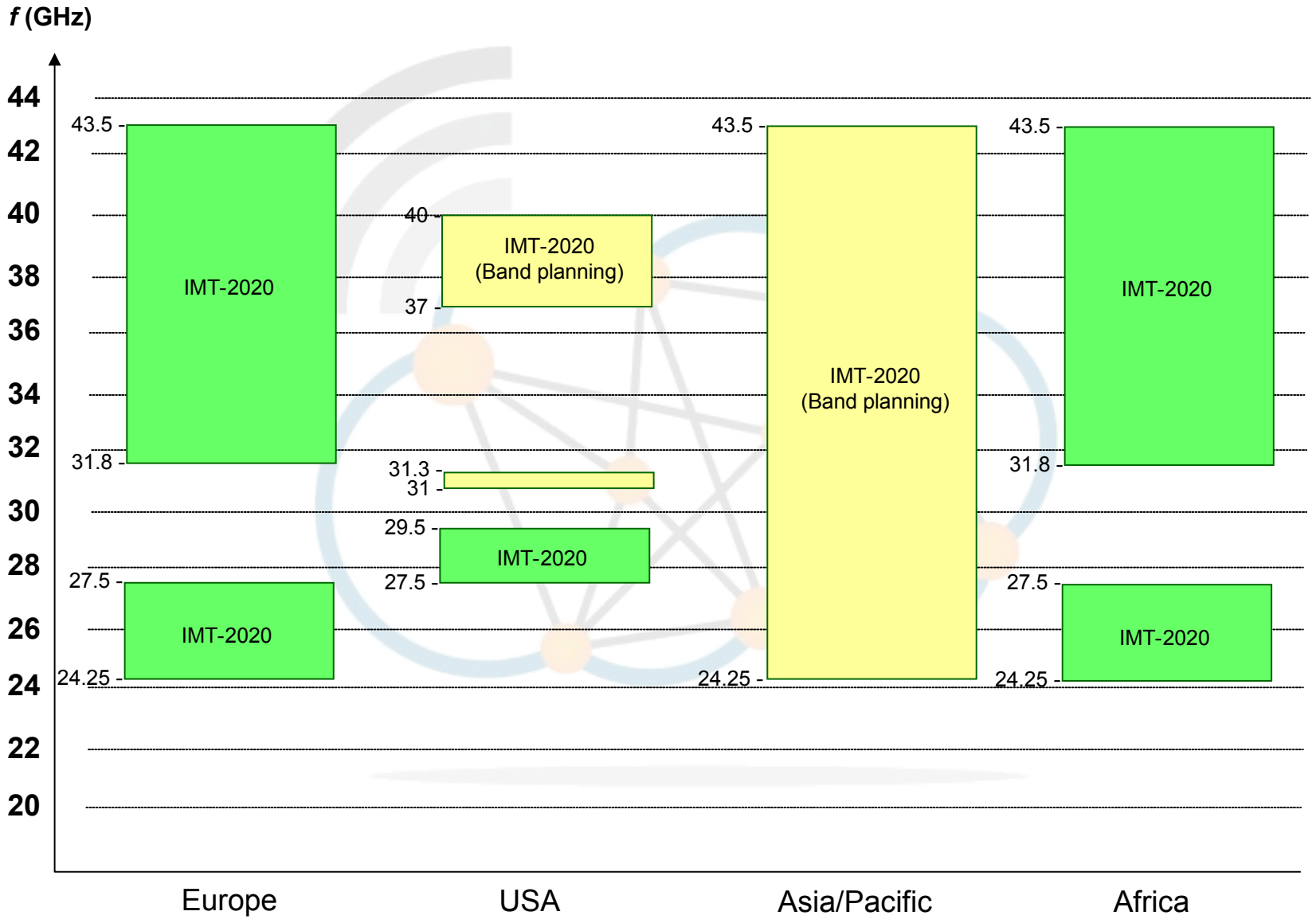
IMT-2000/IMT-E – Spectrum > 2 GHz



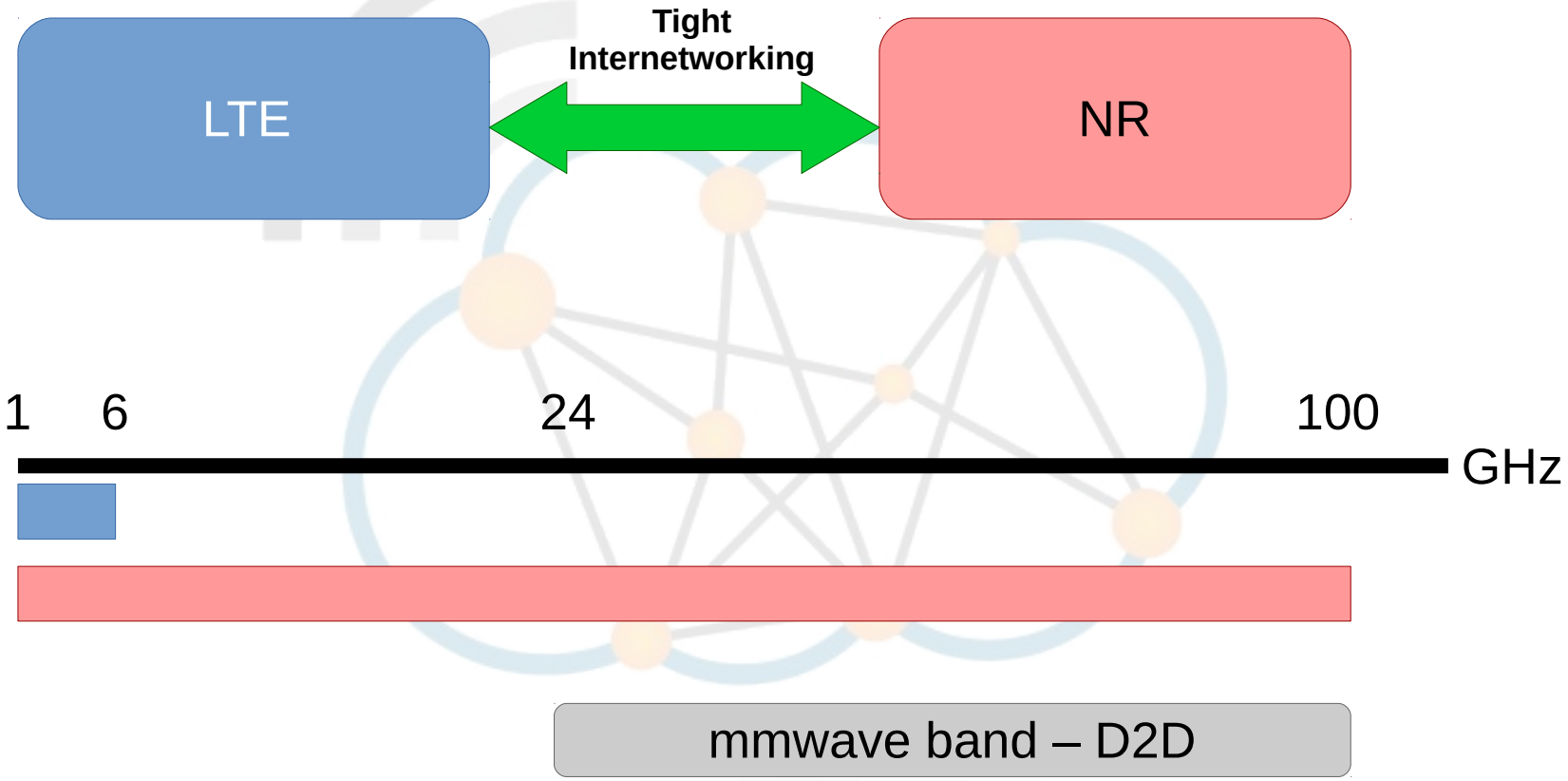
IMT-2000/IMT-E/IMT-2020 > 2 GHz



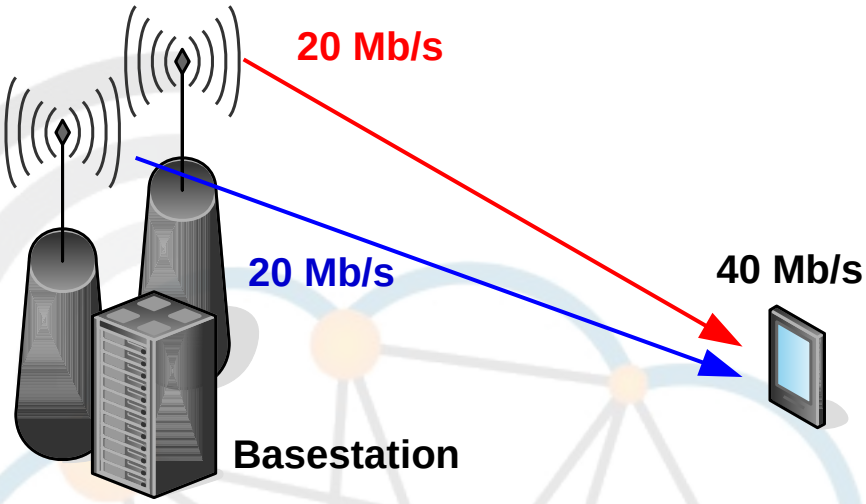
IMT-2000/IMT-E/IMT-2020 mmWave



5G Spectrum

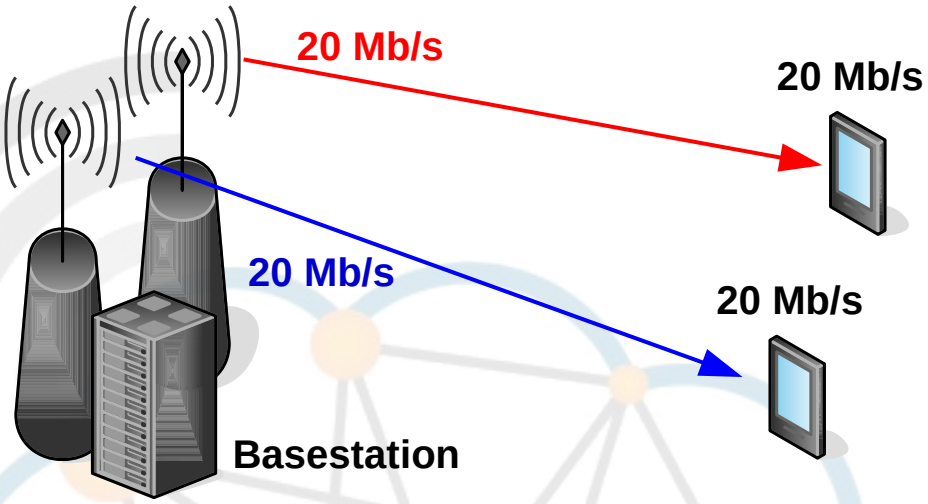


SU-MIMO



- Each device waits its turn to send and receive data to the transmitter.
- Increases the throughput of one user at a time.

MU-MIMO



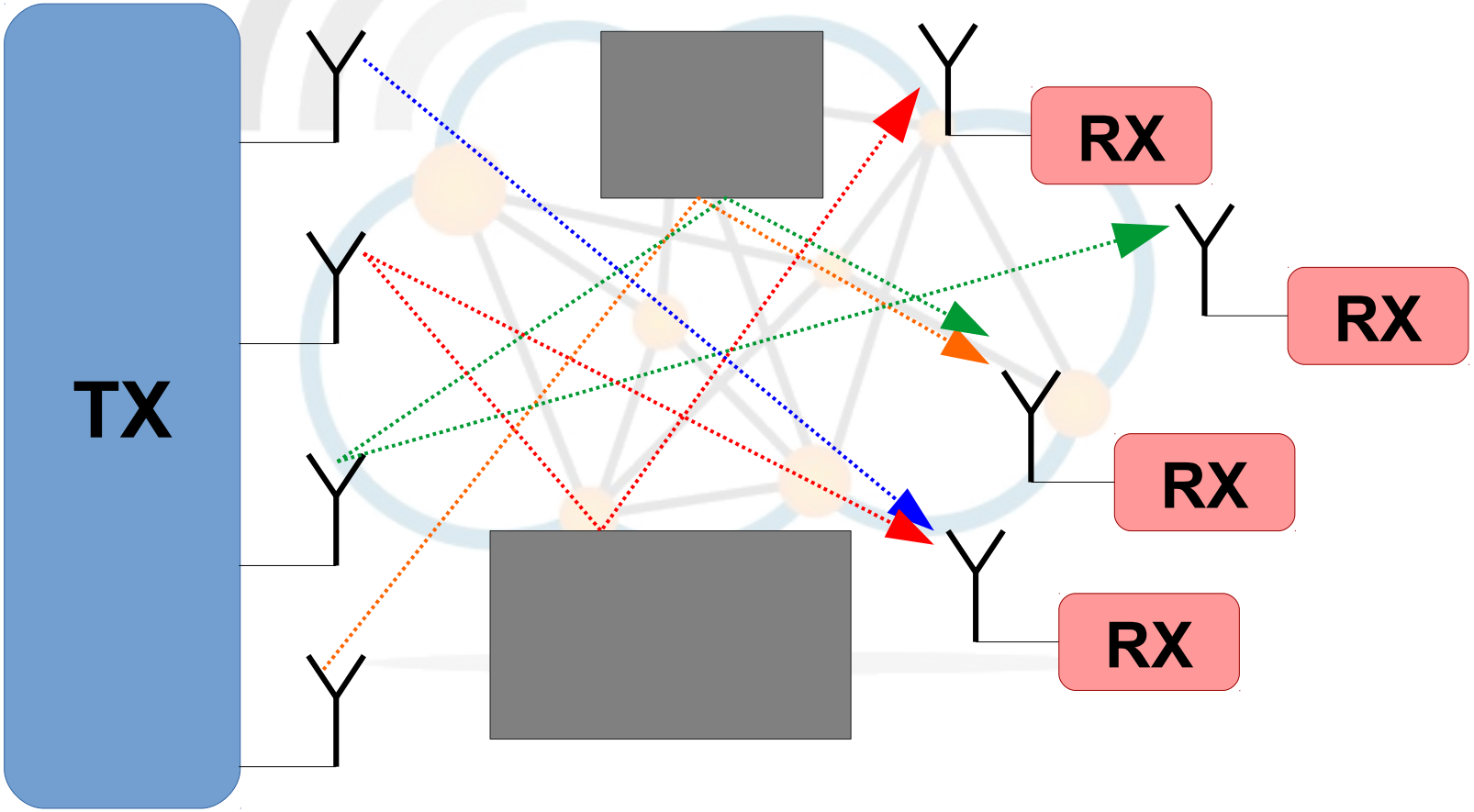
- Transmitter communicates with devices simultaneously.
- Increases the overall system capacity as opposed to increasing the data transfer rate of one user.

Massive MIMO

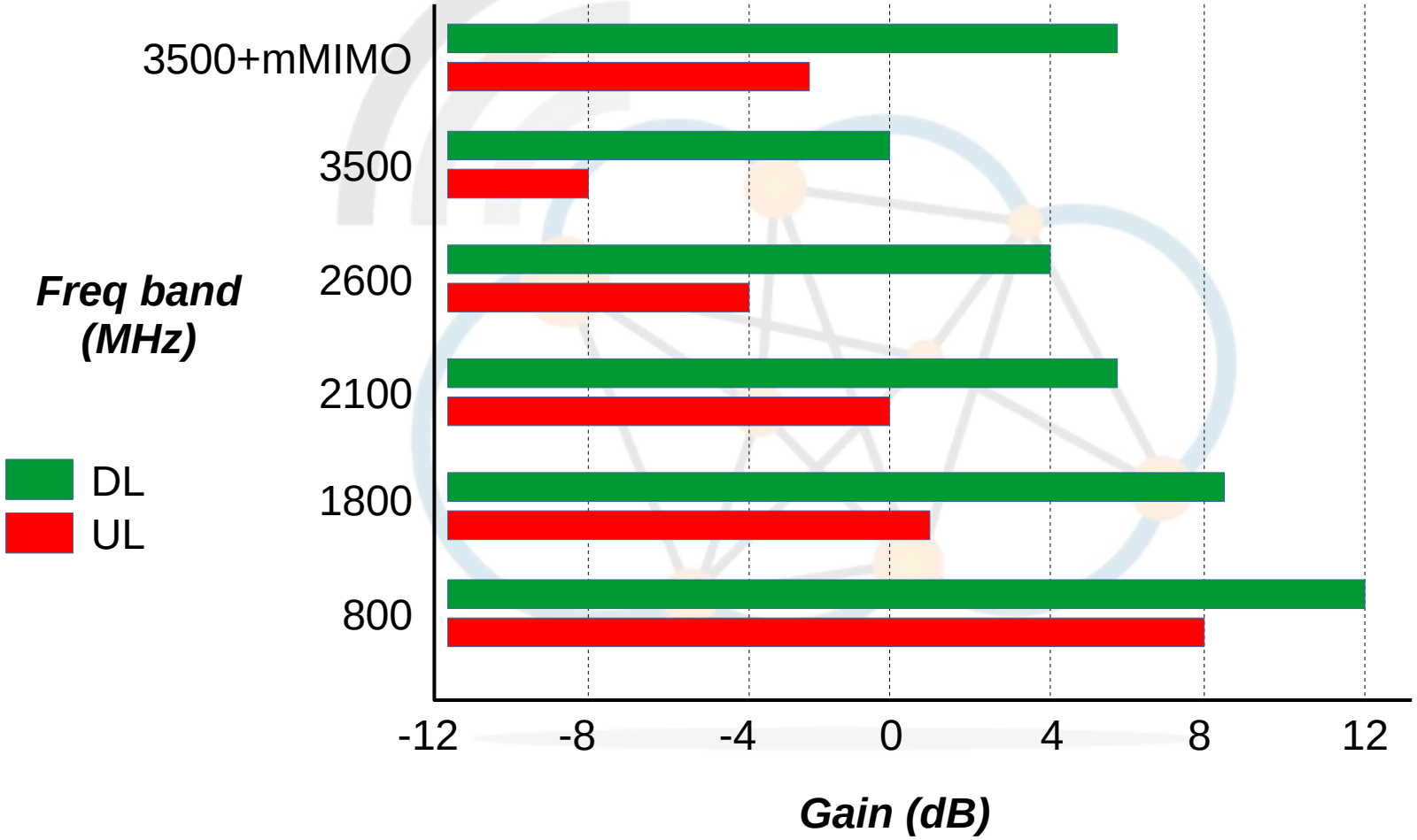
- Form of multi-user MIMO.
- Number of antennas at the base station is much larger than the number of mobile stations per signalling resource
  - 4G – 64 antenna on TX and 2 antenna on device
    - 16.32 b/s/Hz for LTE with 4x4 MIMO
    - 30 b/s/Hz for LTE-Advanced with 8x8 MIMO.
  - 5G – 256 antenna on TX and 64 antenna on device
    - High spectral efficiency (145 b/s/Hz).
- Gain of 6 dB compared to 2x2 MIMO.

Beamforming

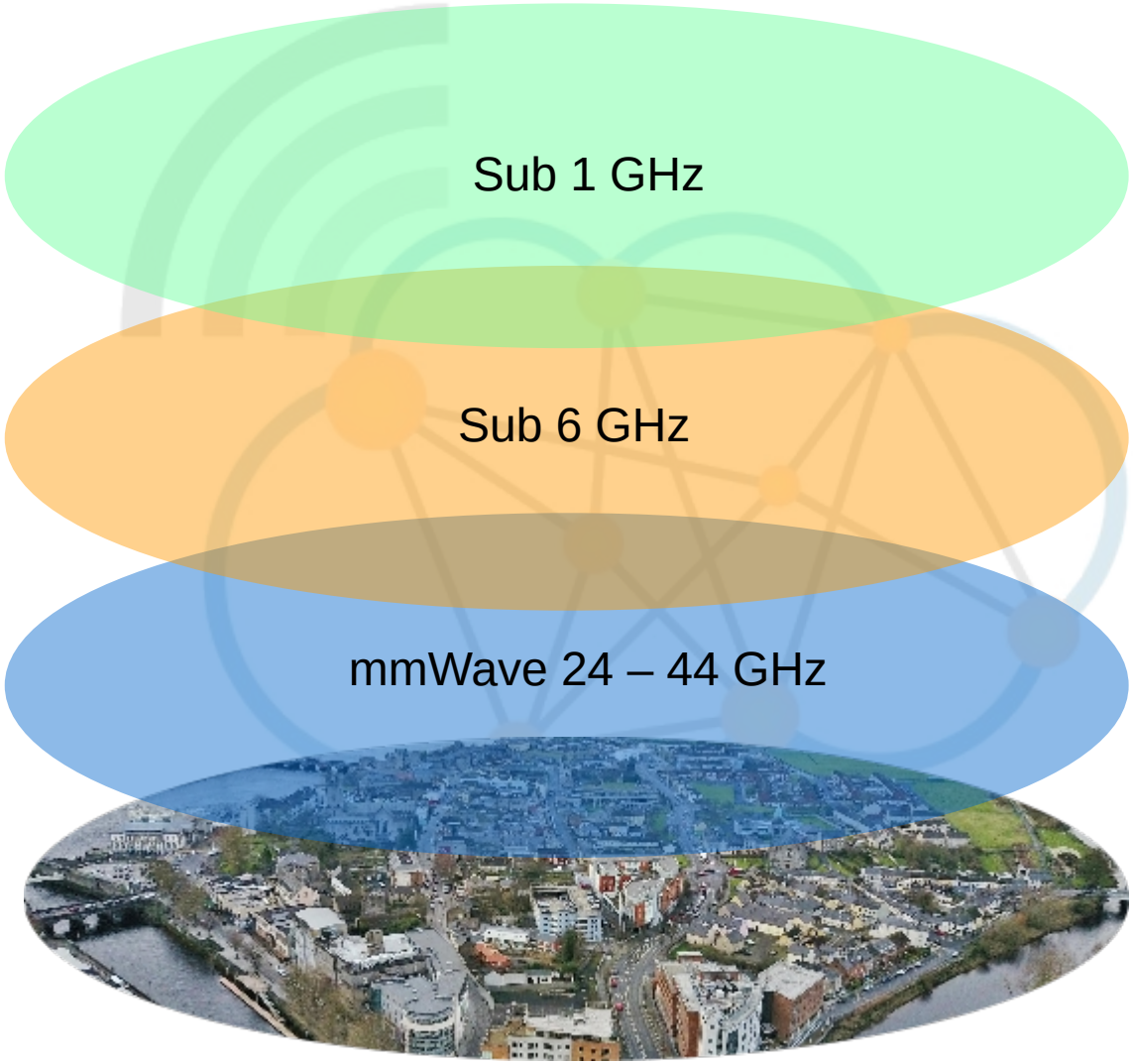
- Identifies the most efficient data-delivery route to each user, and it reduces interference for nearby users using a signal-processing algorithm.



Outdoor coverage differences



5G Tiers of coverage



Sub 1 GHz bands

- Characteristics
  - Wide coverage with indoor penetration
  - Massive IoT and ultra reliable low latency
  - Reusing existing sites for 800/900 MHz.

Sub 1 GHz bands

- Provides deep indoor penetration, reliable UL and large coverage
  - 600 MHz, in US
  - 700 MHz, to become available first
  - 900 MHz, is mainly occupied by 2G and 3G today.
    - SPs are likely to keep 2G and 3G running until 2020.
- Limited option to use 5G features like massive MIMO
  - Handheld devices are typically not large enough to accommodate more than two sub-1 GHz antennas.
- Narrow bandwidths available
  - Typically 2x 10 MHz FDD.

Sub 6 GHz bands

- Characteristics
  - Dense urban coverage
  - Supports enhanced mobile broadband
  - Reusing existing sites for 2 GHz.

Sub 6 GHz bands

- Slightly higher frequencies than those used in IMT-2000
  - 3.4 – 3.8 GHz.
- Suitable for dense urban coverage.
- High data rates and capacity supporting eMBB.
- Reuse of 2 GHz sites.

Sub 6 GHz bands - 5G versus 4G capacity

- 5G versus 4G capacity per cell

	LTE 1800 with 2X2 MIMO		5G NR 3500 with mMIMO
Frequency band	1.8 GHz		3.5 GHz
Channel size	20 MHz	10 – 20 X	100 MHz
Spectral efficiency	2 bps/Hz		4-8 bps/Hz
Cell throughput	40 Mb/s		400 – 800 Mbps

mmWave bands

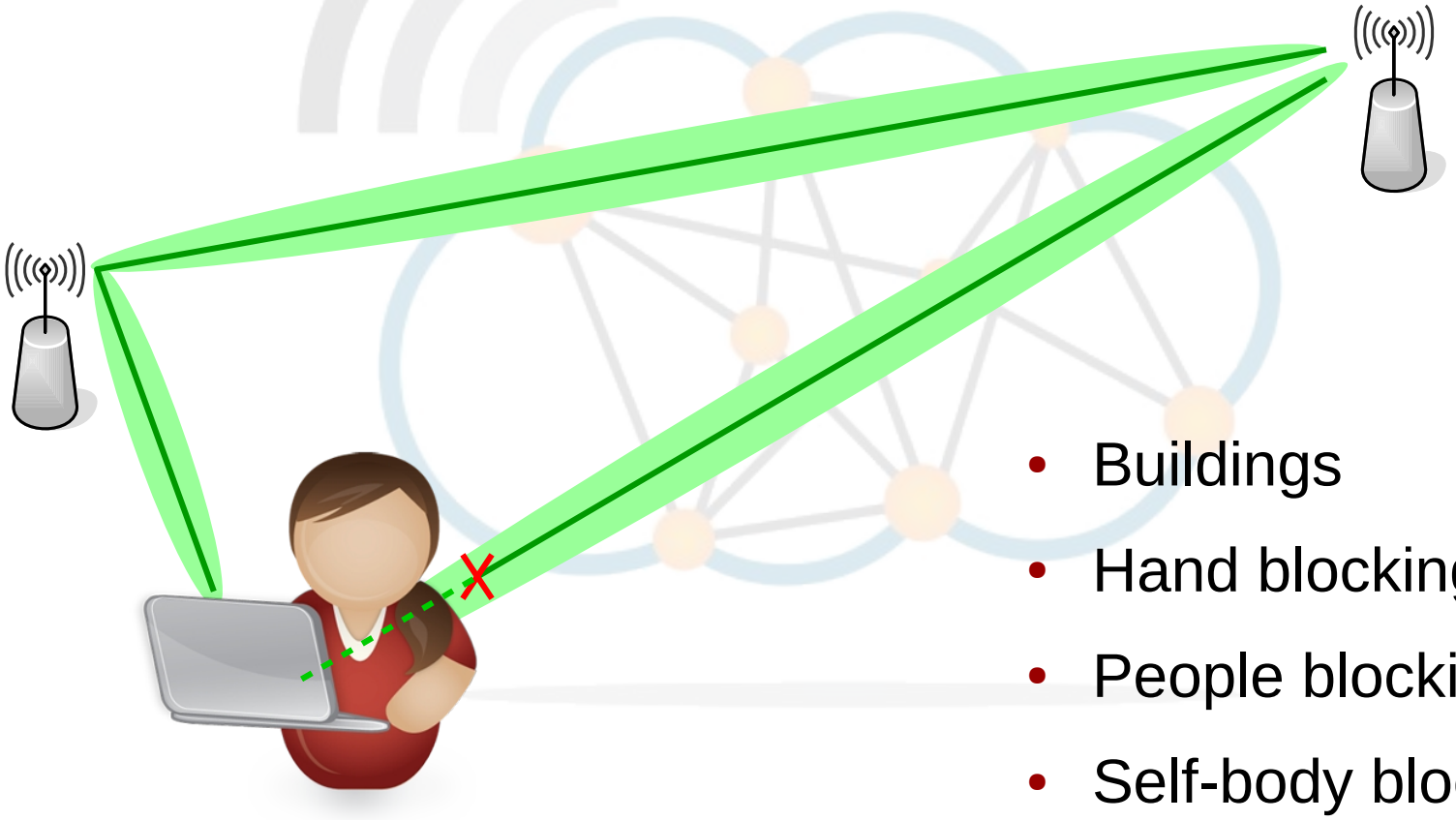
- Characteristics
  - Hot spots like airports and stadiums
  - Supports full enhanced mobile broadband
  - Data rates exceed 10 Gbps.

mmWave bands

- Wavelength (λ) ranges from 1 mm - 10 mm.
- Abundant spectrum available.
- Capable of delivering extreme data speeds and capacity.
- TX suffer from much higher path loss.
- Susceptible to blocking.
- Short TX paths and high propagation losses.
- Tiny antennas
  - Multi-element, dynamic beamforming antennas that will be small enough to fit into handsets.
- Hotspots, shopping centre, public areas.

mmWave bands - blocking

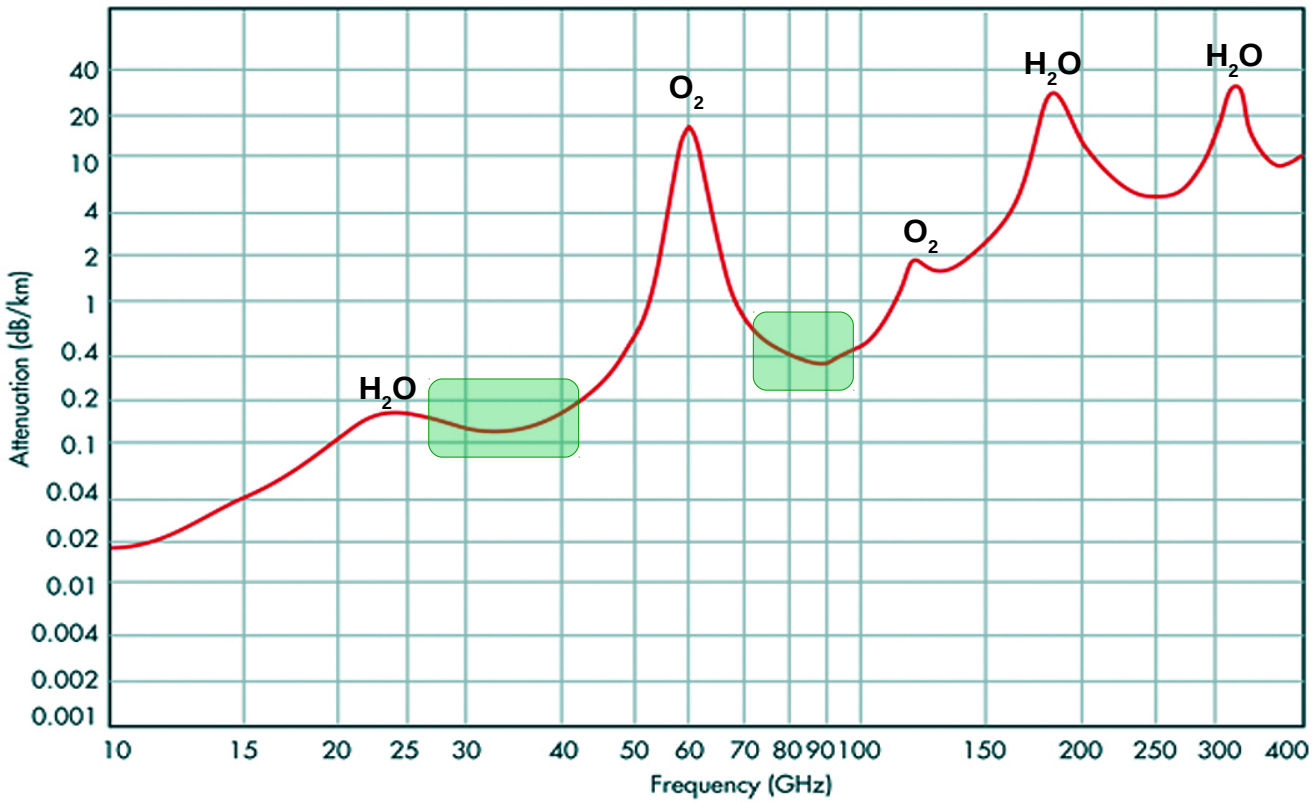
- Directional beamforming



- Buildings
- Hand blocking
- People blocking
- Self-body blocking

MmWave attenuation versus frequency

- Absorption by atmospheric gases at particular points.
- Less atmospheric attenuation at areas marked in green.

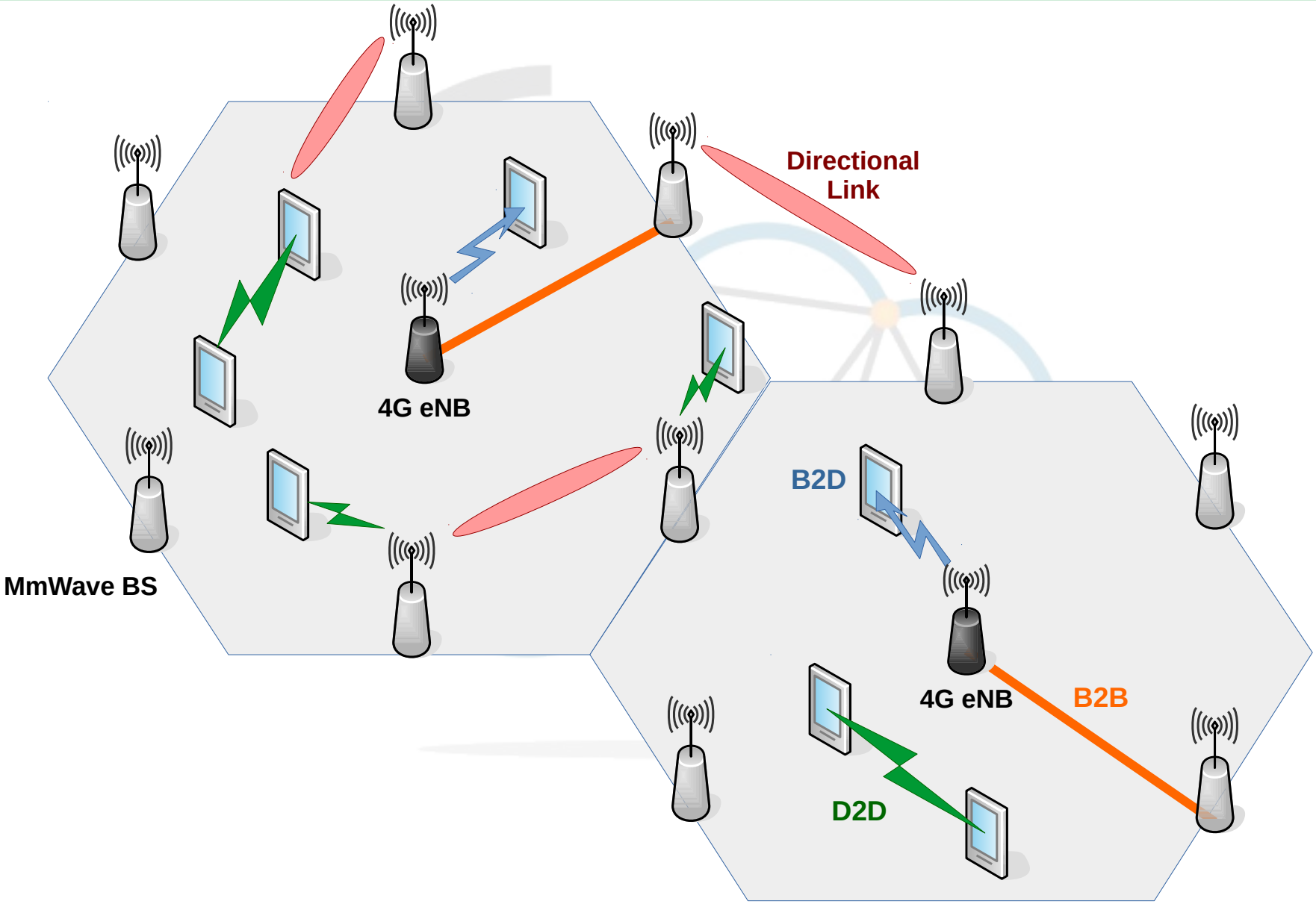


mmWave bands

Band	Bandwidth
28 GHz	500 MHz
38 GHz	1 GHz
72 GHz	2 GHz

- Up to 40 GHz
  - Carriers are aggregated to achieve higher bandwidth of 1GHz.
- Above 40GHz
  - Bandwidths from 500MHz to 2 GHz can be achieved without carrier aggregation.

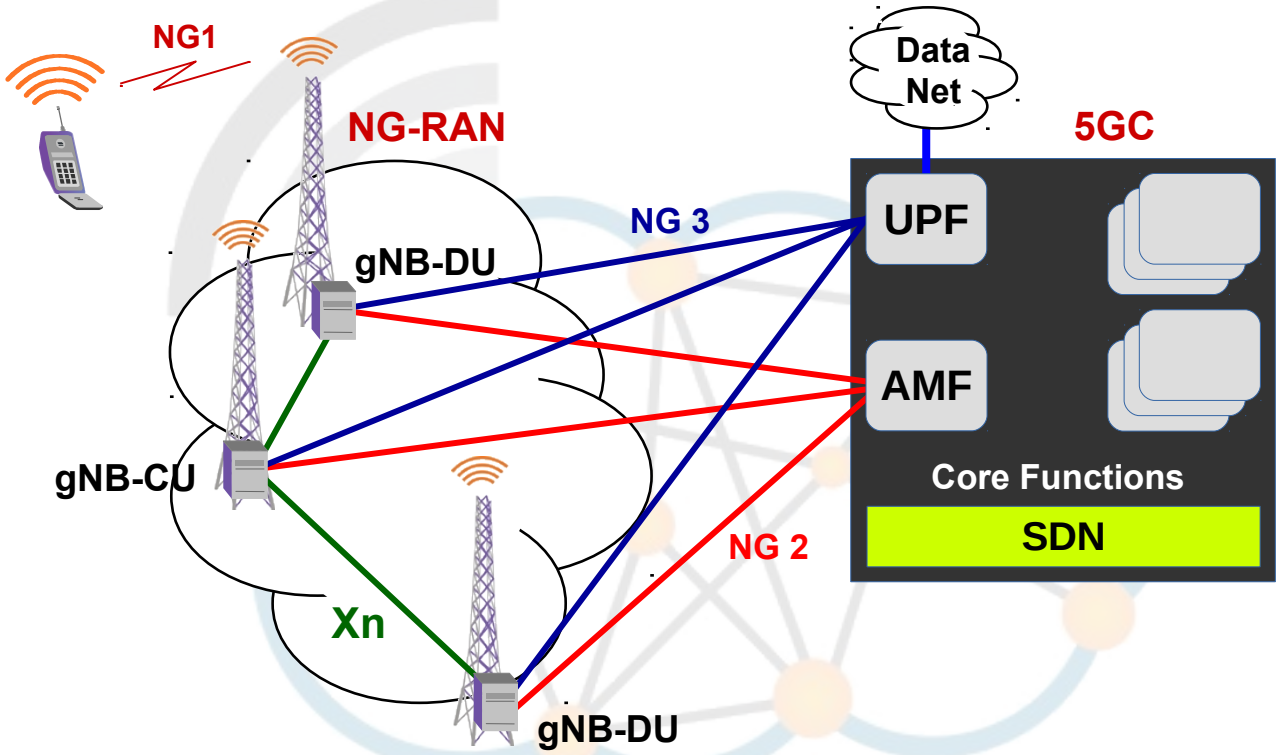
mmWave 5G cellular network architecture



5G Connection pathways

- Device-to-Device (D2D)
  - Provide the connection between two wireless devices either directly or by hopping.
  - Local D2D communications
    - Build path between two wireless devices associated with the same BS.
  - Global D2D communications
    - Connect two wireless devices associated with different BS by hopping via backbone networks.
- BS-to-BS (B2B)
  - 4G – Fibre links
  - 5G - mmWave with a highly directional antenna.
- Device-to-BS (D2B)

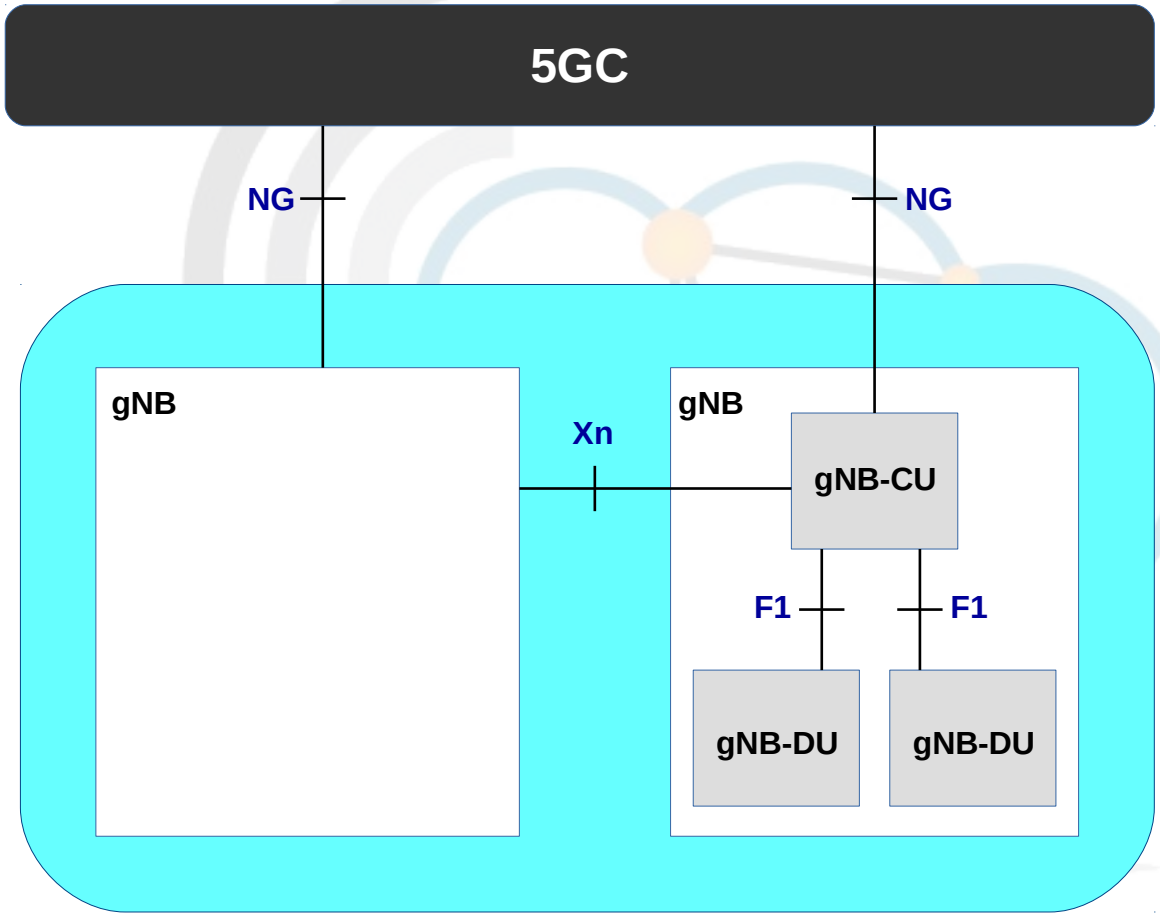
5G NR Reference Architecture



- Next Generation RAN **(NG-RAN)**
- Next Generation NodeB **(gNB)**
- gNB Central Unit **(gNB-CU)**
- gNB Distribution Unit **(gNB-DU)**

- 5G Core Network **(5GC)**
- Access and Mobility Management Function **(AMF)**
- User Plane Function **(UPF)**
- Software Defined Networking **(SDN)**

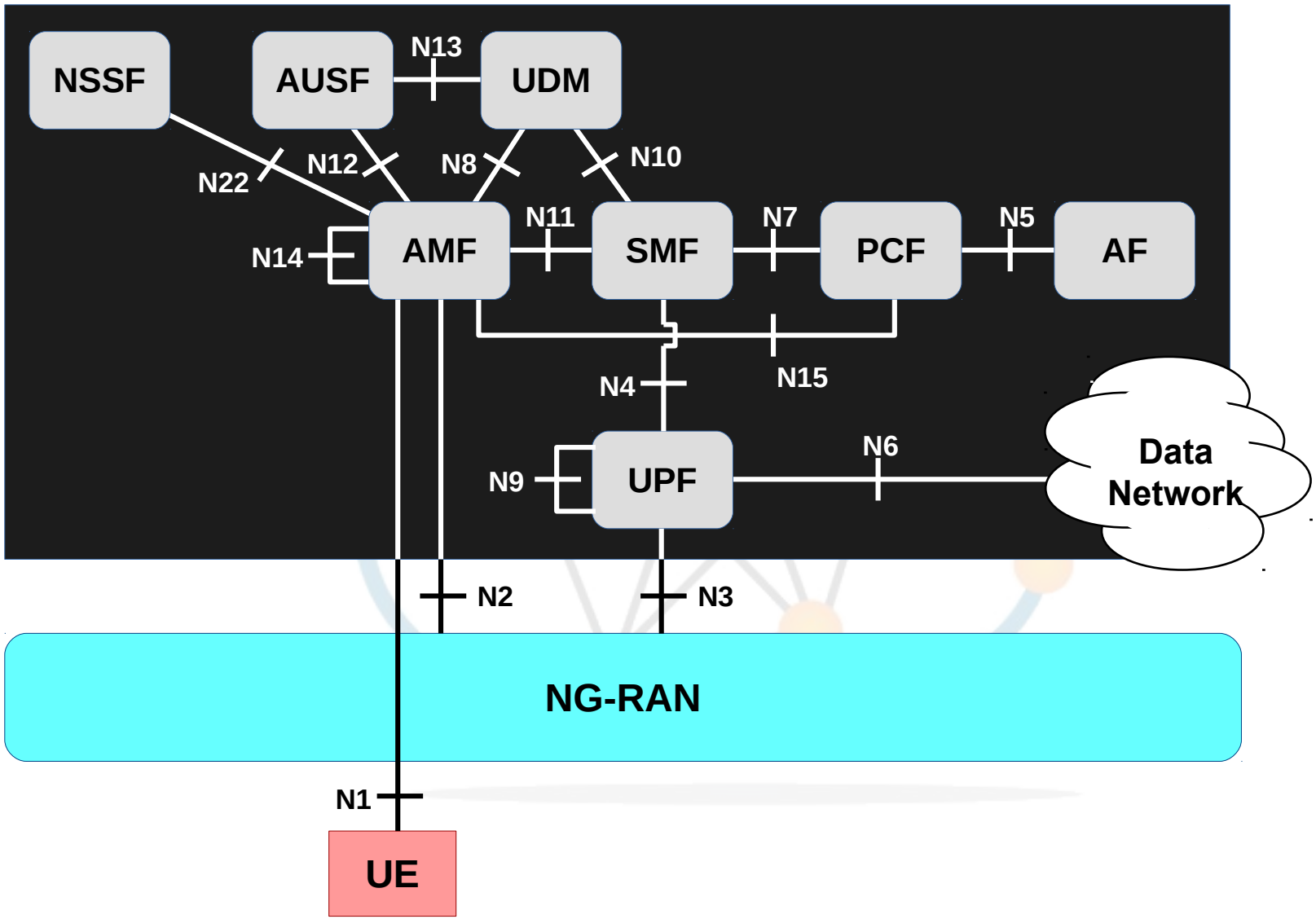
NG-RAN



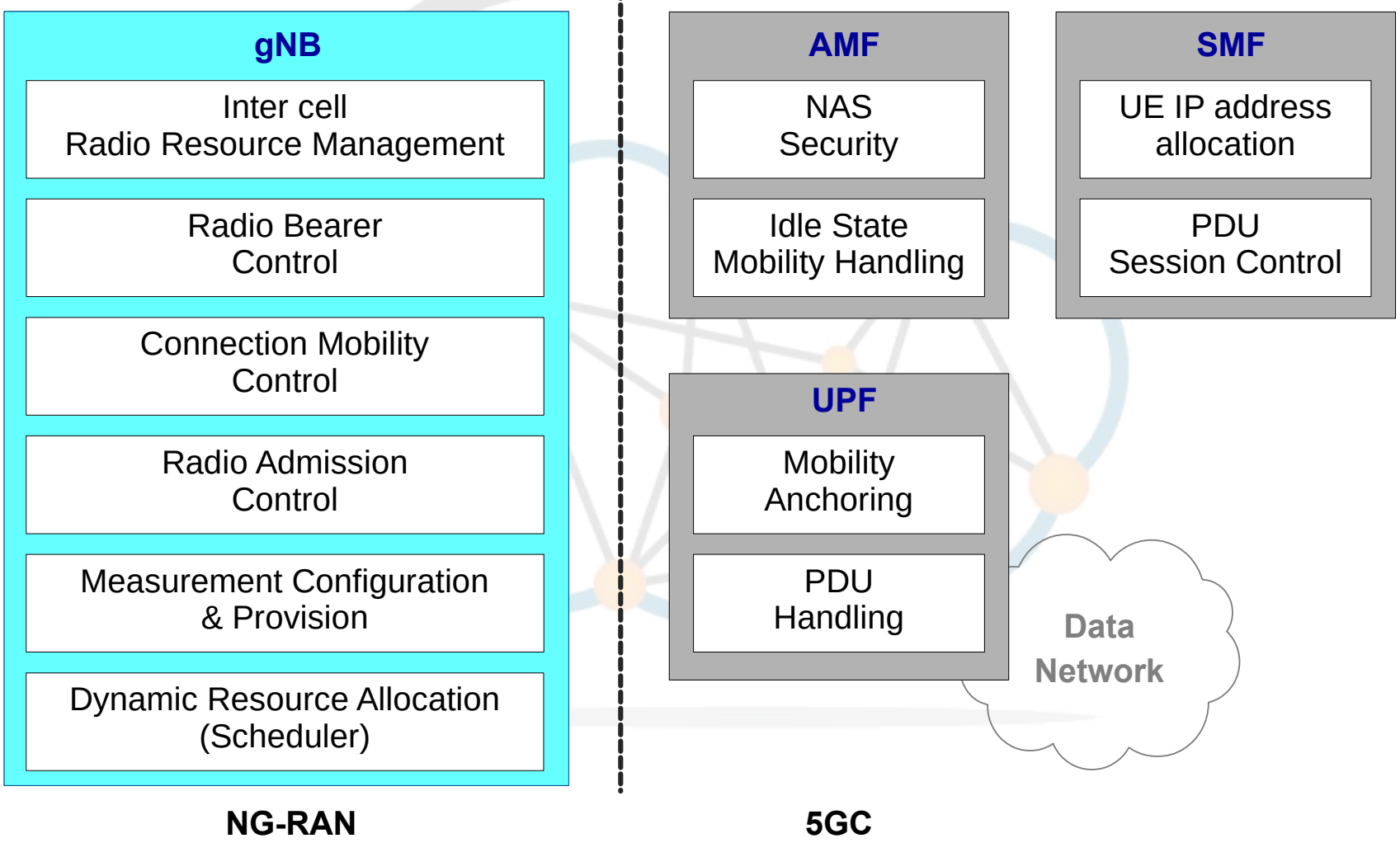
Cloud native – 5GC – Functions

- Core Access & Mobility Management Function **(AMF)**
- User Plane Function **(UPF)**
- Session Management Control Function **(SMF)**
- Application Function **(AF)**
- Unified Data Management **(UDM)**
- Policy Control Function **(PCF)**
- Authentication Server Function **(AUSF)**
- Network Slice Selection Function **(NSSF)**

Cloud native – 5GC – Basic Architecture



Functional Split between NG-RAN and 5GC



5G NR Summary

- Higher capacity and density than current 4G.
- 5G have the following requirements:
  - Data rates of 10s of Mb/s for 10,000+ users
  - Data rates of 100 Mb/s for metropolitan areas
  - 1 Gb/s simultaneously to many workers on the same office floor
  - Support 100,000+ wireless sensors
  - Spectral efficiency significantly enhanced
  - Coverage improved
  - Signalling efficiency enhanced
  - Latency reduced significantly compared to LTE.

Thank You

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