The Path from 4G to 5G:

Air interface and core network in change of numbers

www.tkb-schmidt.de/36C3-P25G.pdf

Heurekus
blog.wirelessmoves.com

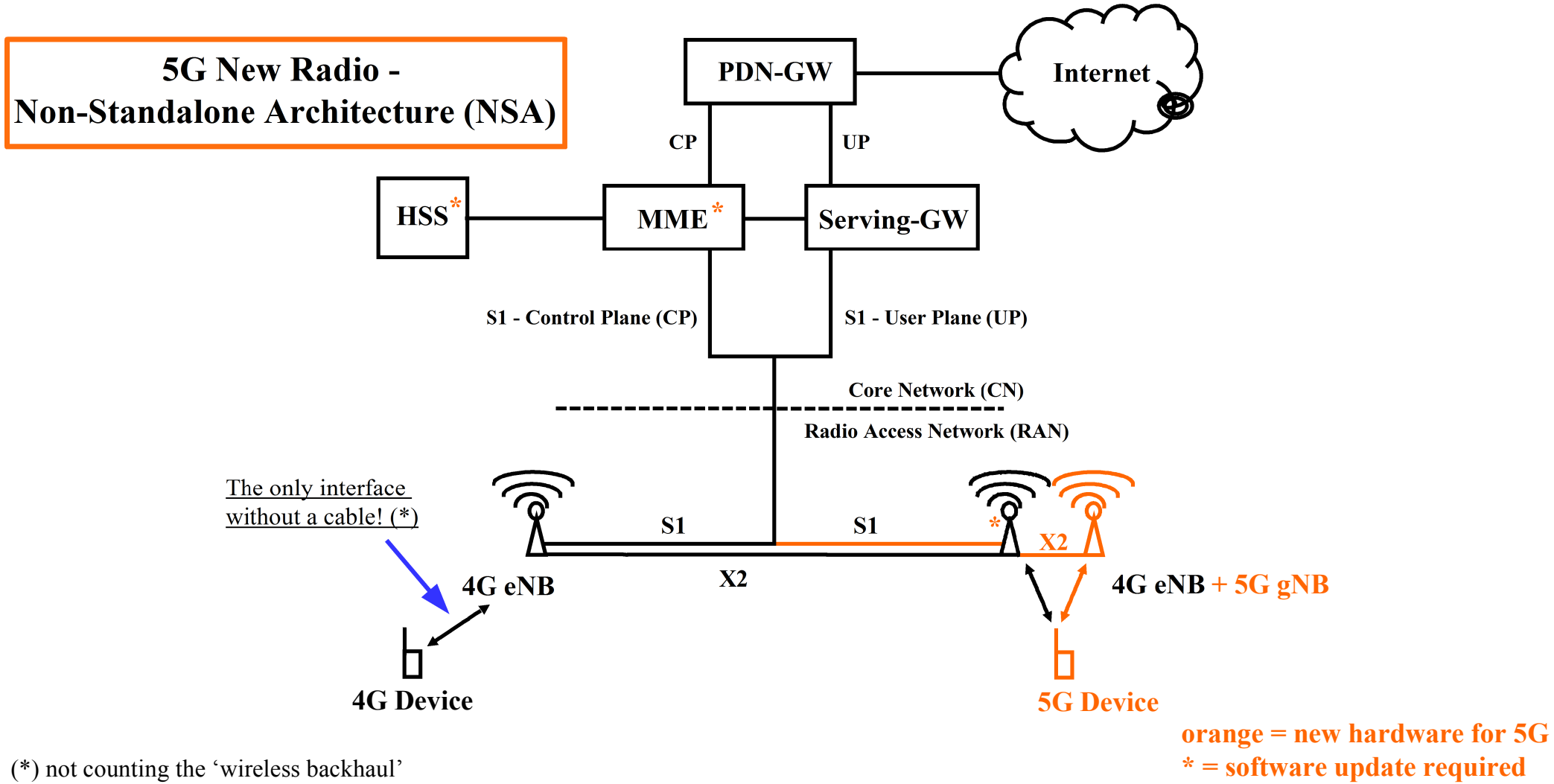
Peter Schmidt
@33dBm

If you want to speak about 5G, at first you need to define, what you expect from it!

The name „5G“ is like, if you want to describe an unique kind of tree with the word „forest“.

The 5G **WE** Are Talking About Today...

5G Network TODAY – 3GPP NR Option 3

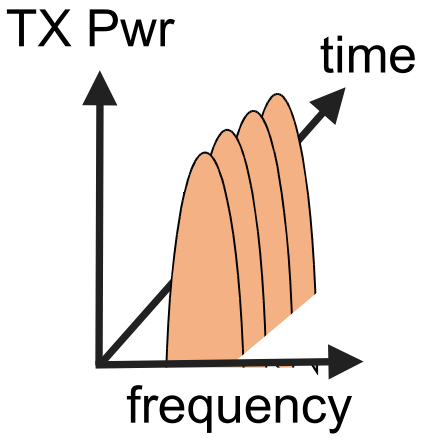


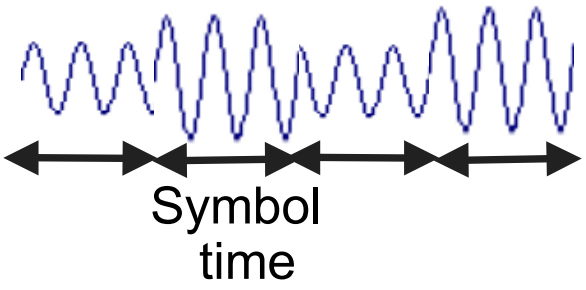
orange = new hardware for 5G
* = software update required

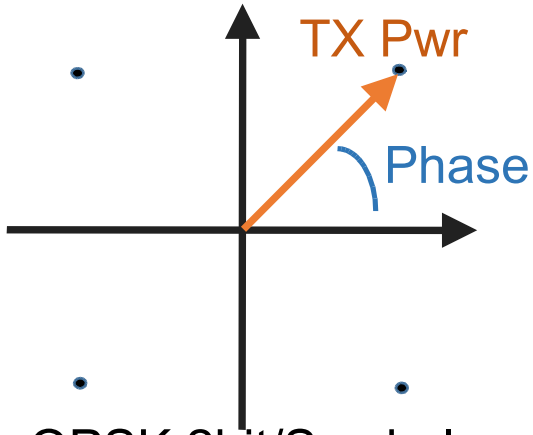
(*) not counting the 'wireless backhaul'

4G to 5G Air Interface

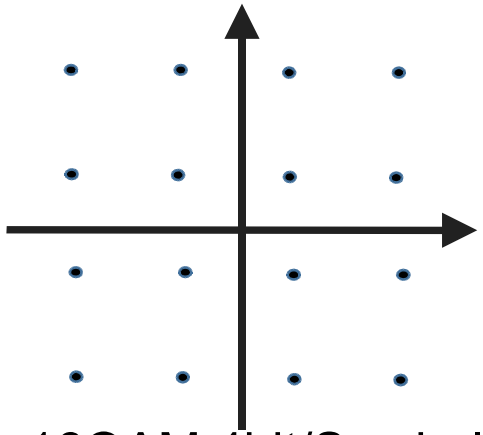
Carrier, QPSK … 256QAM



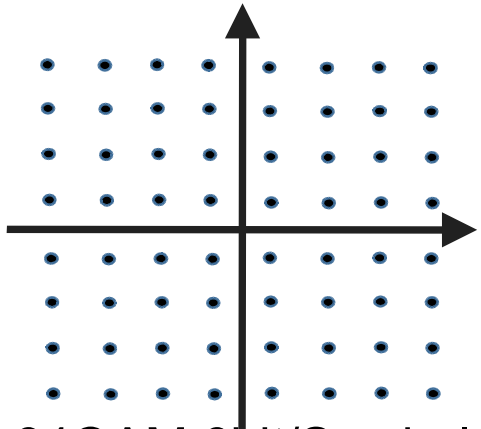




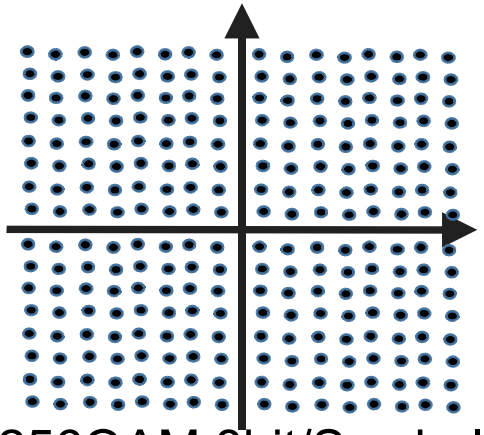
QPSK 2bit/Symbol



16QAM 4bit/Symbol

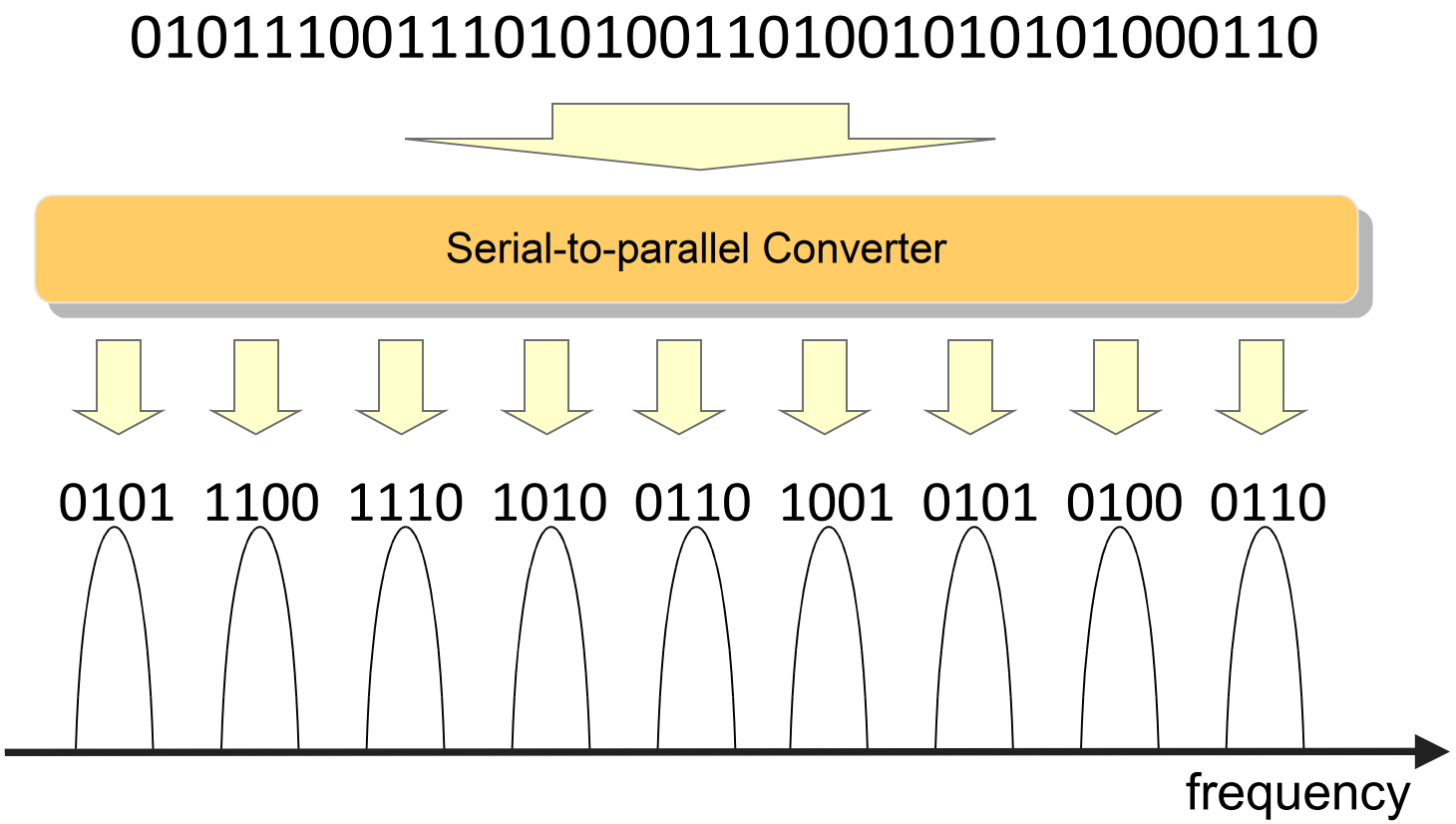


64QAM 6bit/Symbol

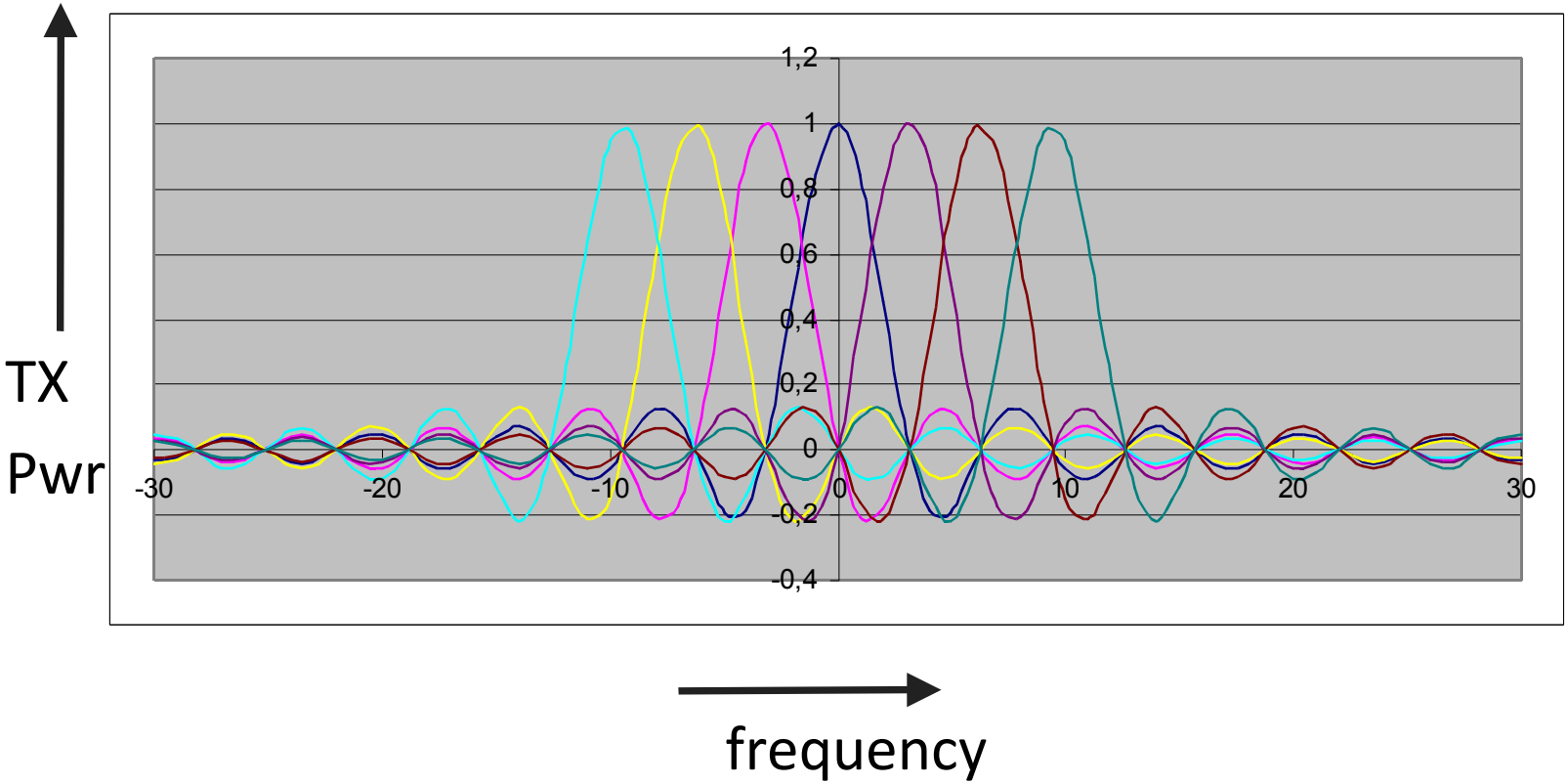


256QAM 8bit/Symbol

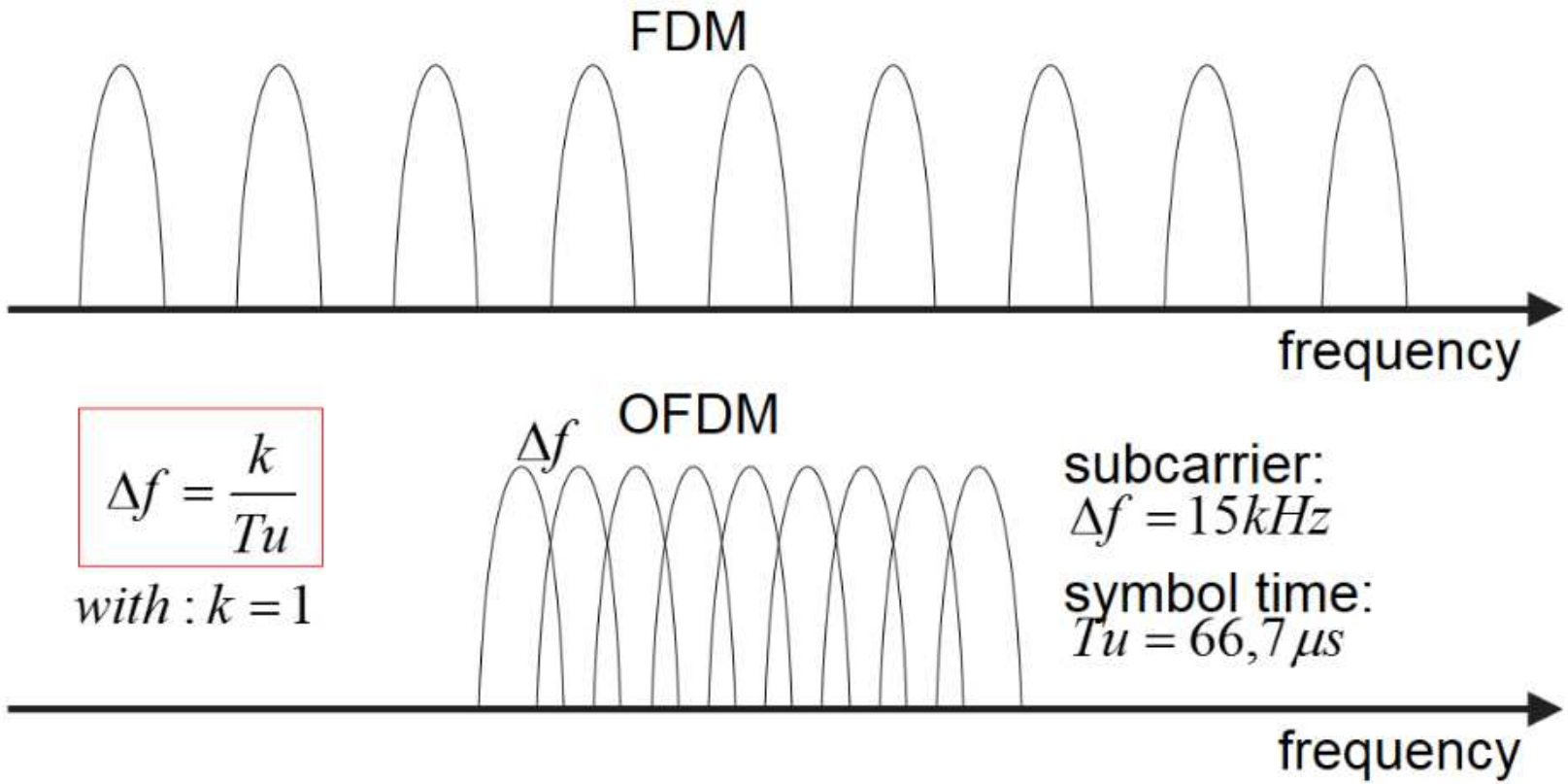
Subcarrier, Subcarrierspacing, Symbol



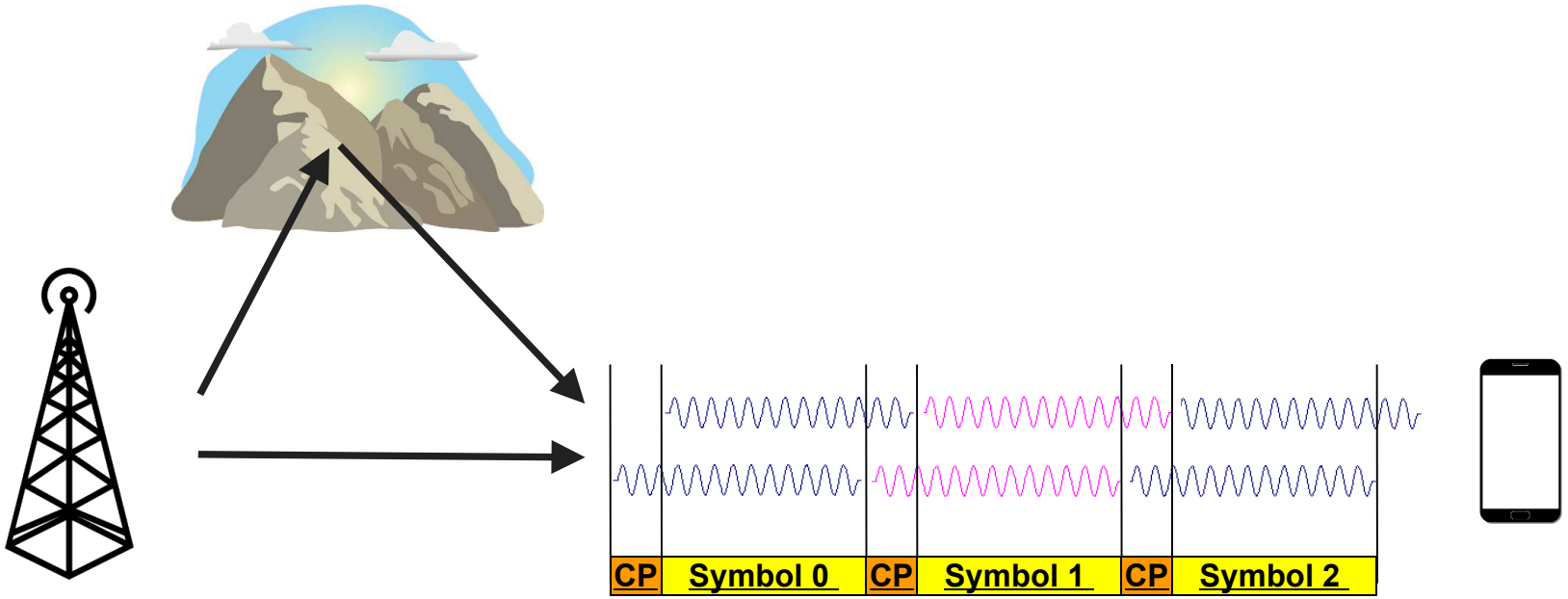
Subcarrier, Subcarrier Spacing, Symbol



OFDMA


FDM
frequency
$\Delta f = \frac{k}{Tu}$
$with : k = 1$
Δf
OFDM
subcarrier:
$\Delta f = 15kHz$
symbol time:
$Tu = 66,7\,\mu s$
frequency

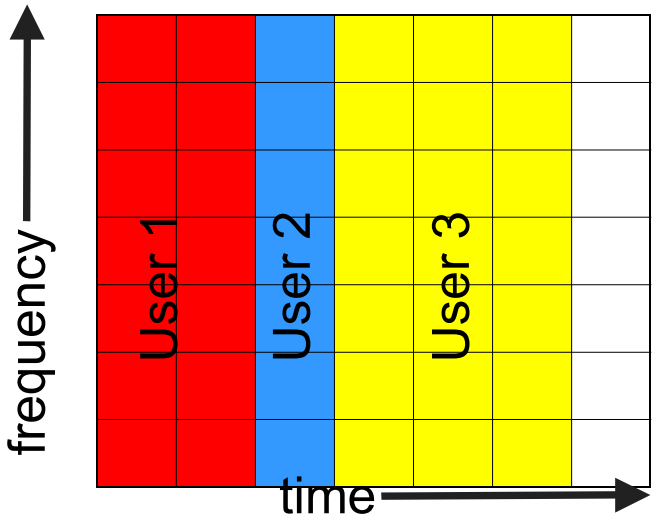
Guard Period



OFDM - OFDMA

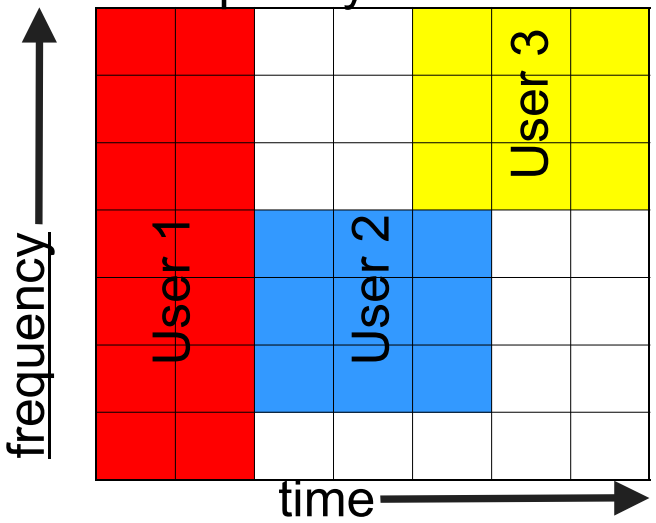
OFDM
(Orthogonal Frequency Division Multiplex):

One user per time

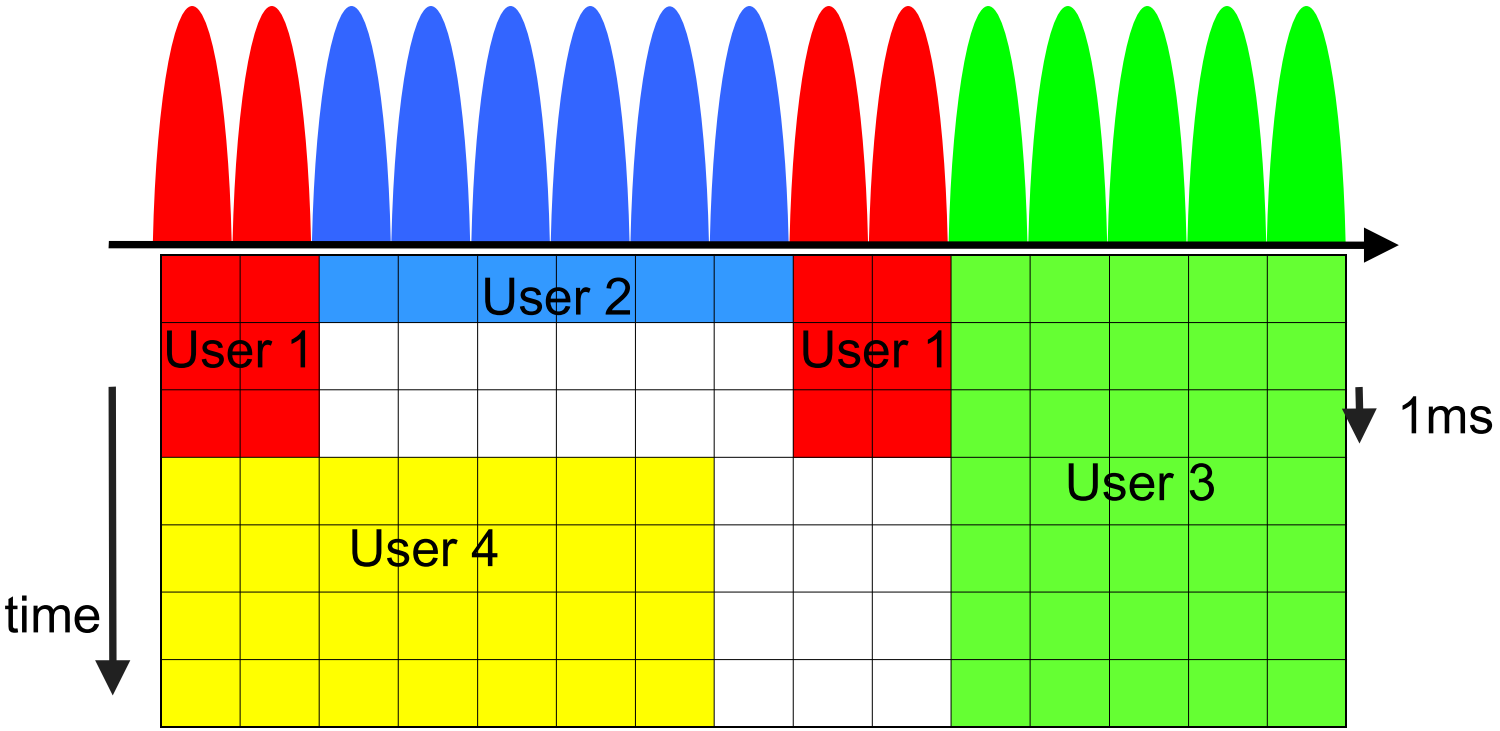


OFDMA
(Orthogonal Frequency Division Multiple Access):

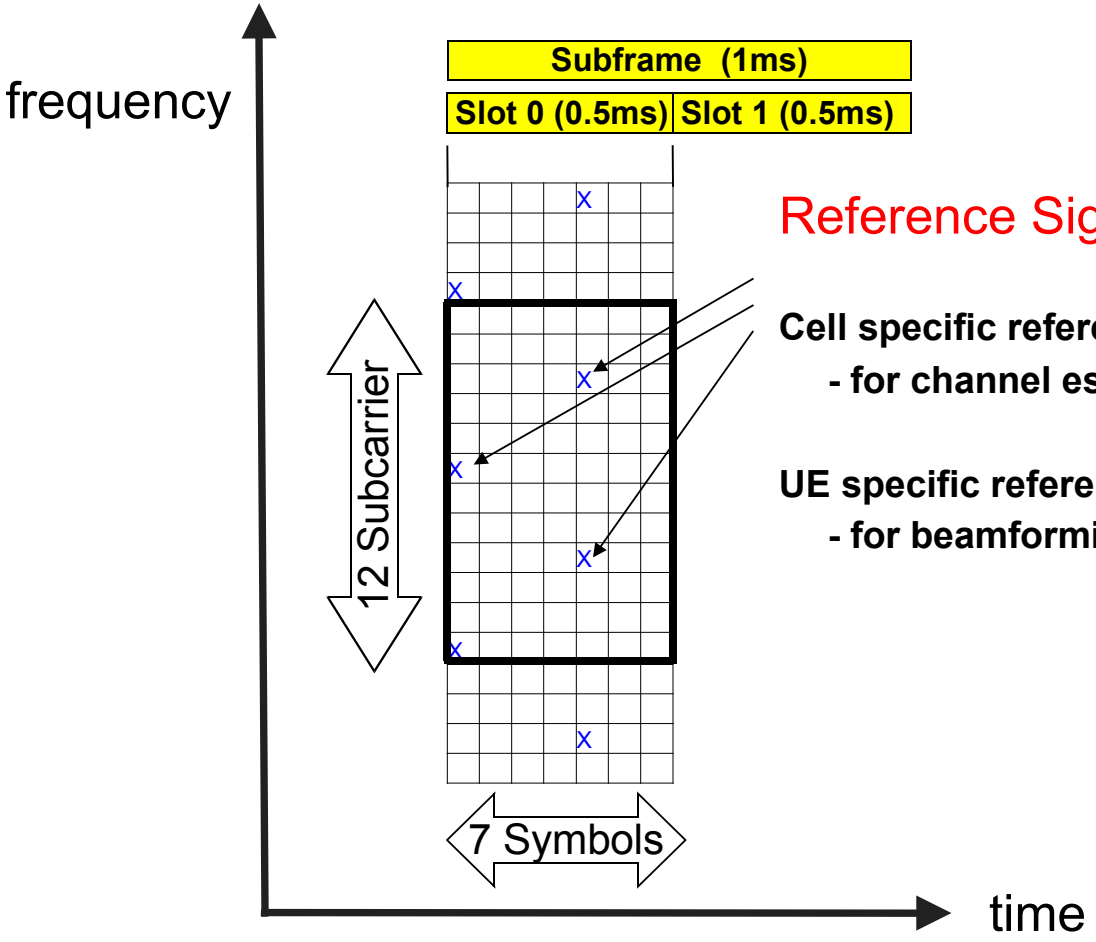
Allocates user in time and frequency domain



OFDMA



LTE Resource Block and Reference Signal

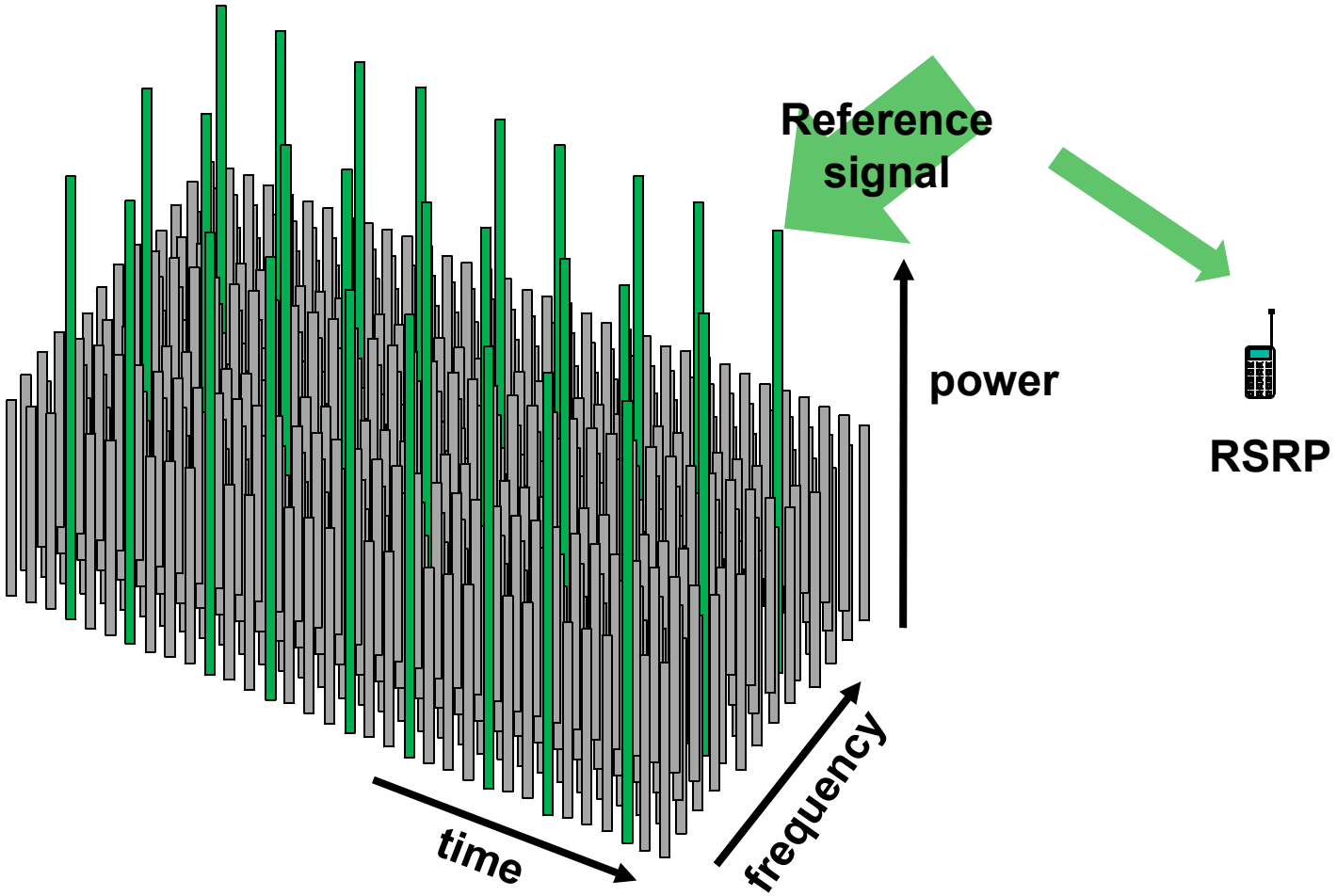


Reference Signals:

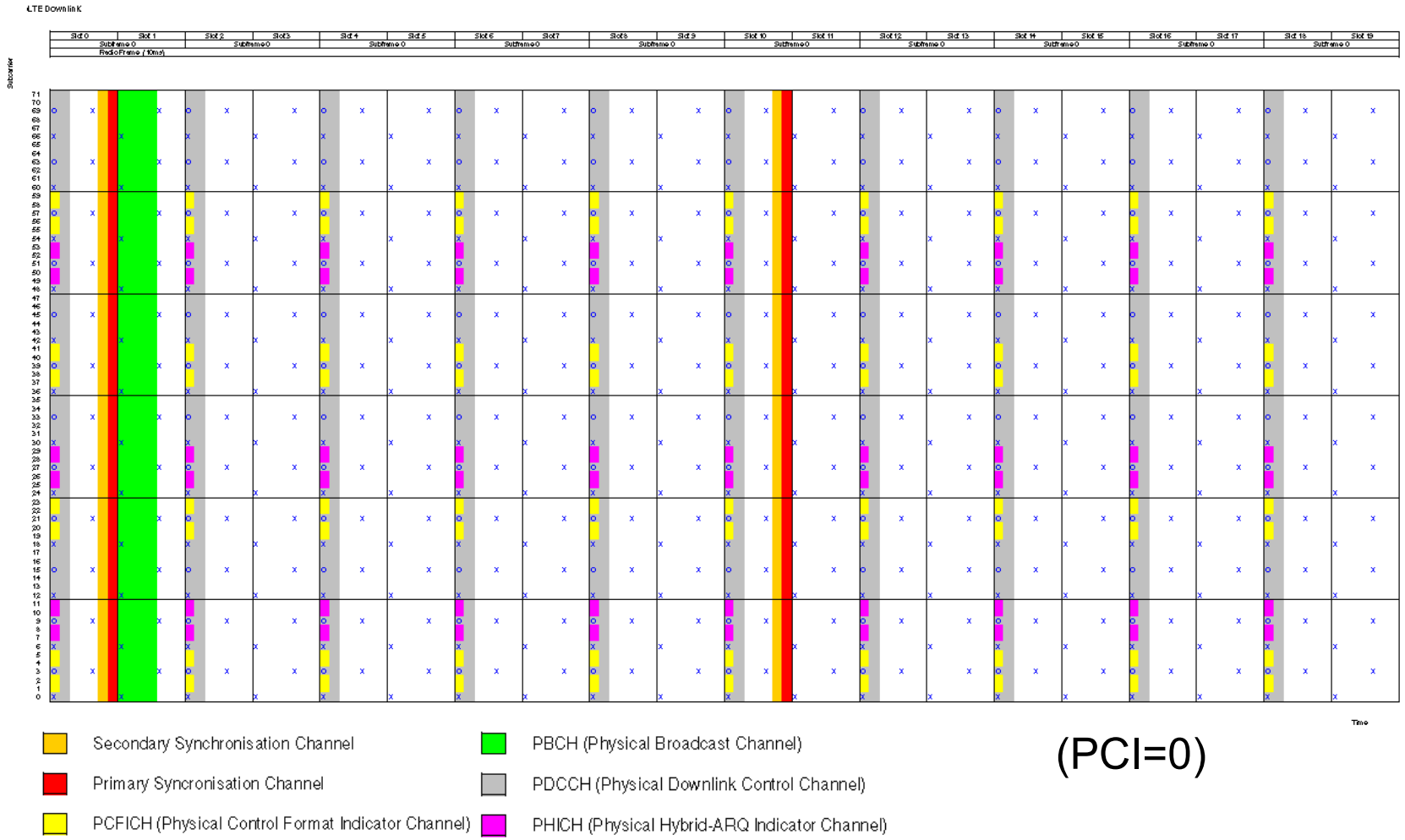
Cell specific reference signal
- for channel estimation

UE specific reference signal
- for beamforming to a single UE (antenna port 5)

Resource Block and Reference Signals

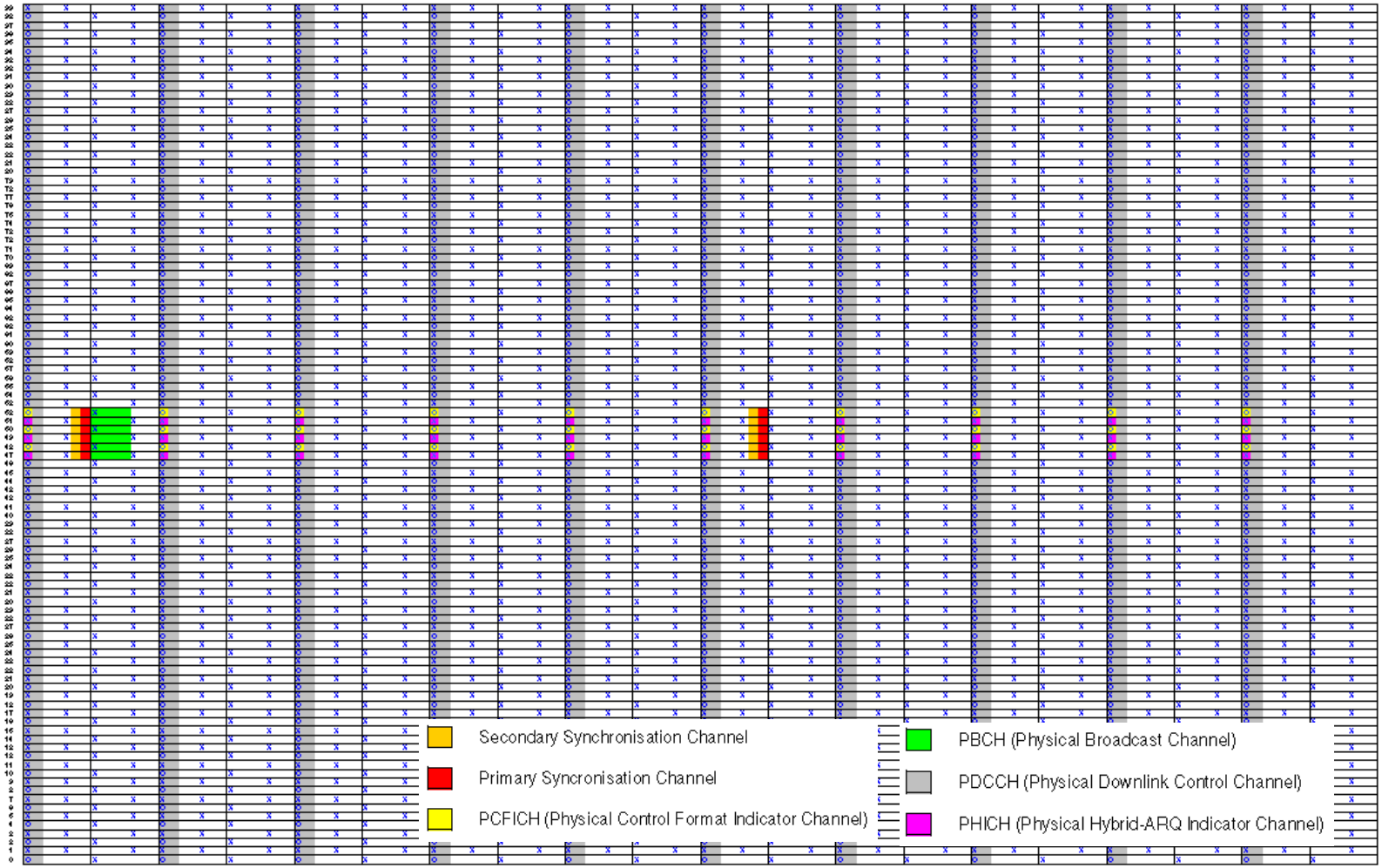


Resource Grid and Physical Channels (1,4MHz, 6RB)

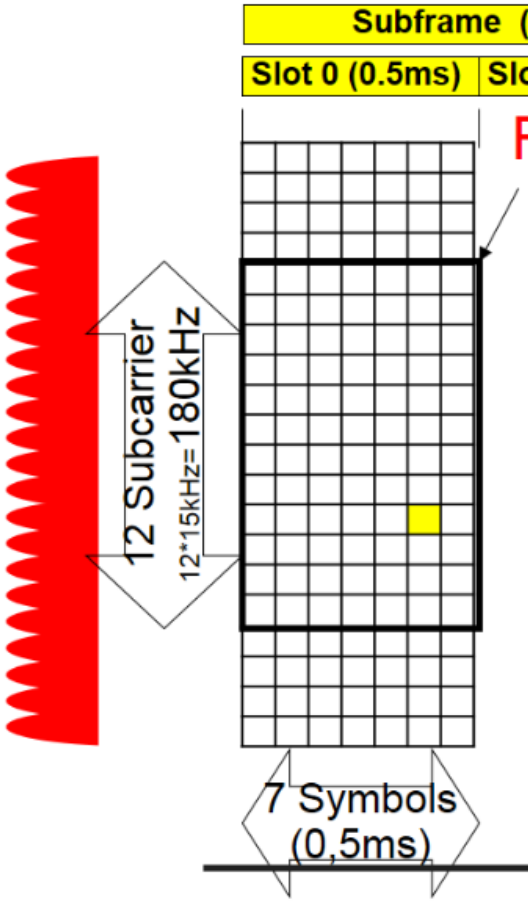


(PCI=0)

Resource Grid and Physical Channels (20MHz, 100RB)



Maximum data speed in 4G



Resource per Resource Block (RB):

12 Subcarrier * 7 Symbols = 84 Resource Elements

4 of these are Reference Signals = 80 Resource El.

(The number of User Bits in one symbol is depending on modulation:
QPSK: 2 bit per symbol, 16QAM: 4 bit, 64QAM: 6 bit, 256QAM: 8 bit)

QPSK: 160 Bit/RB (ca. 320kBit/s)

16QAM: 320 Bit/RB (ca. 640kBit/s)

64QAM: 480 Bit/RB (ca. 960kBit/s)

256QAM: 640 Bit/RB (ca. 1.28MBit/s)

20MHz carrier has 100 Resource Blocks:

64QAM: 960kBit/s *100 = 96Mbit/s (approx. 100Mbit/s)

256QAM:1.28MBit/s*100 = 128Mbit/s (approx. 130Mbit/s)

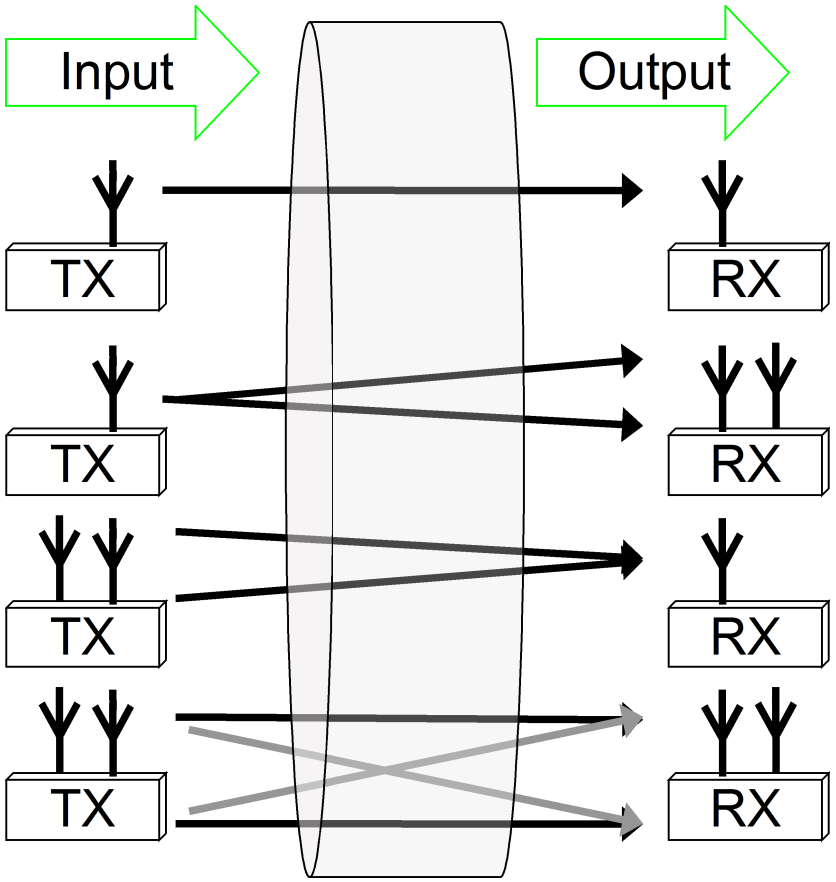
MIMO

SISO

SIMO

MISO

MIMO



So What's New In 5G?

Restrictions of 4G and Possibilities with 5G

4G: Max. 20 MHz Carrier bandwidth

Only potato cells

Idle to active time 100ms (for every purpose)

Ping time not faster than 10ms @AirInterface, E2E: 10..17ms

5G: A lot of possibilities for new services (possibilities, yes?)

100 MHz Carrier bandwidth (<6GHz)

Beamforming and Multiuser MIMO possible

Idle to active time variable depending on purpose

Shorter Ping times possible

LTE and 5G Frequency Bands in Germany

LTE Capacity

LTE Indoor VoLTE + NB-IoT

LTE Rural + Indoor

5G NR today !

Band	Downlink (DL) (MHz)	Uplink (UL) (MHz)	Duplex mode	Carrier bandwidth (MHz) typically used	Total Bandwidth available in the band (MHz).
Europe					
1	2110-2170	1920-1980	FDD	10	60
3	1805–1880	1710–1785	FDD	20-30	75
7	2620–2690	2500–2570	FDD	20	70
8	925-960	880-915	FDD	10	35
20	791–821	832–862	FDD	10	30
28	703-748	758-803	FDD	10	30
32	1452-1496	(Nur DL)	TDD	20	50
38	2570-2620	2570-2620	TDD	20	50
n78	3300-3800	same	TDD	80-100	400

- A lot of bandwidth/capacity in band n78. **BUT**: Not good for rural coverage due to **limited range**!
- LTE bands will be converted to use in 5G NR. Downside: **Very limited bandwidth/capacity compared to n78**!

Subcarrier Spacing

5G NR features flexible numerologies

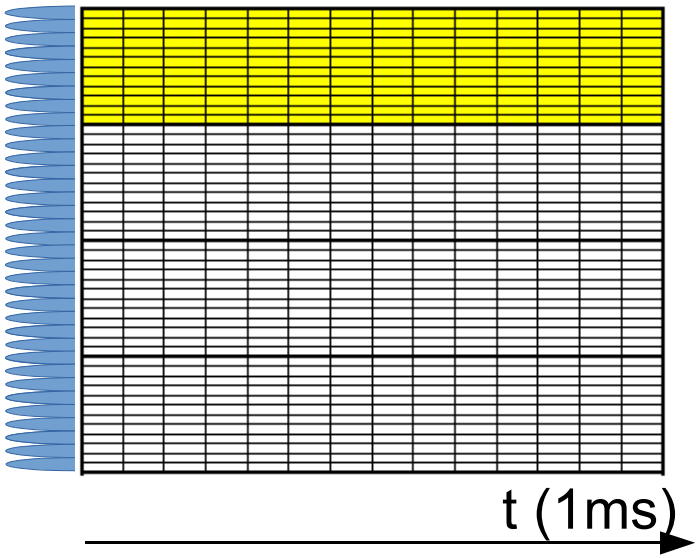
Subcarrier spacing (kHz)	15	30	60	120	240
Symbol duration (µs)	66.7	33.3	16.7	8.33	4.17
Max. nominal BW (MHz)	20/25/50	40/50 /100	80/100/200	160/200/400	320/400/400
Slots per subframe	1	2	4	8	16
Slots per frame	10	20	40	80	160
Restrictions			Not Sync&PBCH		Not for Data

5G NR flexible numerologies versus bandwidth (<6GHz)

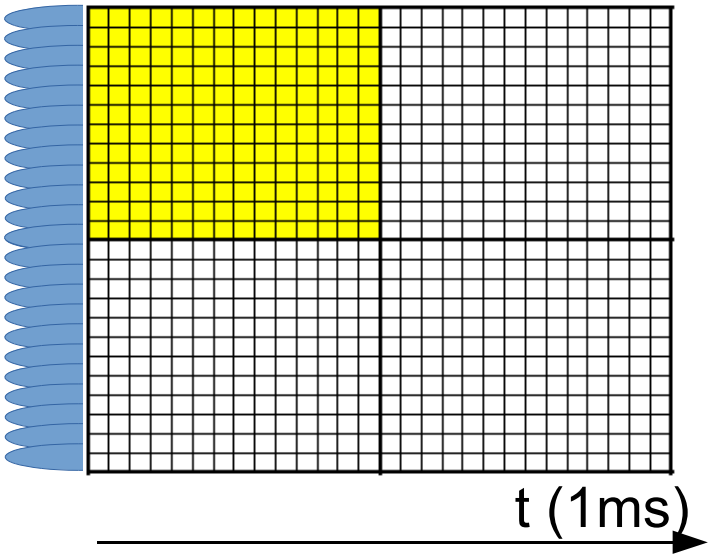
Band	Max BW for 15kHz	Max BW for 30kHz	Max BW for 60kHz
Band n78: 3.3 – 3.8GHz	50MHz	100MHz	100MHz
Band n1 (FDD)	20MHz	20MHz	20MHz
Band n3 (FDD)	30MHz	30MHz	30MHz
Band n8 (FDD)	20MHz	20MHz	

SC spacing of 30 or 60kHz attractive as for larger bandwidth

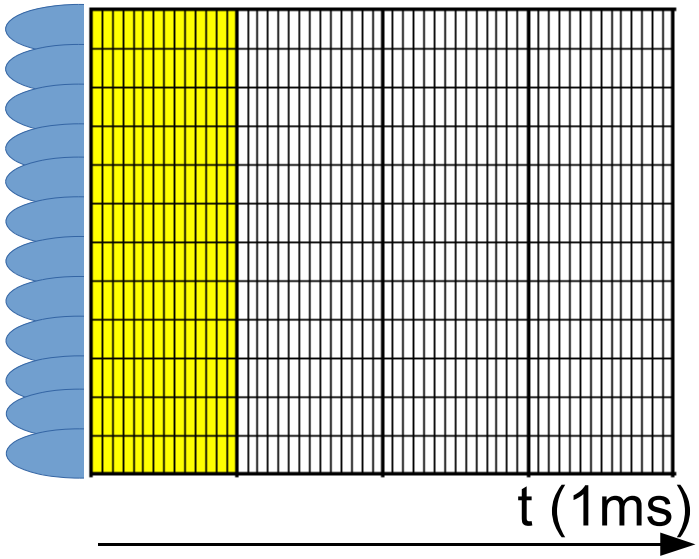
15kHz (4G und 5G < 3.5 GHz)



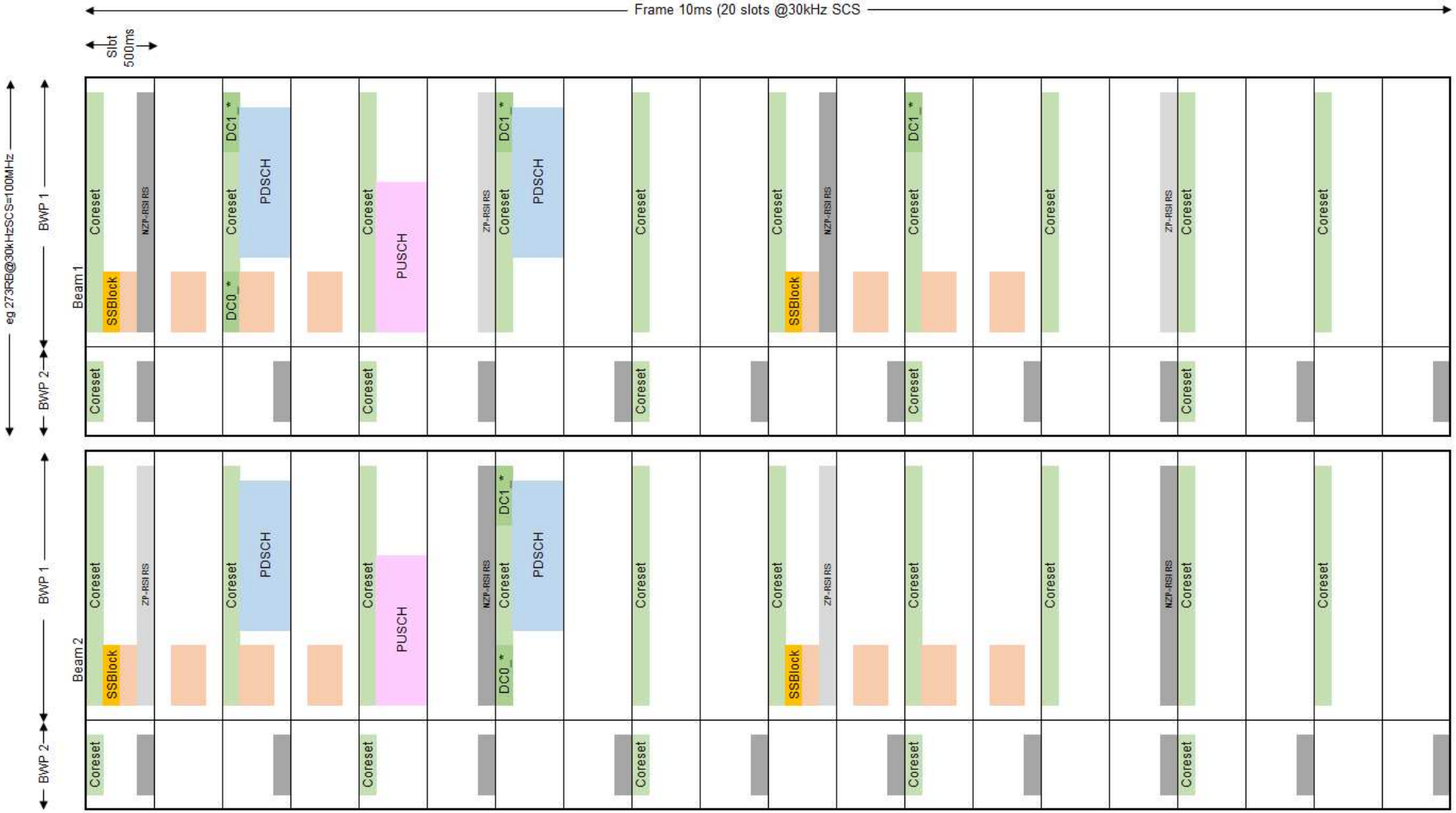
30kHz (5G @ 3.5 GHz)



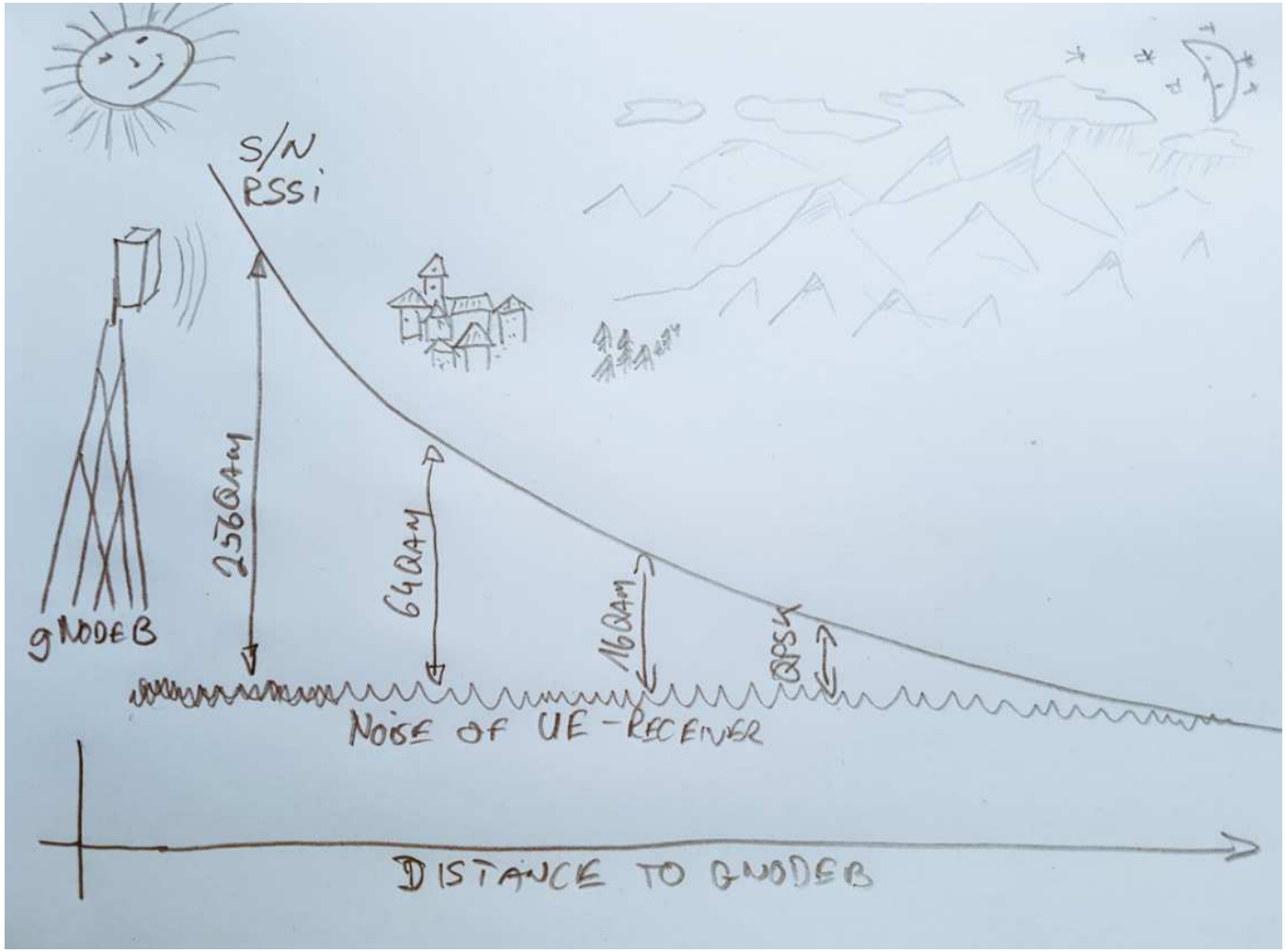
60kHz



NR Frame Structure scheduling example



Maximum and Real Data Speeds in 4G&5G



Maximum and Real Data Speeds in 5G

Approximation of Data Speed (/Mbit/s) in 4G and 5G depending on bandwidth and available MIMO rate

	Bandwidth	Modulation	SISO Theorie	2*2 MIMO Theorie	4*4 MIMO Theorie	2*2 MIMO Max Speed Ideal cond's TDD@n78	4*4 MIMO Max Speed Ideal cond's TDD@n78	2*2 MIMO Normal Use Low traffic
	5MHz	64QAM	25	43	82	**43**	**82**	**20**
	5MHz	*256QAM*	*33*	*57*	*109*	*57*	*109*	*27*
i.E. 5G at 700	**10MHz**	64QAM	50	86	163	**86**	**163**	**40**
	10MHz	*256QAM*	*67*	*115*	*217*	*115*	*217*	*53*
i.E. 5G at B1,3,...	**20MHz**	64QAM	100	172	326	**172**	**326**	**80**
	20MHz	*256QAM*	*133*	*229*	*435*	*229*	*435*	*107*
5G at n78	***60MHz***	*256QAM*	*410*	*706*	*1338*	***536***	***1017***	***813***
5G at n78	***90MHz***	*256QAM*	*616*	*1059*	*2007*	***805***	***1525***	***492***
5G at n78	***100MHz***	*256QAM*	*684*	*1176*	*2230*	***894***	***1695***	***547***

5G Speed in Theory and Practice

Similar calculation as for LTE:

- 30 kHz sub-carriers, 28 symbols per 1 ms, 273 resource blocks (PRBs) for 100 MHz
- Modulation of 16-QAM (4 bits), 64-QAM (6 bits) and 256-QAM (8 bits) per Symbol
- Overhead ca. 14% (Control and Reference Channels)
- TDD Uplink Downlink Pattern DDDSU is ~3.8 : 5
  (D = Downlink, U = Uplink, S = D + Gap + U)
- SISO to 4x4 MIMO

Theoretical maximum with best values: 273 (PRBs) * 12 (subcarriers) *
28 symbols * 8 (256 QAM) * 1000 (milliseconds) * 4 (MIMO) * (3.8/5) = **2.23 Gbit/s**.

In Practice observed so far: **~1 Gbit/s** with good signal conditions due to additional coding, retransmissions, lower MIMO, lower modulation order

Add to this the data transmitted on the LTE side with Carrier Aggregation. 400 Mbit/s possible, so **~1.4 Gbit/s**.

- In practice, many people use the same cell, some with significantly worse signal conditions. Thus even the realistic speeds given above can't be achieved when not alone in the cell.
- Overall speed for all users is lower than 1.4 Gbit/s due to some users having bad signal conditions.

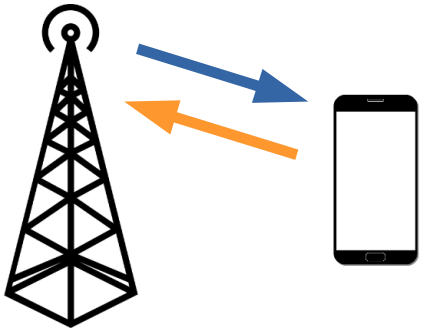
Not the single user peak performance is important, it's what 5G does for network capacity!

TDD vs FDD (Time/Freq Division Duplex)

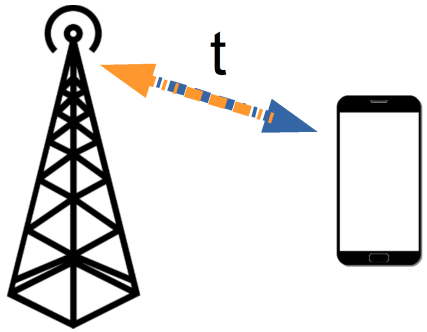
FDD

f1 DL:

f2 UL:



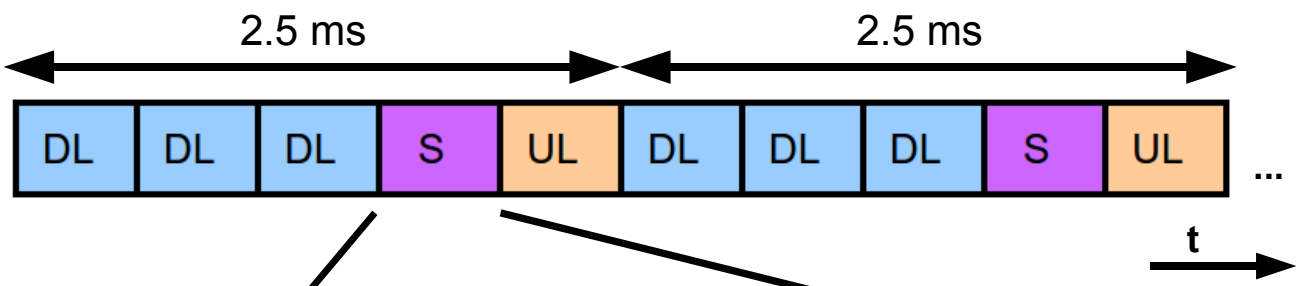
TDD: f1 DL and UL on same freq - swiched over time



- dynamic balancing by load in UL and DL possible, if… (see below)
- need empty gaps (‚flex') because of air delay time between gNodeB and UE

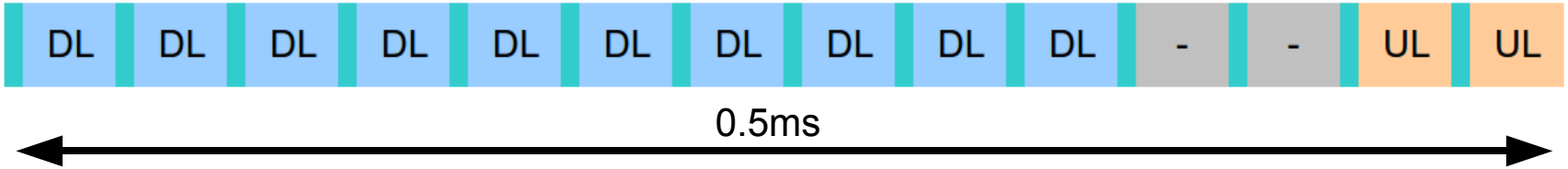
TDD – 5G NR Slot Definitions

"DDDSU"



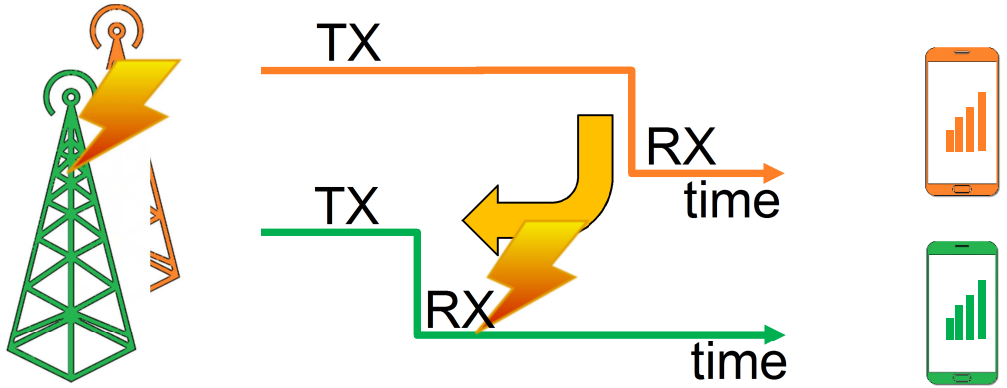
Slot Types :
(0.5 ms @ 30 kHz subcarrier spacing)
DL = Downlink Slot
UL = Uplink Slot
S = Special Slot
(14 symbols each)

Special Slot: 14 Downlink + Empty + Uplink Symbols

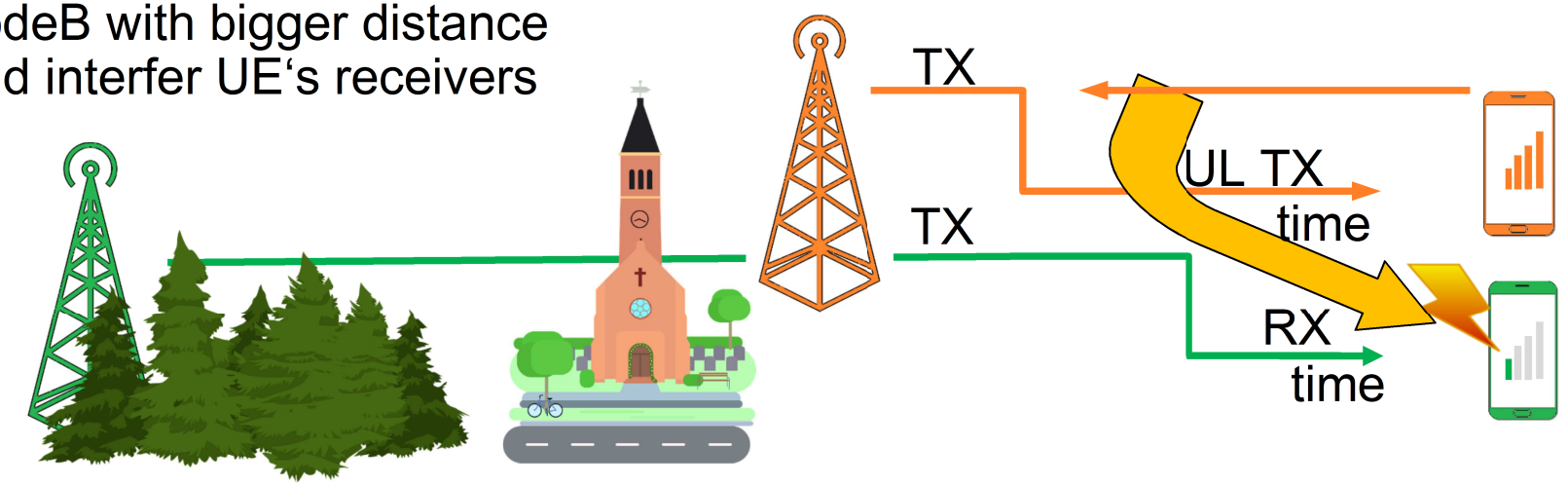


TDD – Sync of all providers neccessary

gNodeB of different providers nearby could interfer their receivers



gNodeB with bigger distance could interfer UE‘s receivers



Massive MIMO Antenna

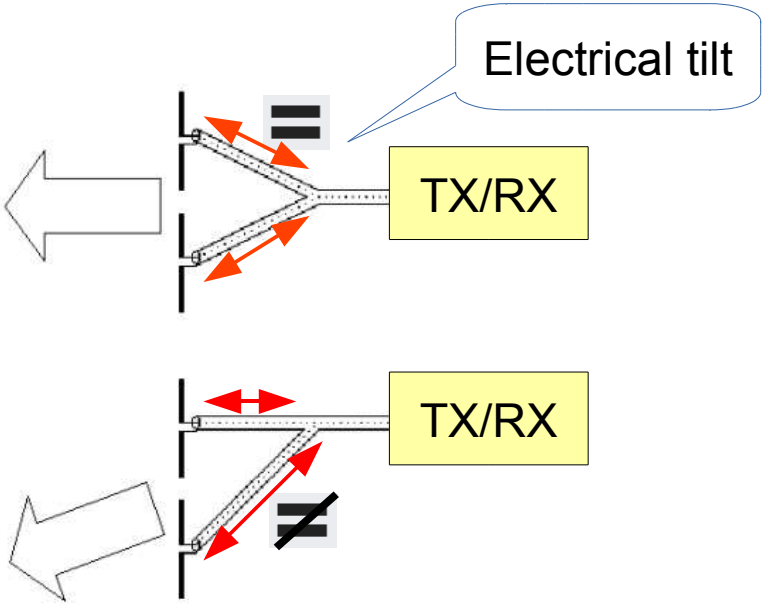
Massive MIMO Antenna

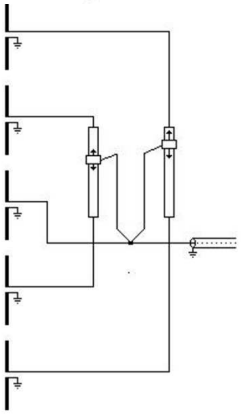
https://www.youtube.com/watch?v=neSNVBjPIoY Telekom Netz: Eine Frage: Was ist eine 5G Antenne?

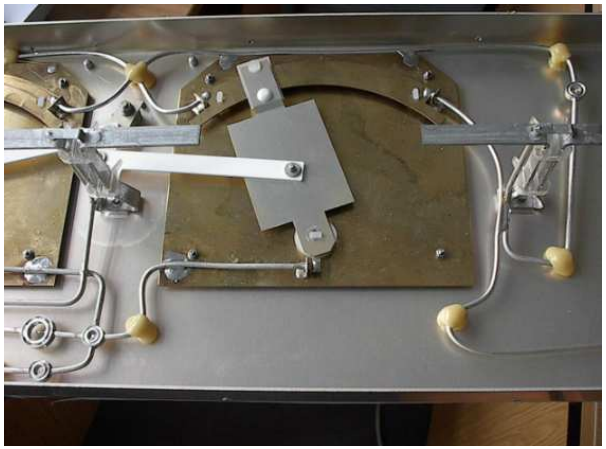
Massive MIMO Antenna

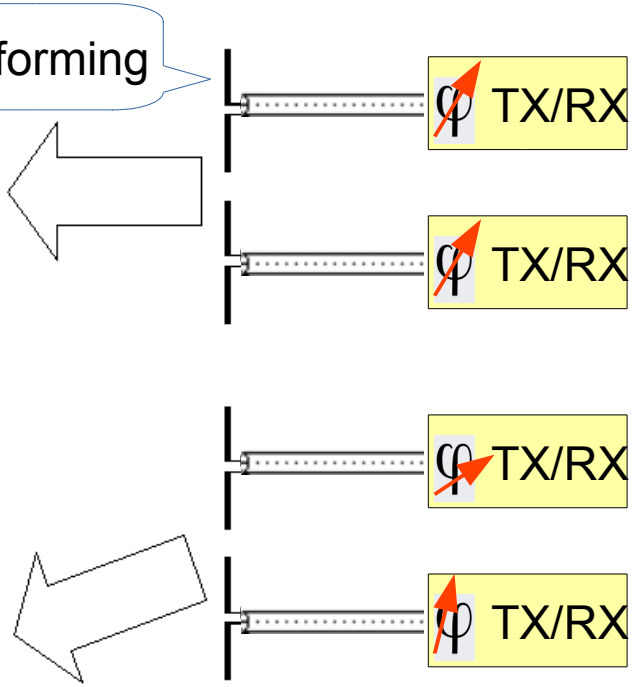
https://www.youtube.com/watch?v=neSNVBjPIoY Telekom Netz: Eine Frage: Was ist eine 5G Antenne?

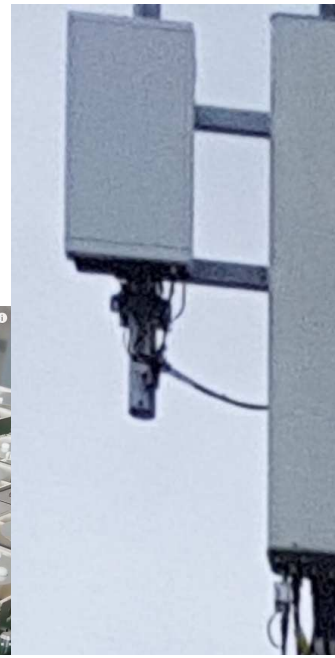
Phase controlled Antennas - Massive MIMO - Beams

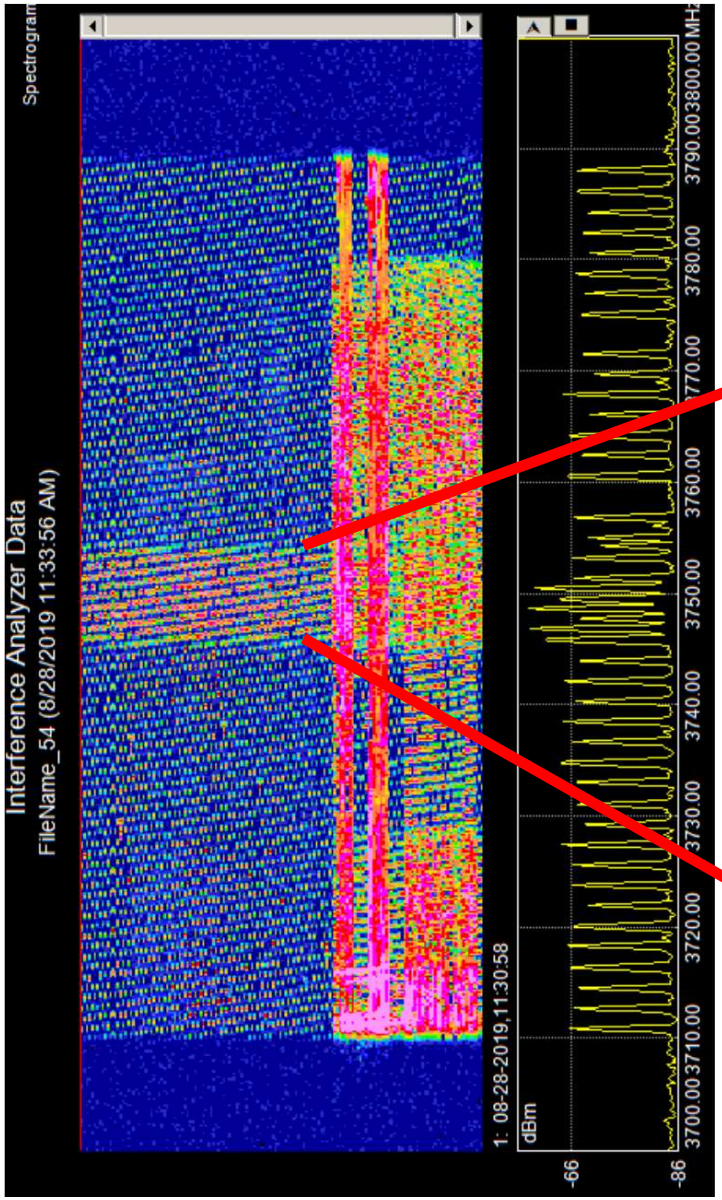






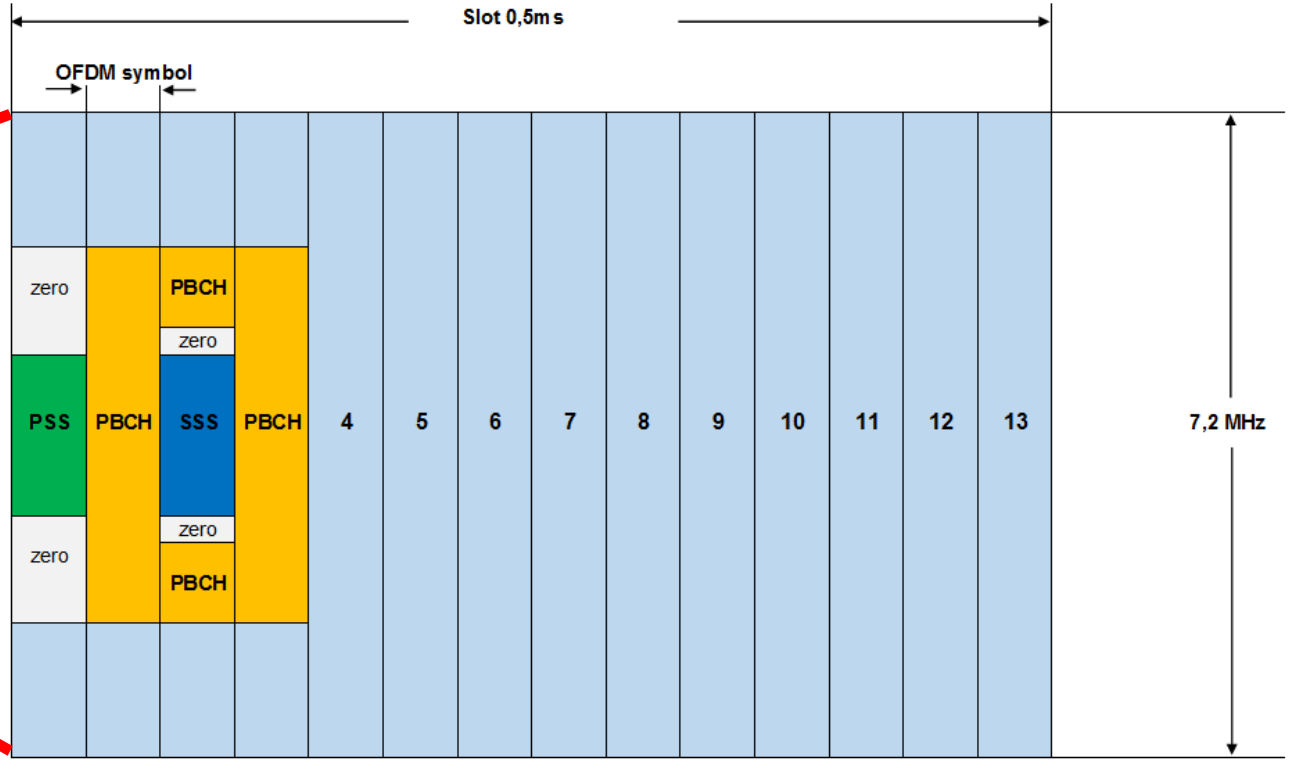




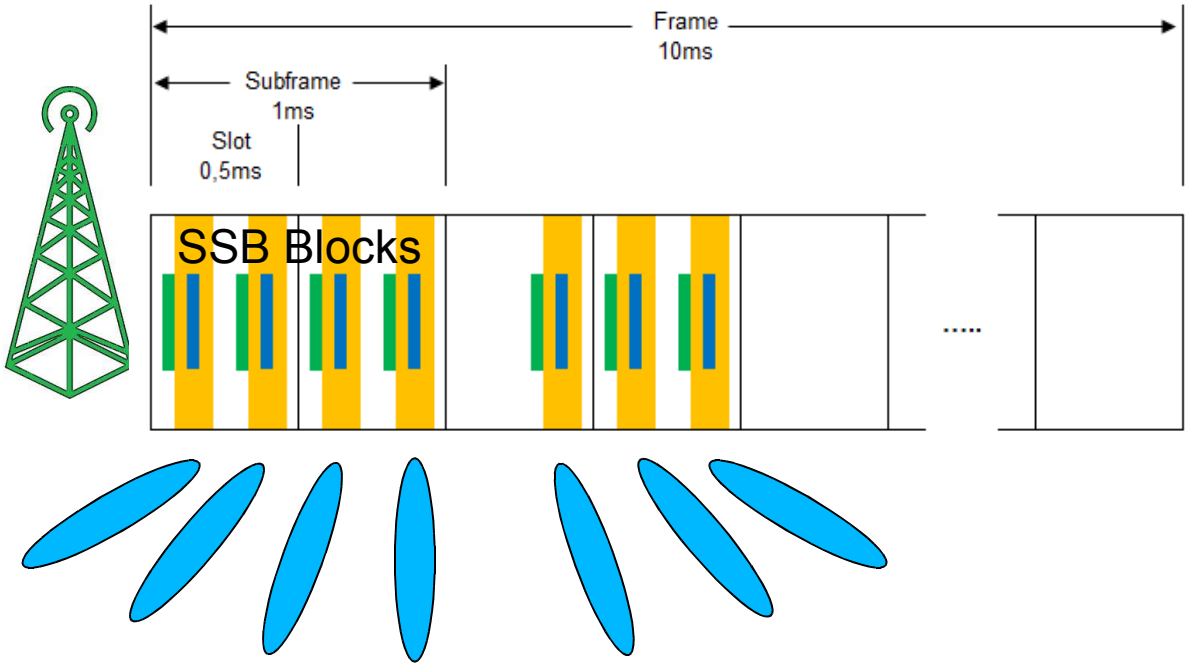


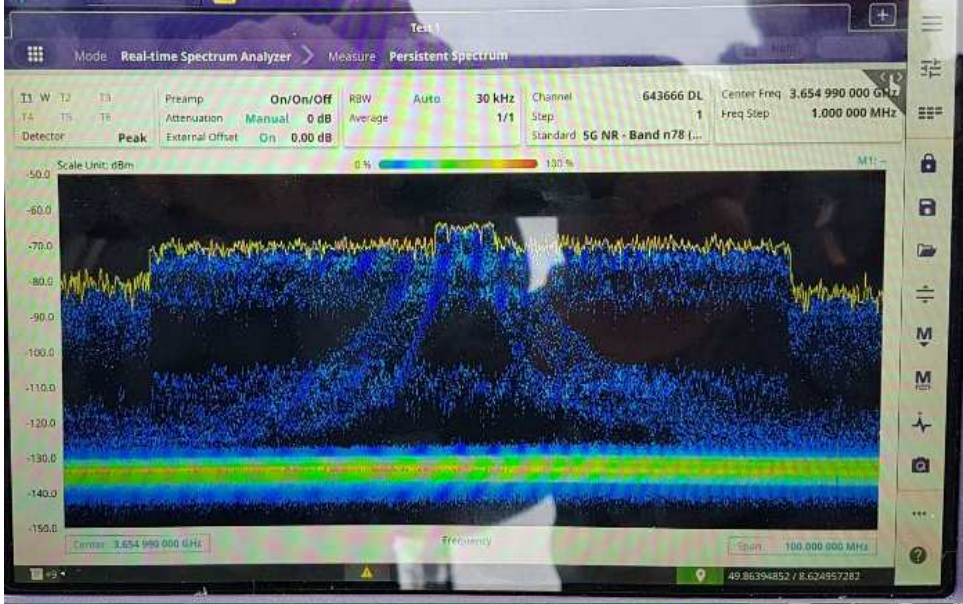
SSB/PBCH

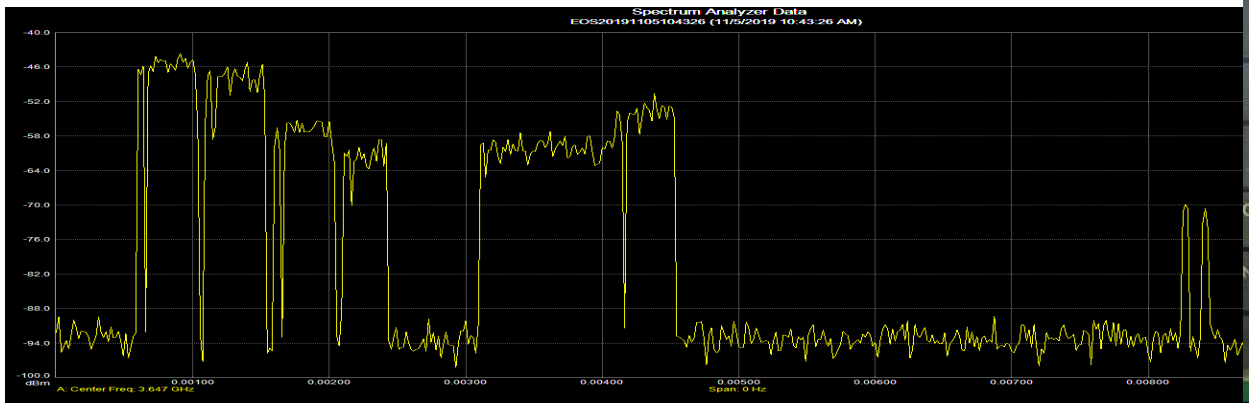
Synchronisation Signal Block / Physical Broadcast Channel



Static Beams – Beam Sweeping

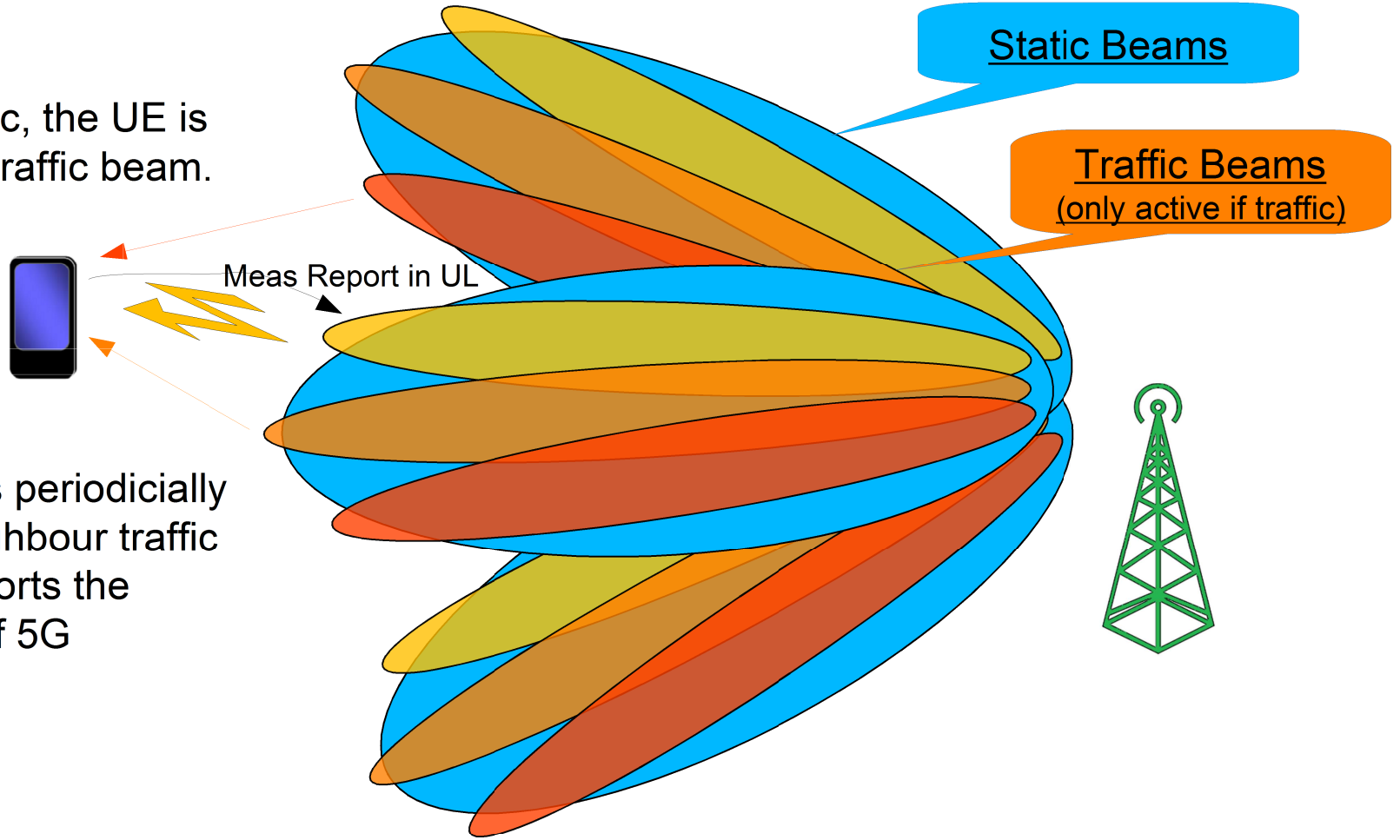






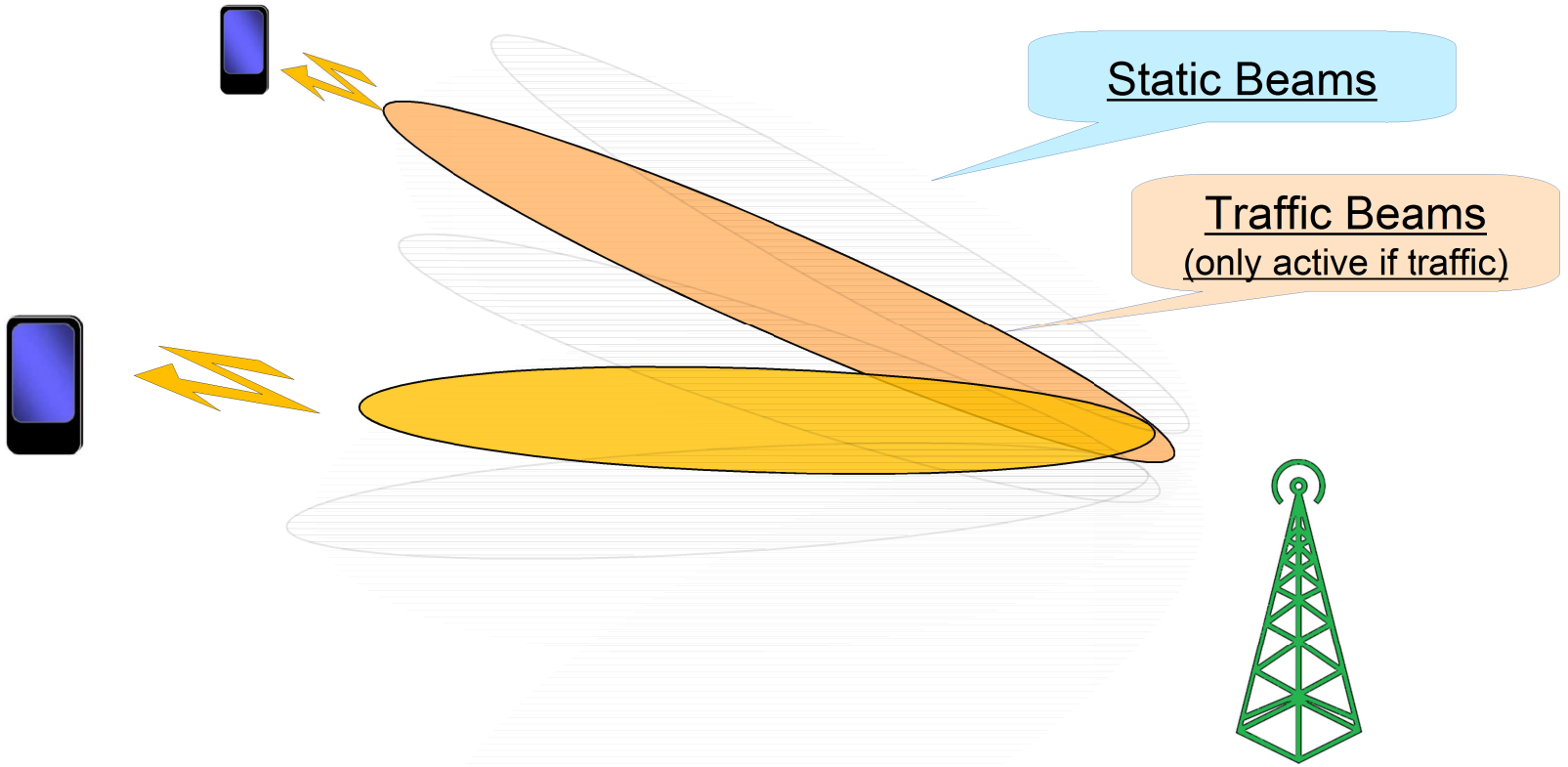
Static Beams – Beam Sweeping @NSA

While making traffic, the UE is connected to one traffic beam.



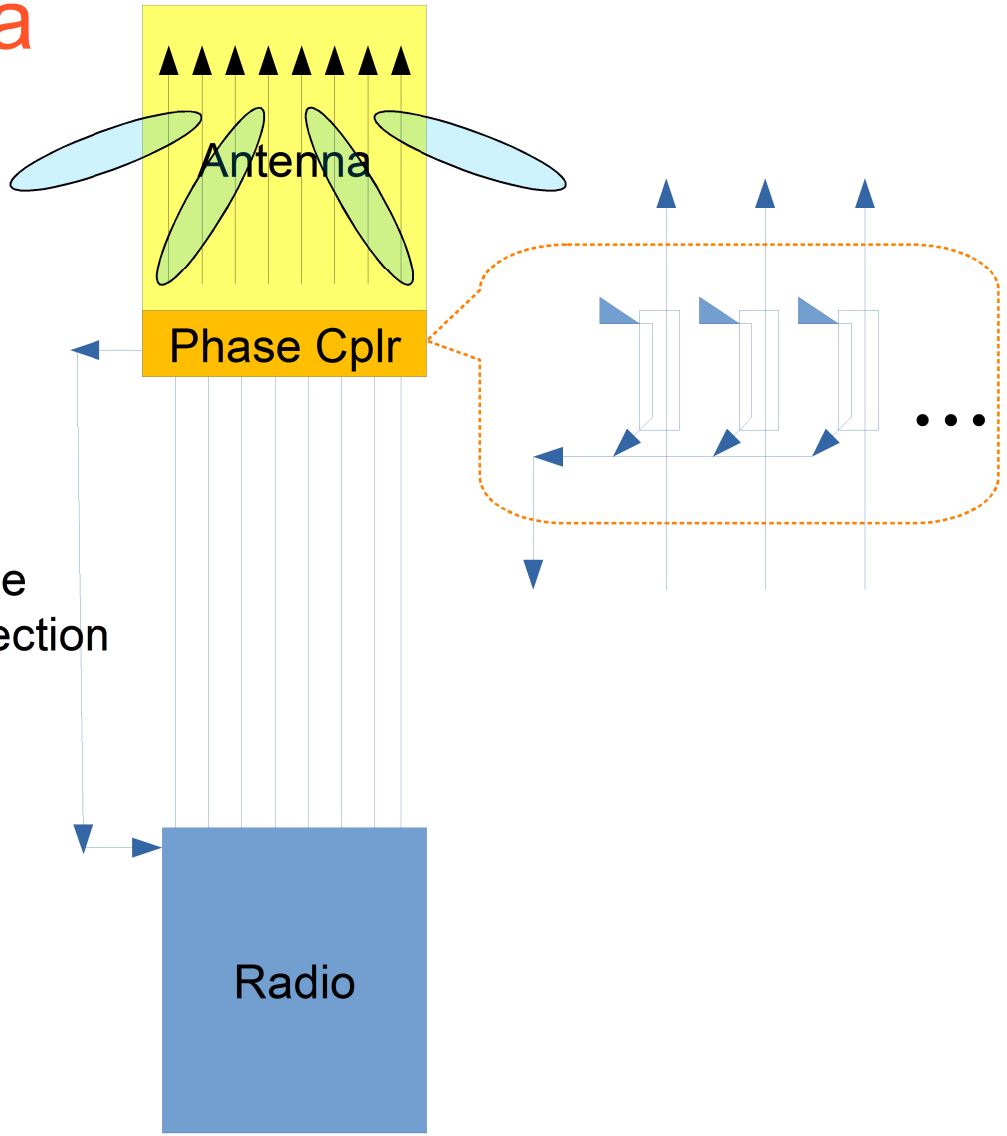
The gNodeB sends periodicially test signals on neighbour traffic beams and UE reports the CQI using Uplink of 5G

Beams are avoiding Cell Interference



Massive passive MIMO Antenna

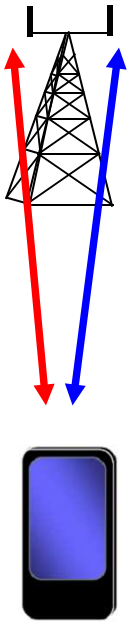
https://twitter.com/antennekaart/status/1193653728357879808?s=20
Author: https://twitter.com/antennekaart



In 5G Air Interface – MIMO

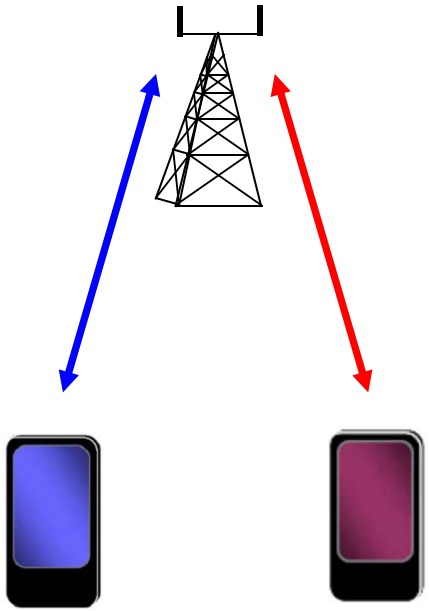
Single User MIMO

one UE gets different data from different antenna ports of one eNB sector

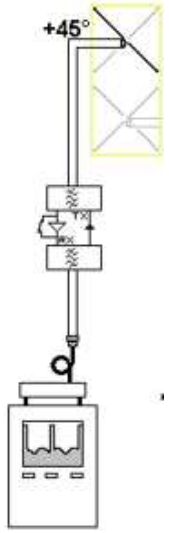


Multi User MIMO

one eNB sends/receives data to/from different UE with its different antennas



Measurements to check 5G Antennas



Passive antennas:

Return loss, Distance to fault, PIM

tkb-schmidt.de/MAA.pdf
tkb-schmidt.de/MAE.pdf

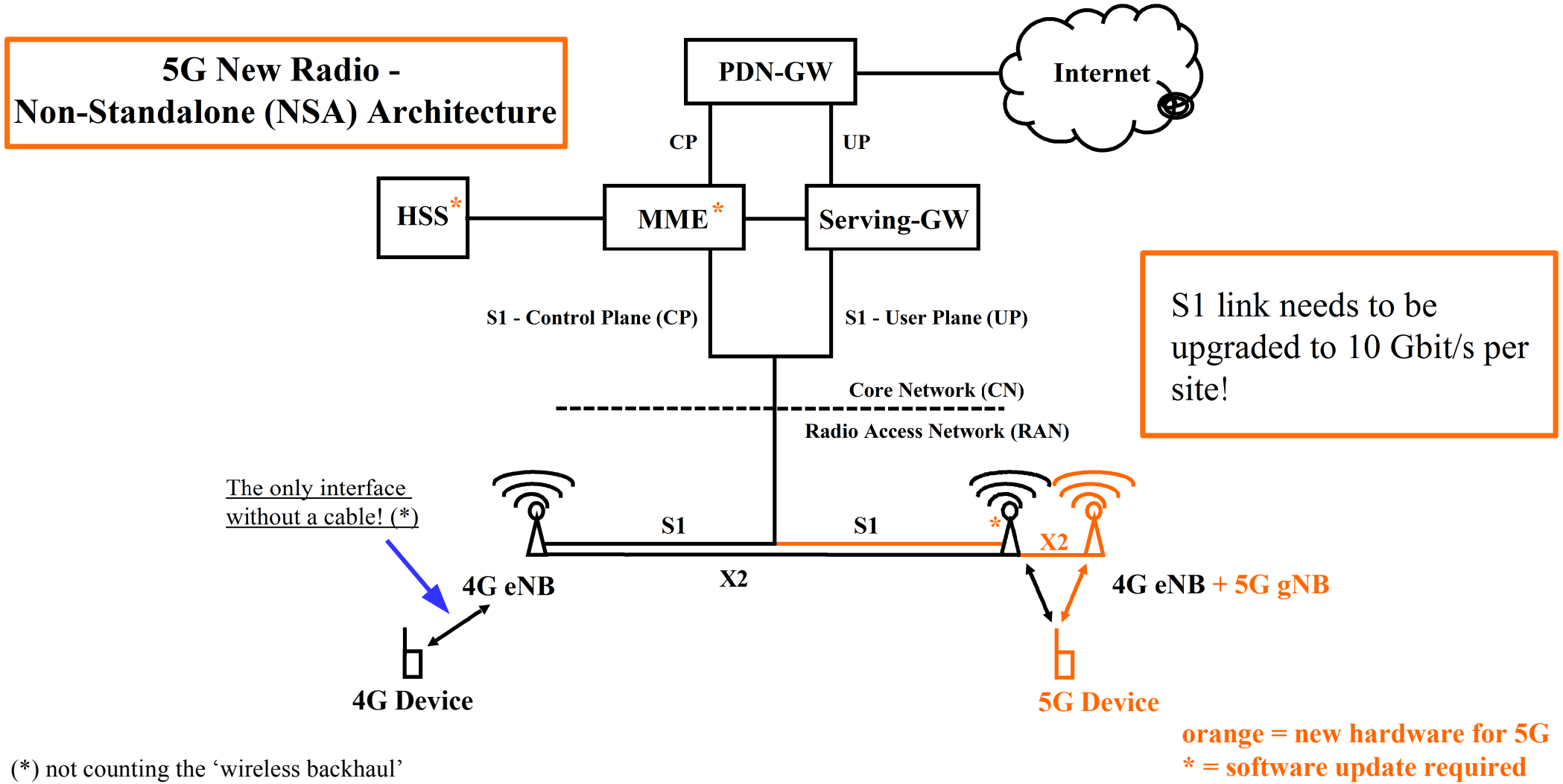
Active antennas:

There is no separable interface between antenna elements and RX/TX-modules, RL/DTF check and Uplink interference detection has to be done and alarmed by gNodeB

In addition: Checking geograpic location and
EVM of static beams with drive test

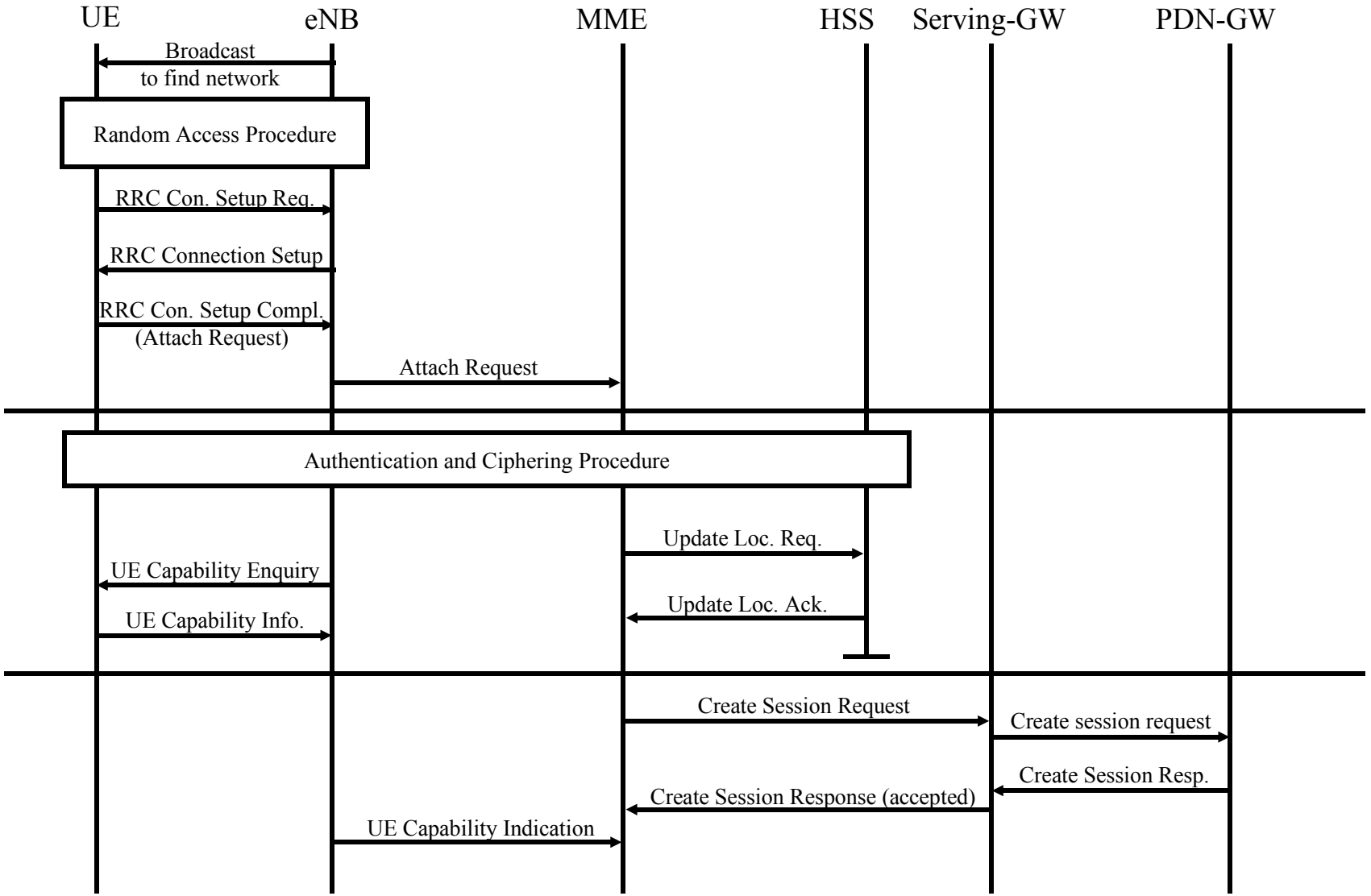
Netzarchitektur

5G Network TODAY – 3GPP NR Option 3

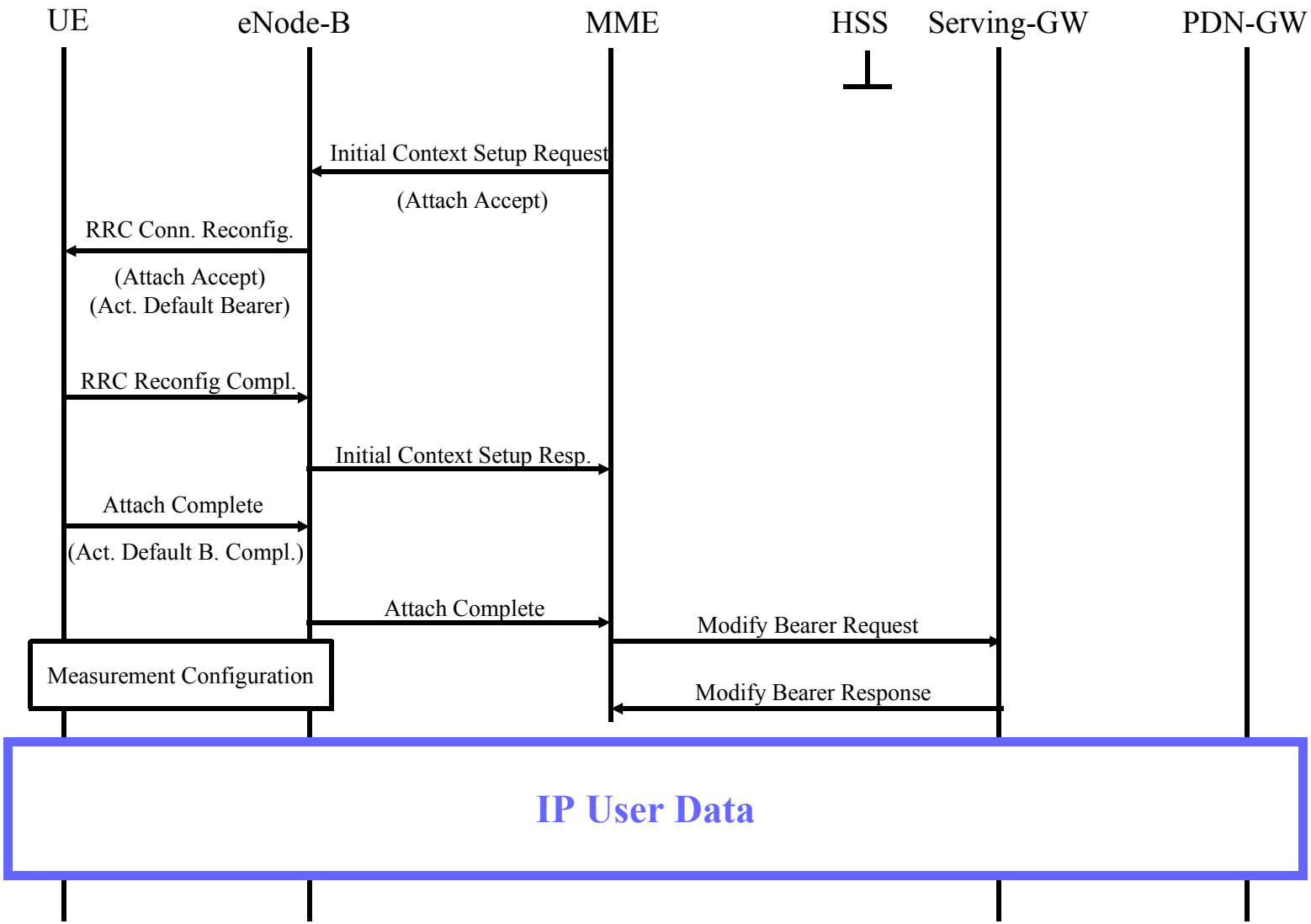


(*) not counting the 'wireless backhaul'

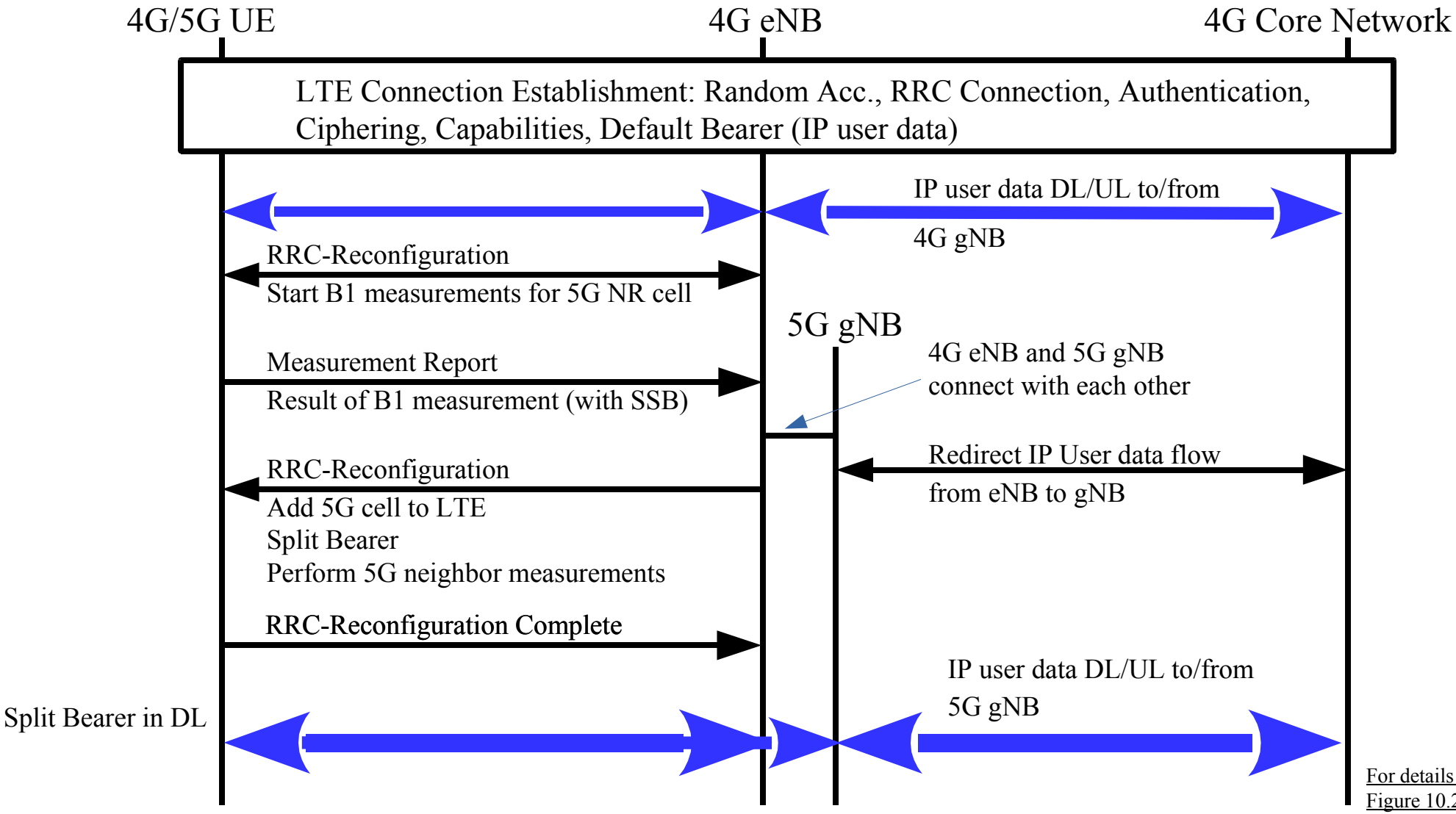
LTE Connection Establishment – Part 1



LTE Connection Establishment – Part 2

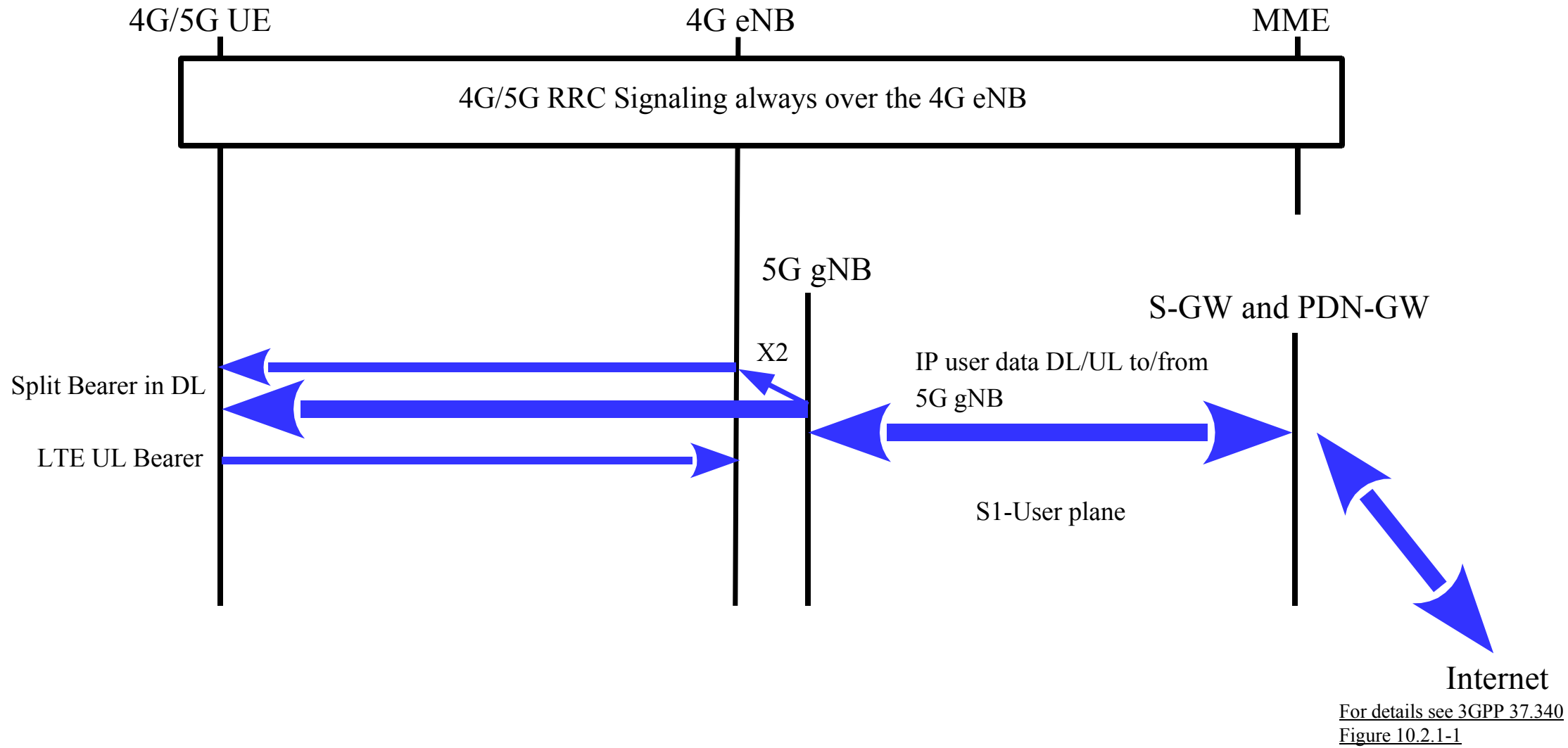


Adding 5G to a 4G Connection



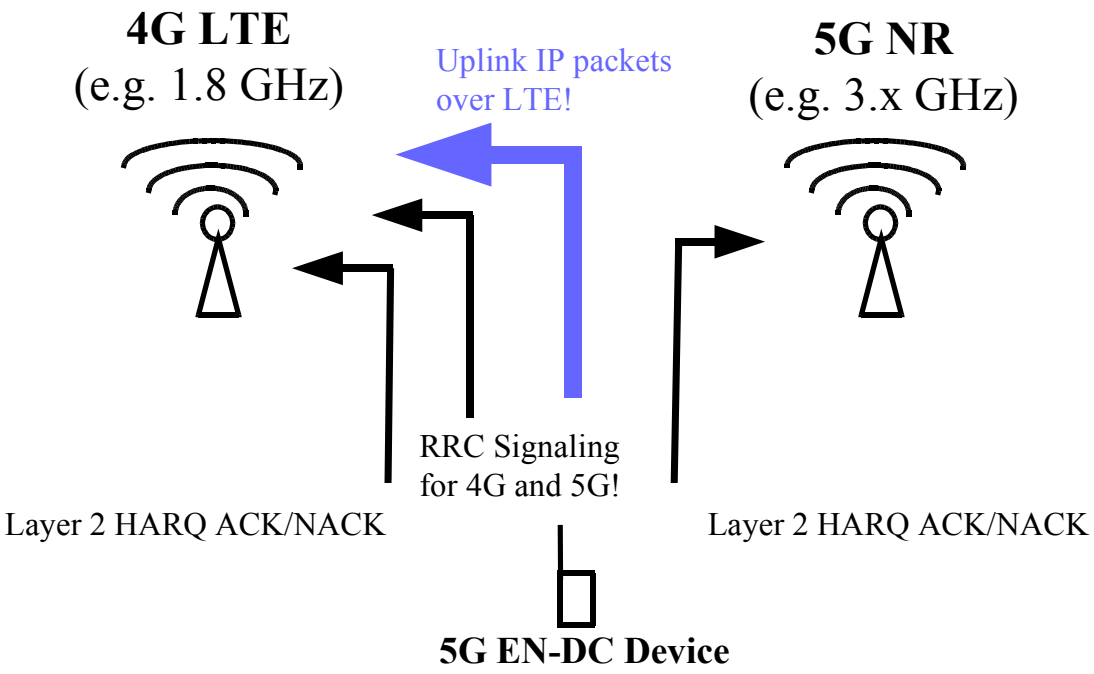
For details see 3GPP 37.340 Figure 10.2.1-1

The 4G-5G Split Bearer



For details see 3GPP 37.340
Figure 10.2.1-1

4G and 5G and Uplink Transmissions



The 'Catch':

- LTE Carrier Aggregation: All L2 HARQ ACK/NACK on the 'primary cell'.
  Benefit: Requires only one UE transmitter!
- LTE – 5G Dual Connectivity (EN-DC): 5G HARQ Ack/Nack on 5G.
  Problems: Requires 2 UE transmitters! Also, potential interference between uplink and downlink and the two transmitters!!!!

- **IP Uplink via LTE:** A common configuration, simple, better due to lower frequency of LTE part if n78 high band is used.
- **IP Uplink via NR (not shown):** Can also be used in practice today. However: Range more limited if NR band is higher, potentially requires reconfigurations, so mobility is more challenging.
- **Split Bearer (4G+5G) (not shown)**: More speed, but also higher complexity to implement.
- **Typical Data Rate:** 50 Mbit/s under very good radio conditions for LTE or NR (only) options.

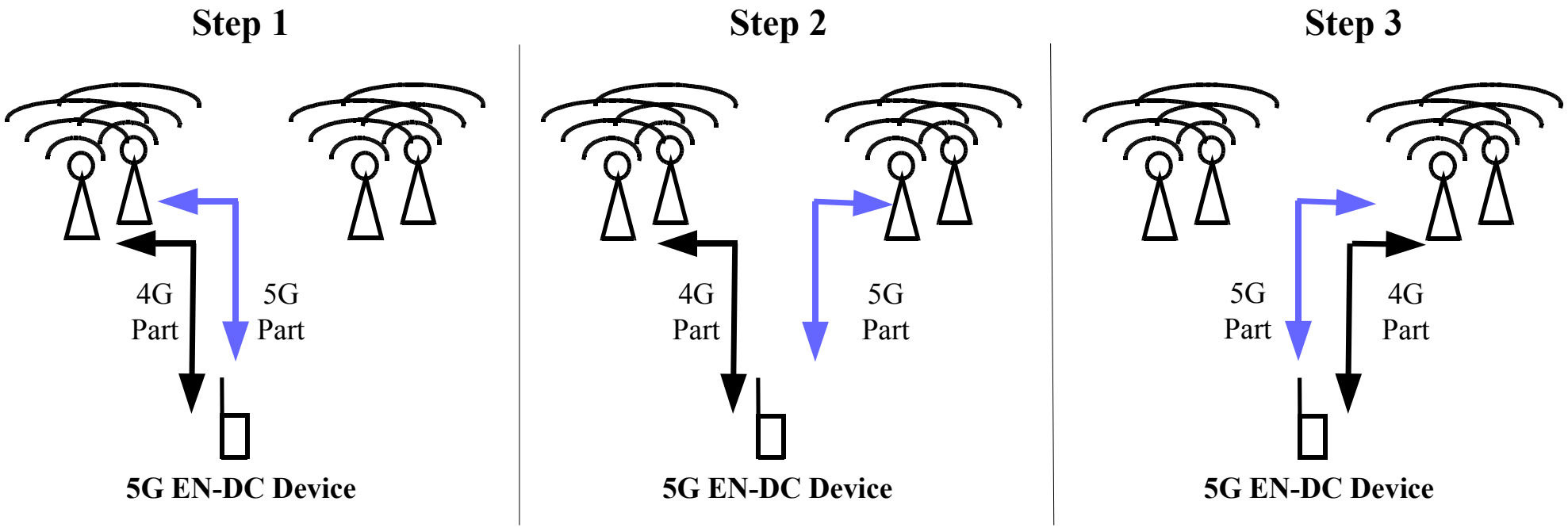
When and How to Show a 5G Logo

```
SIB2
[...]
freqInfo
  ul-Bandwidth: n100 (5)
  additionalSpectrumEmission: 1
timeAlignmentTimerCommon: sf1920
plmn-InfoList-r15: 1 item
  Item 0
    PLMN-Info-r15
      upperLayerIndication-r15: true
```

- In GSM, UMTS and LTE it was simple: Even if the UE is not connected to the network it is only connected to **one** air interface and hence can show ‚G' ‚E' ‚3G' '4G', LTE and so on.
- Doesn't work anymore with LTE-5G Dual Connectivity (EN-DC) as in ‚idle' state (i.e. not connected), the UE is on LTE even if 5G is available at the location (and hence, the 5G logo should be shown).*
  - **Solution**: Announce in the System Information 2 broadcast (SIB2) that 5G is available. The indicator is referred to as UpperLayerIndication bit.
- But what if the subscriber does not have a 5G subscription? In this case don't show the logo despite the UpperLayerIndicatin bit being set…
  - **Solution**: In attach accept, inform the UE if it is not allowed to use 5G New Radio: NR-Restricted bit.
- Some Implementations: Show slightly different 5G logos in idle and when really connected to the 5G cell.

* This is option D in 3GPP R2-1713952, for more, see https://blog.3g4g.co.uk/2019/02/displaying-5g-network-status-icon-on.html

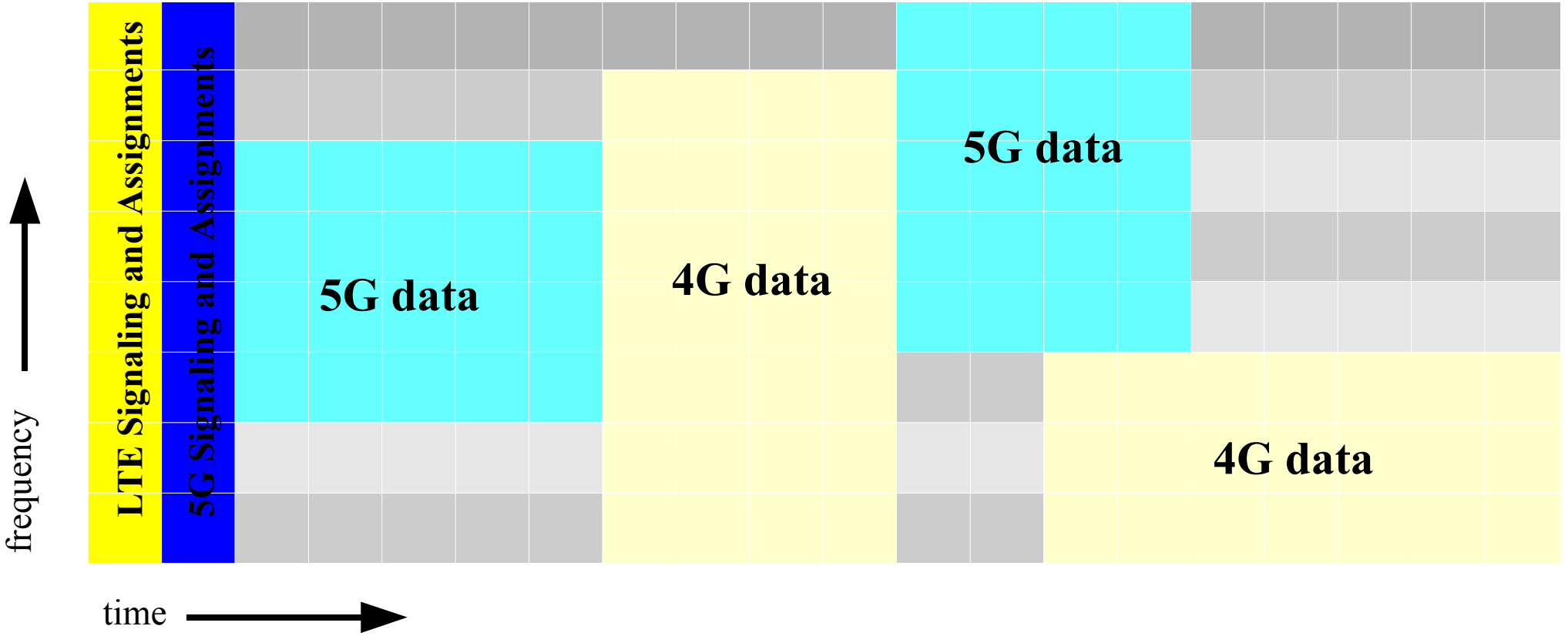
5G Handover Scenarios



- **Step 1:** 4G and 5G part connected to the **same** cell site. UE sends a Measurement Report about a better 4G or a better 5G cell (5G in this example)
- **Step 2**: 5G part is moved with an RRCReconfiguration command to another cell site
- **Step 3**: Somewhat later, the UE sends a measurement report that there is a better LTE site. Network then moves the 4G part as well.
- Note: This is just one of many scenarios. Examples: LTE could be handed-over first. Simpler variant also used in practice: Delete 5G leg, make the LTE handover, measure and add 5G again.

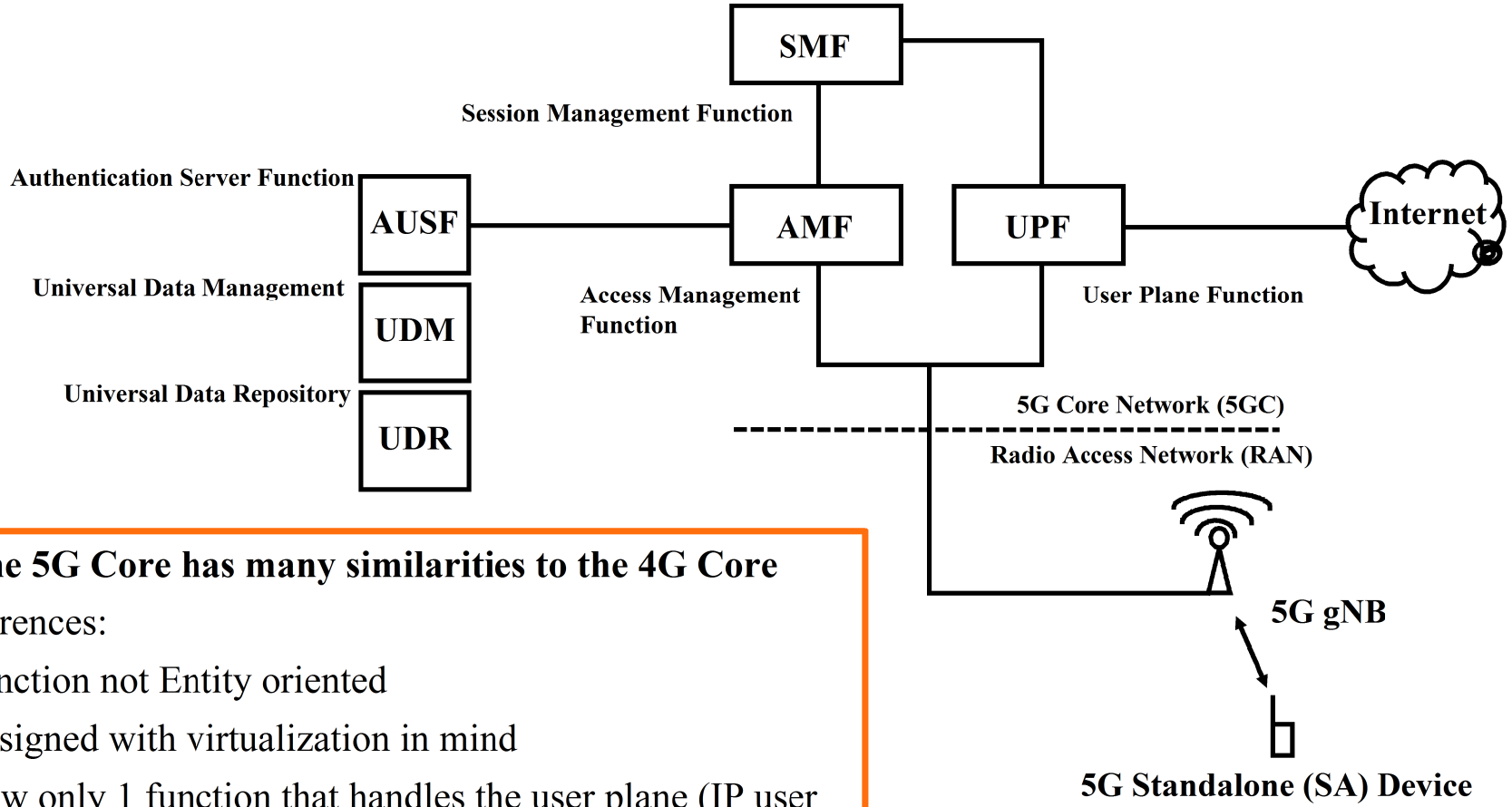
3GPP TS 37.340 NR; Multi-connectivity; Overall description; Stage-2

5G In Low- and Mid-Bands + Dynamic Spectrum Sharing



5G in 'Mid-' and 'Low-Bands' for nationwide 5G coverage and evolution to a 5G Core Network

5G Tomorrow – The 5G Core Network



The 5G Core has many similarities to the 4G Core

Differences:

- Function not Entity oriented
- Designed with virtualization in mind
- Now only 1 function that handles the user plane (IP user packets
- New protocol between 5GC and mobile devices

3GPP TS 23.501 – System Architecture – Stage 2

It‘s All in the Specs and Public: 3GPP

- Everything described in this talk is **publicly** available at **no charge** in the specification documents at the 3rd Generation Partnership Project website: https://www.3gpp.org/

- And not only specification documents but also technical reports (feasibility studies) also every meeting contribution and meeting reports!

- Granted, 3GPP Specs are not easy to read without prior knowledge where to look. But there are books out there that are good starters which reference relevant standardization documents.

Thanks for listening!

and...

Enjoy the walk from 4G to 5G

Your Questions?

36c3

Heurekus
blog.wirelessmoves.com

Peter
Twitter: @33dBm