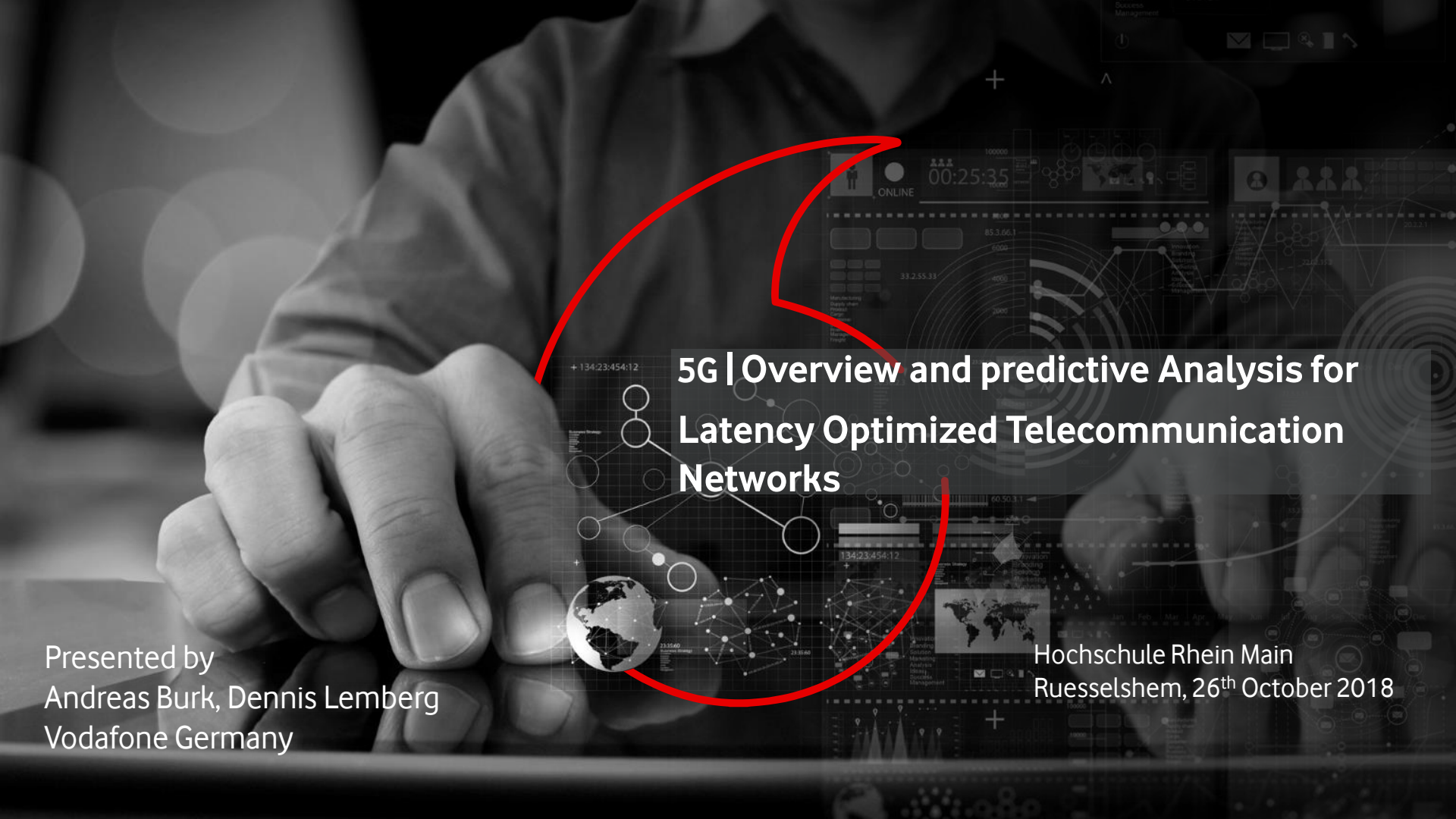


5G | Overview and predictive Analysis for Latency Optimized Telecommunication Networks

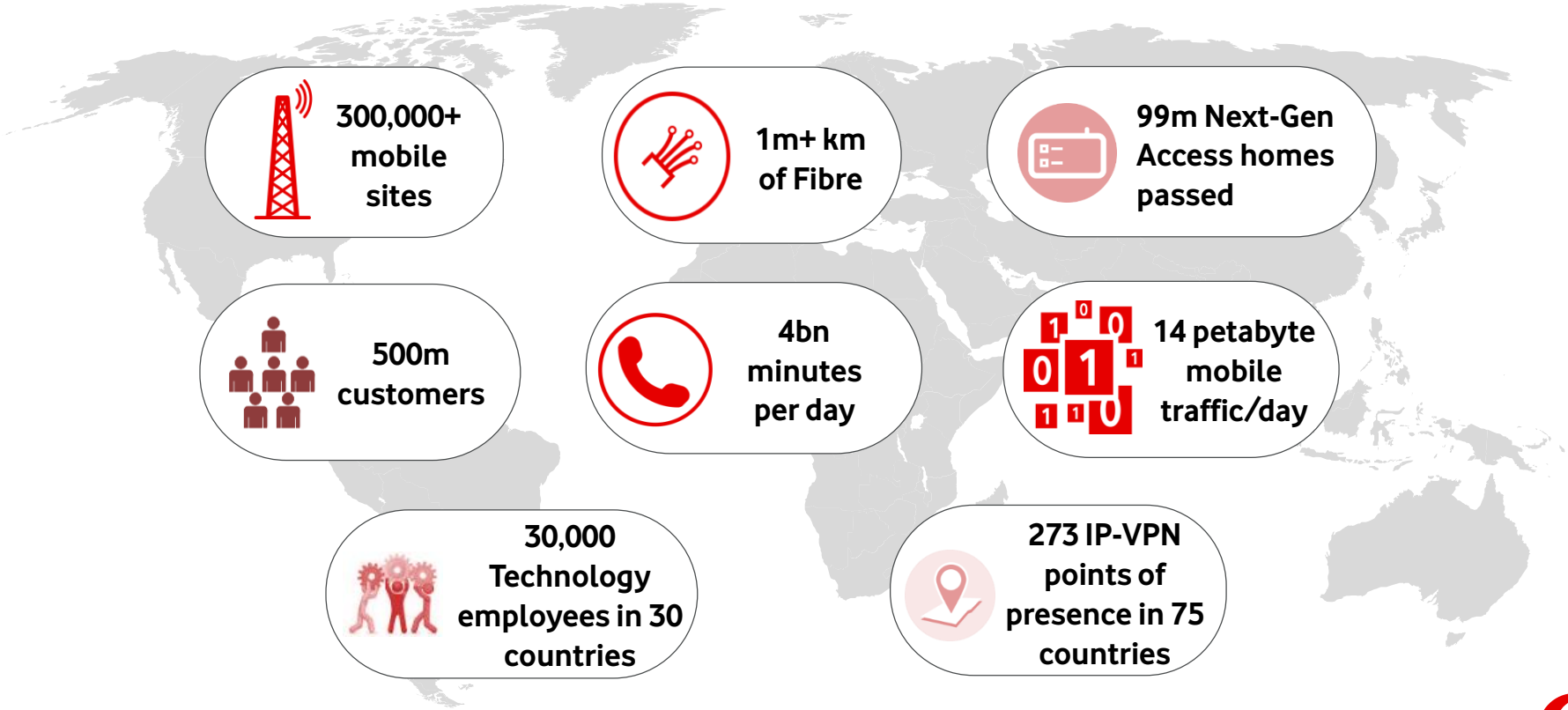
Presented by
Andreas Burk, Dennis Lemberg
Vodafone Germany

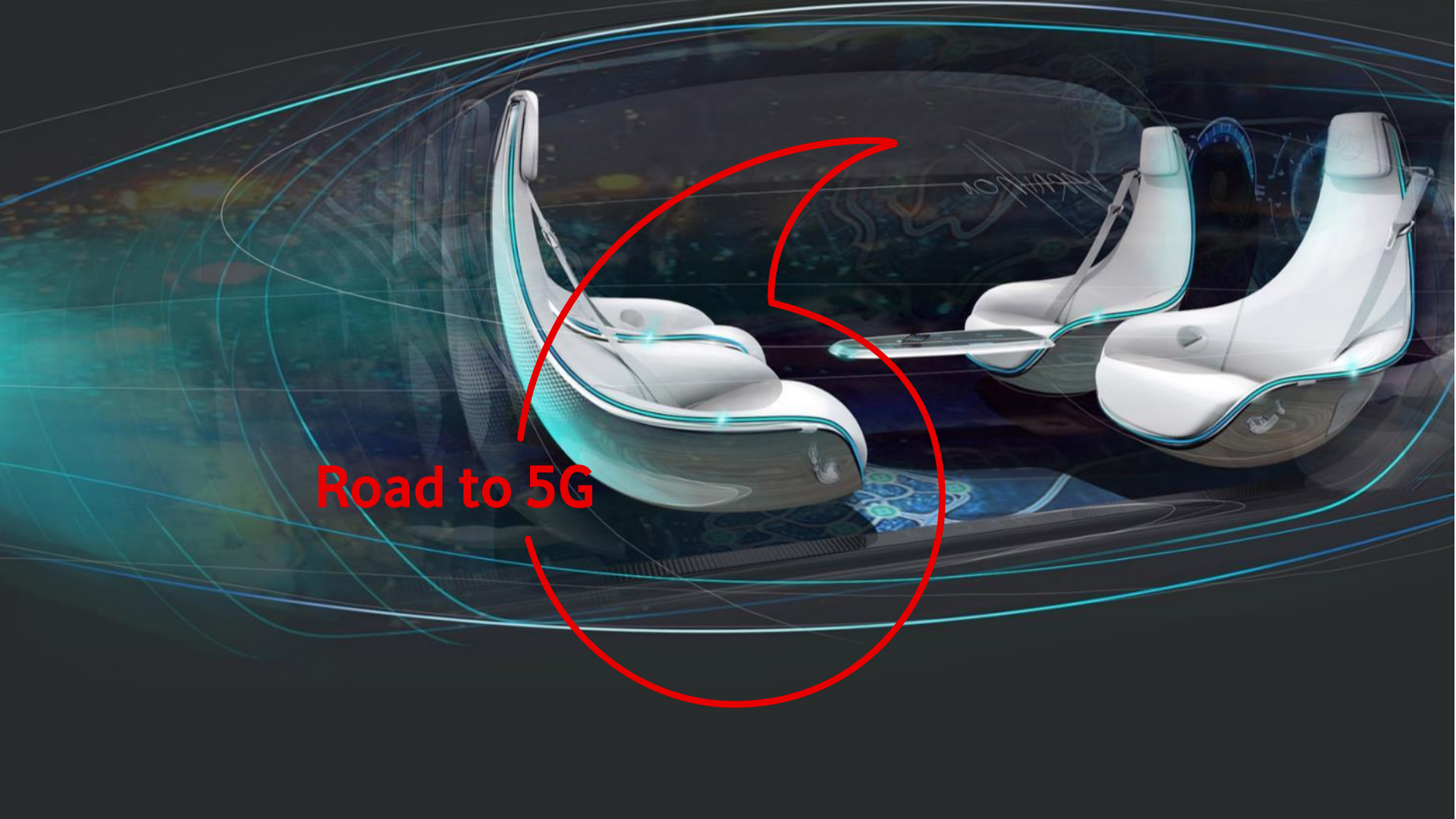
Hochschule Rhein Main
Ruesselsheim, 26th October 2018

Vodafone is one of the world's largest telecoms operators

26	countries in which we have mobile operations
19	countries in which we have fixed operations
49	Partner Markets
66m	IoT connections
100	countries connected by our submarine cables
£61bn	market capitalisation (23 November 2017)

Vodafone Technology | Scale and diversity of operation




Road to 5G

Evolution of wireless networks

1G

1st Generation wireless network
- Basic voice service
- Analog based protocols

2G

2st Generation wireless network
- Designed for voice
- Improved coverage and capacity
- First digital standards (GSM, CDMA)

3G

3st Generation wireless network
- Designed for voice with some data consideration (multimedia, text, internet)
- First mobile broadband

4G

4st Generation wireless network
- Designed primarily for data
- IP-based protocols (LTE)
- True mobile broadband

Main focus of current wireless networks is voice and data.

5G

5st Generation wireless network
- Designed for connection of everything
- low latency, high bandwidth
- less battery consumption

Beside voice and internet services 5G will be developed for new applications which are specified in the 3GPP Release (TR 22.891).

5G | Use Cases an Categories

Network Operation

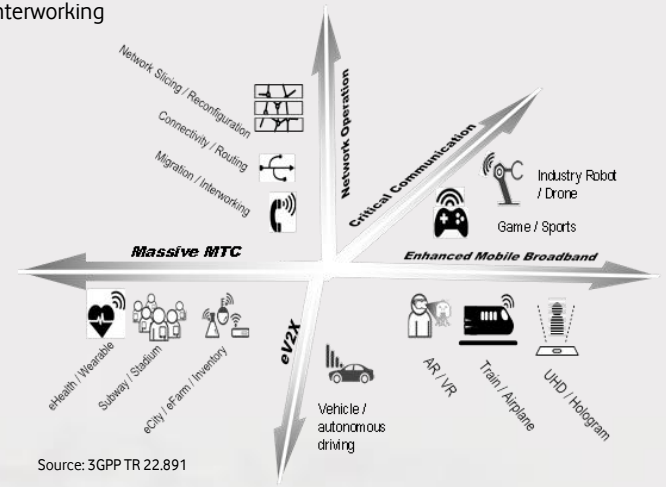
e.g.

- Network Slicing
- Routing
- Migration and Interworking
- Energy Saving

Critical Communication

e.g.

- Interactive Games / Sports
- Industrial Control
- Drone / Robot / Vehicle
- Emergency



Source: 3GPP TR 22.891

Massive Machine Type Communications

e.g.

- Subway / Station Service
- eHealth
- Wearables
- Inventory Control

Enhanced Mobile Broadband

e.g.

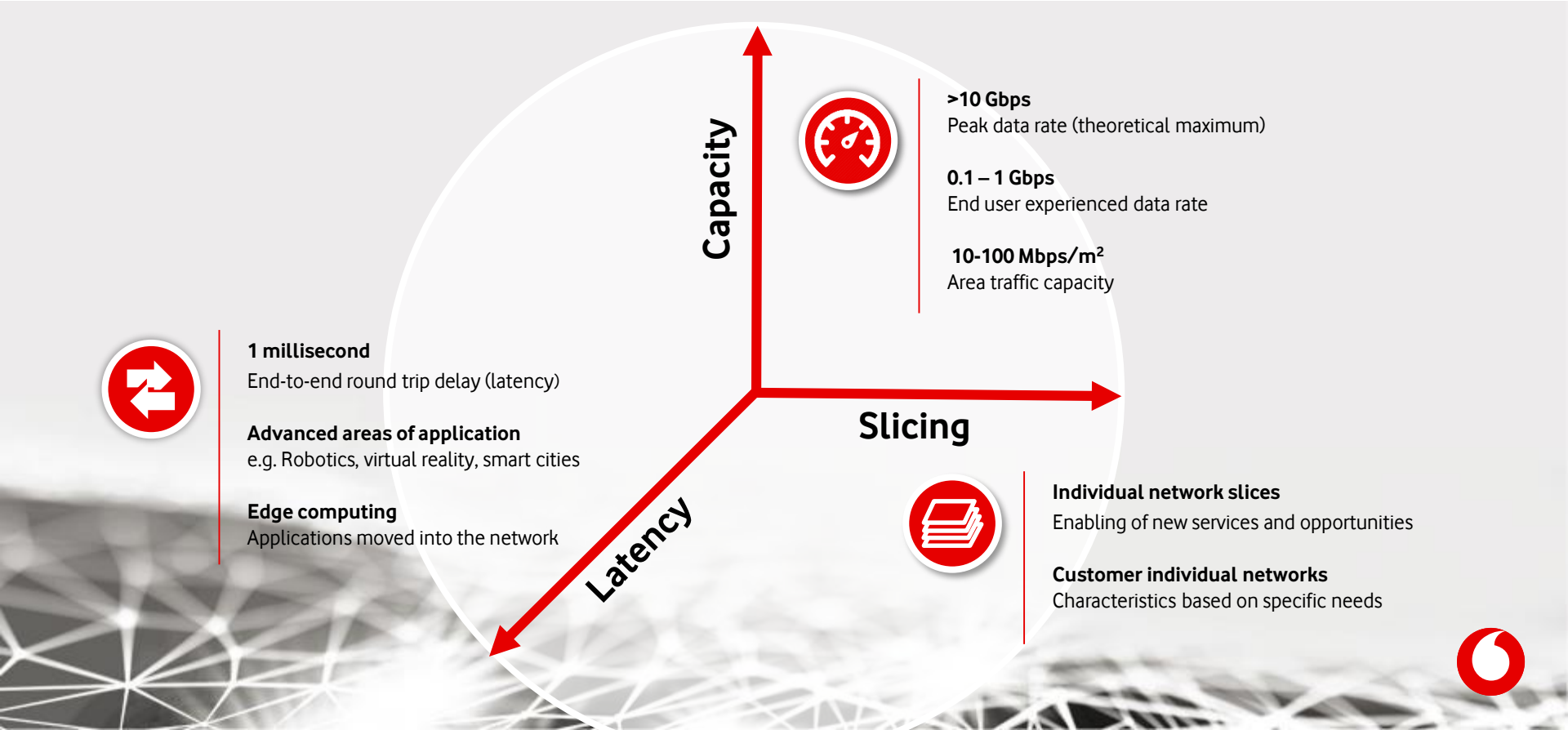
- Mobile Broadband
- UHD / Hologram
- High-mobility
- Virtual Presence

Enhancement of Vehicle-to Everything (V2x)

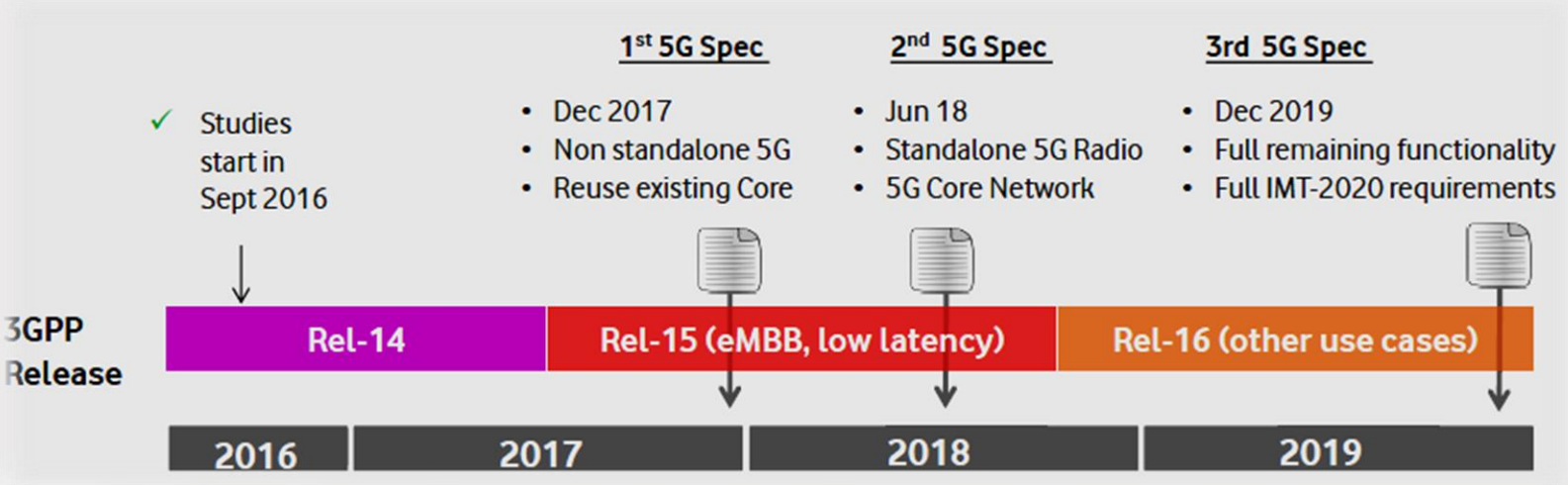
e.g.

- Autonomous Driving
- safety and non-safety aspects associated with vehicle

5G | stands for huge capacity, ultra low latency as well as reliability by network slicing

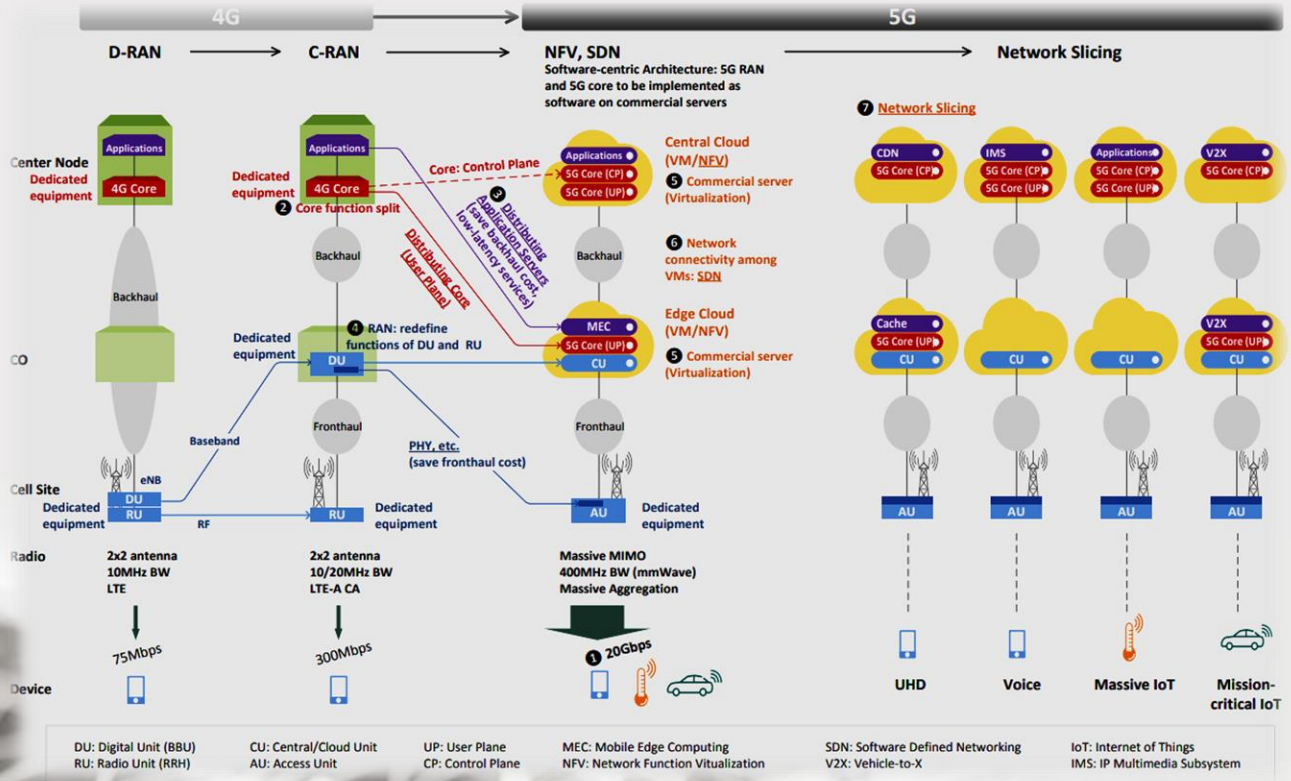


5G | 3GPP Timeline for 5G



- 5G comes in multiple releases

5G | Network Architecture Evolution: 4G → 5G

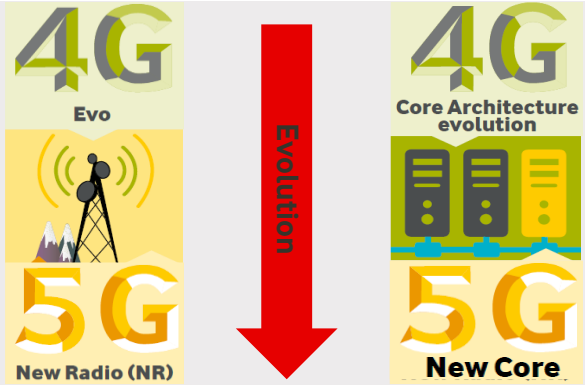


Source: www.netmanias.com


4,5G / 5G Concepts and
Technologies

5G | Architectural Evolution

- 4G Evo act as a bridge to 5G
- 5G encompasses 4G Evo
- For the first time two generations of technologies are going to be closely integrated together



Radio:

- 5G NR is a new radio standard interface offering data rates higher than 1 Gbps.
- The NR can transmit more data in the same amount of spectrum, as well as utilize more spectrum at once.
- It was defined in the 3GPP standard in Dec' 17.

Core:

- There are two phases for the Core Network to support the 5G New Radio
- Non Stand Alone (5GNSA)
- Stand Alone (5G SA)

5G | Radio Access

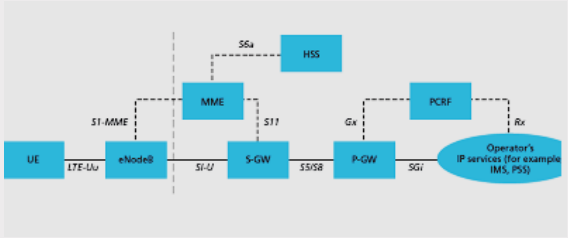
- The "New Radio" cellular technology that is being developed as part of the 5G network is based on a similar design to the existing LTE (4G Evo) technology but:
  - it works more efficiently in larger spectrum allocations than 4G Evo.
  - the maximum carrier bandwidth in 5G is 100MHz while in 4G is 20 MHz.
  - it's able to operate in frequencies up to "millimeter wave" range, as well as in existing cellular frequencies.
  - it's has a leaner design allows any future vertical or service specific enhancements to be added more easily, and enables more opportunity for Network energy saving.
  - it's able to easily integrates with existing LTE network and at same sites to minimize initial integration cost.

Generation	2G			3G			4G		5G
Funktechnik	GSM	GPRS	EDGE	UMTS	HSPA	HSPA+	LTE	LTE-A	New Radio
Zugriffs-verfahren	TDMA	TDMA	TDMA	CDMA	CDMA	CDMA	OFDMA	OFDMA	OFDMA
Modulations-verfahren	GMSK	GMSK	8-PSK	QPSK	QPSK, 16-QAM	QPSK, 16-QAM	QPSK, 16-, 64-QAM	QPSK, 16-, 64-, 256-QAM	QPSK, 16-, 64-, 256-QAM, 1024-QAM
Bandbreite	0,2 MHz	0,2 MHz	0,2 MHz	5 MHz	5 MHz	5 MHz	1,4-20 MHz	20-100 MHz	35-400 MHz
Kanal-bündelung	nein	bis 8	bis 8	nein	nein	nein	bis 4	bis 4	bis 4
Datenraten	0,01 Mbps	0,1 Mbps	0,2 Mbps	0,4 Mbps	14 Mbps	42 Mbps	150 Mbps	1000 Mbps	>1000 Mbps
Weitere Eigenschaften	–	–	–	–	MIMO	MIMO	MIMO	MIMO, Carrier Aggregation	MIMO, Carrier Aggregation
Latenzzeit	500 ms	500 ms	300 ms	150 ms	100 ms	50 ms	10 ms	5 ms	1 ms

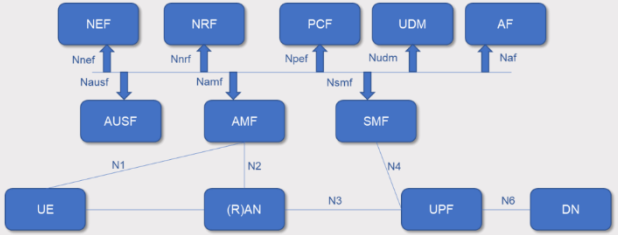
So unterscheiden sich 2G, 3G, 4G und 5G (GSM, UMTS, LTE und New Radio)

Source: https://www.elektronikpraxis.vogel.de/index.cfm?pid=7525&pk=729345&fk=1419511&type=article

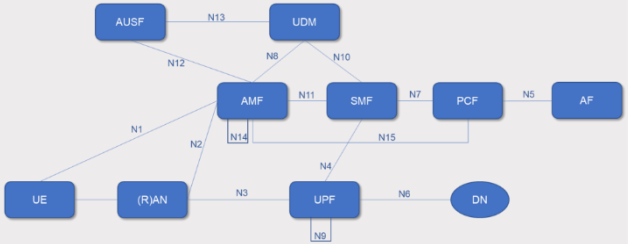
5G | Core Architecture



4G Architecture



5G Service based Architecture



5G Reference based Architecture

- 5G Core Network (5GCN) is a new architecture for the Core Network that is being defined from scratch by 3GPP; if compared to 4G Core Network, it introduces ...
  - ... more flexibility,
  - ... more openness,
  - ... new protocols,
  - ... and will be able to serve all types of 5G radio.

- 5G Core implies a new architecture that:
- maximizes the benefits of Network Functions Virtualization
- Software Defined Networking
- minimizes dependencies with the access networks by introducing a unified authentication framework, unified subscription control, unified QoS framework and charging.

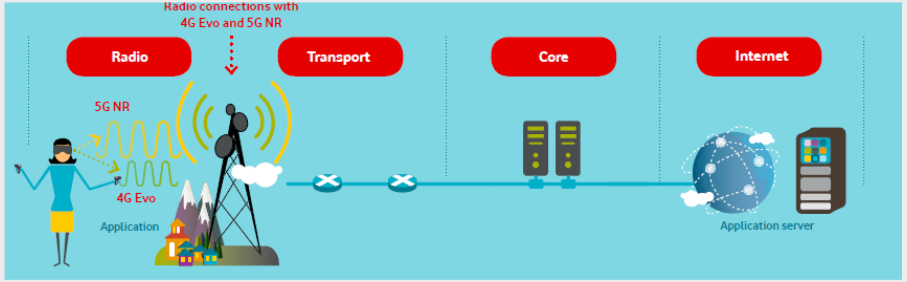
5G | Deployment Scenario

- 3GPP finalized the first implementable specification of "Non-Standalone" 5G NR operation in line with the accelerated plan, in December 2017.
- Operators who are in hurry to deploy 5G will therefore be able to base their early deployments on the specifications on NSA, rather than taking "solo paths" with technology.
- The major 3GPP milestone are:
  - December 2017 – Non Standalone New Radio (Rel. 15)
  - June 2018
    - 5G: Standalone 5G New Radio and New Core (Rel. 15)
    - 4G Evo: Further evolution (Rel. 15)
  - December 2018 – Further RAN – Core Network deployment options (Rel. 15)
  - December 2019 – Further evolution of 5G New Radio and 4G Evo (Rel. 16)
- The 3GPP is not only working on 5G New Radio but also in introducing improvements for 4G Evo both as part of te 5G framework.

5G | Deployment Scenario

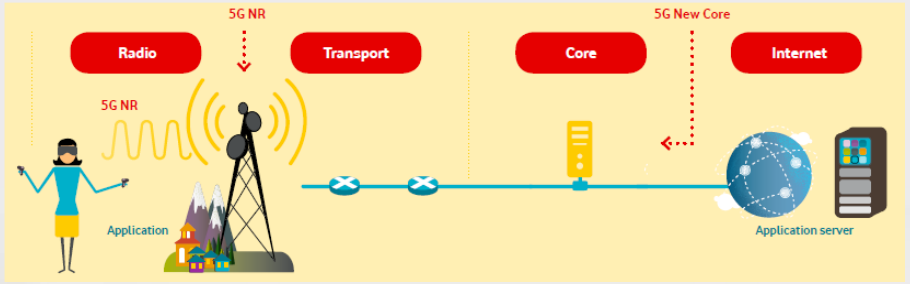
Non Stand Alone (5G NSA)

- In the first phase (as mentioned) the existing 4G core network (EPC) will be used to support the 5G launch, with only minor changes expected for the current core



Stand Alone (5G SA)

- In the second phase the new 5G Core (5GCN) will be introduced. It's currently being standardized in 3GPP and it introduces more flexibility and more functionalities.



5G Key Technical Dimensions

- CAPACITY / SPEED
- SLICING
- LATENCY

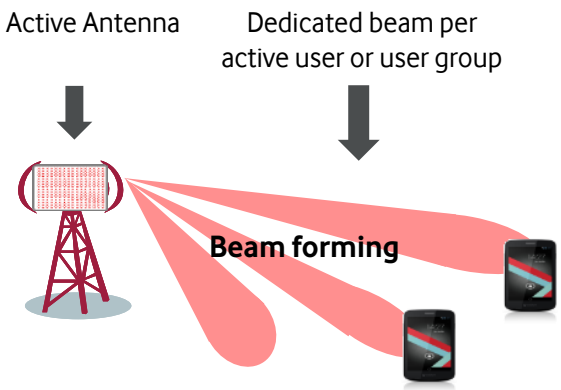
Capacity & Speed | Data, Speed & Capacity

4G Evo and 5G will enable an increase in data rate and capacity.

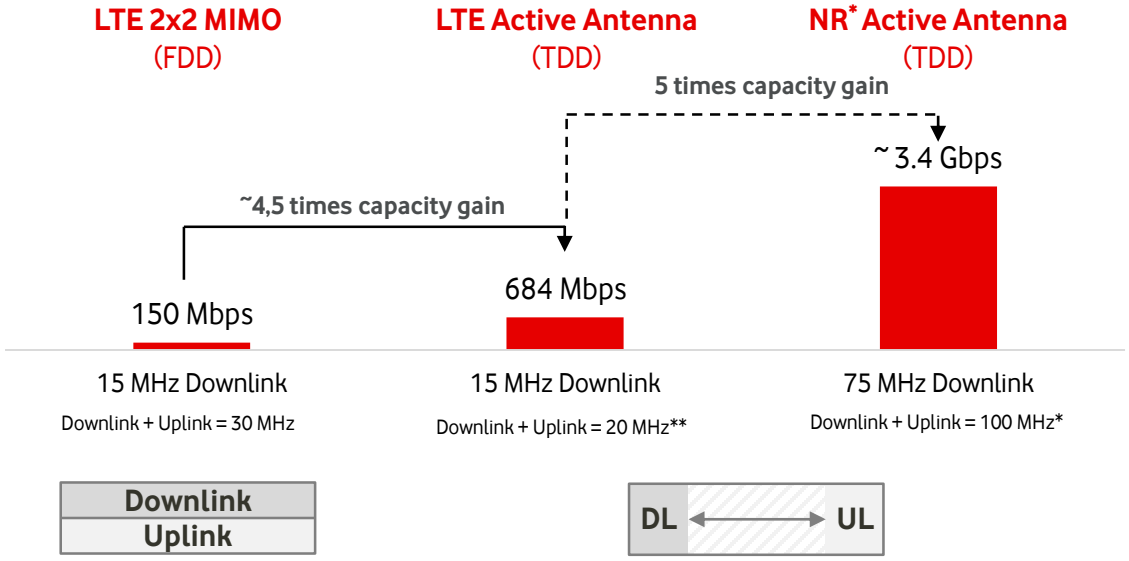
- Massive MIMO:
  - already available in 4G Evo
  - improves capacity, coverage and user throughput.
  - changed the way a signal is radiated,
  - providing of multiple beams of a signals, where each beam is assigned to a unique user or a group of users
- New Spectrum:
  - max. carrier bandwidth in 5G is 100MHz while in 4G is 20MHz.
- Carrier Aggregation
  - Intra and Inter eNodeB Carrier aggregation

Capacity & Speed | 5G capacity gains driven by combination of Active Antenna & huge amount of spectrum

Schematic view on Active Antenna



Vodafone Active Antenna trial results



** NR: New Radio

** Within the trial, the split between DL and UL was 75% to 25%

Capacity & Speed | Leveraging 4G Evo to the maximum with Carrier Aggregation

- Carrier aggregation (CA) is used in LTE Evo in order to increase the bandwidth, and thereby increase the bitrate.
- CA can be used for both FDD and TDD.
- Each aggregated carrier is referred to as a component carrier, CC, which can have a bandwidth of 1.4, 3, 5, 10. 15 or 20 MHz and a maximum of five CC.

225 Mbps
- 2-carrier aggregation

375 Mbps
- 3-carrier aggregation

500 Mbps
- 3-carrier aggregation
- 256 QAM

1 Gigabit
- 4-carrier aggregation
- 256 QAM
- 4x4 MIMO

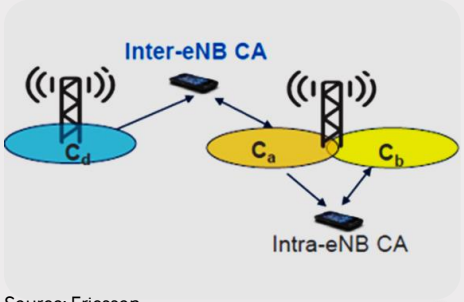
Launched in Oct. 2017

CAPACITY & Speed | Inter eNB Carrier Aggregation

- Inter eNB CA feature enables DL CA between cells not located on the same eNB
- eNB that has the serving cell (Primary eNB) will forward user-data over the X2 interface to the external eNB that has the external Scell (Escell).

Potential Benefits

- The set of cells considered for use as secondary cells is expanded across multiple eNBs. As a result, UEs can find a more nearly optimal set of cells with which to perform carrier aggregation.
- Increase downlink bitrates for CA capable devices also in situations where the user is covered by different eNBs.



Source: Ericsson

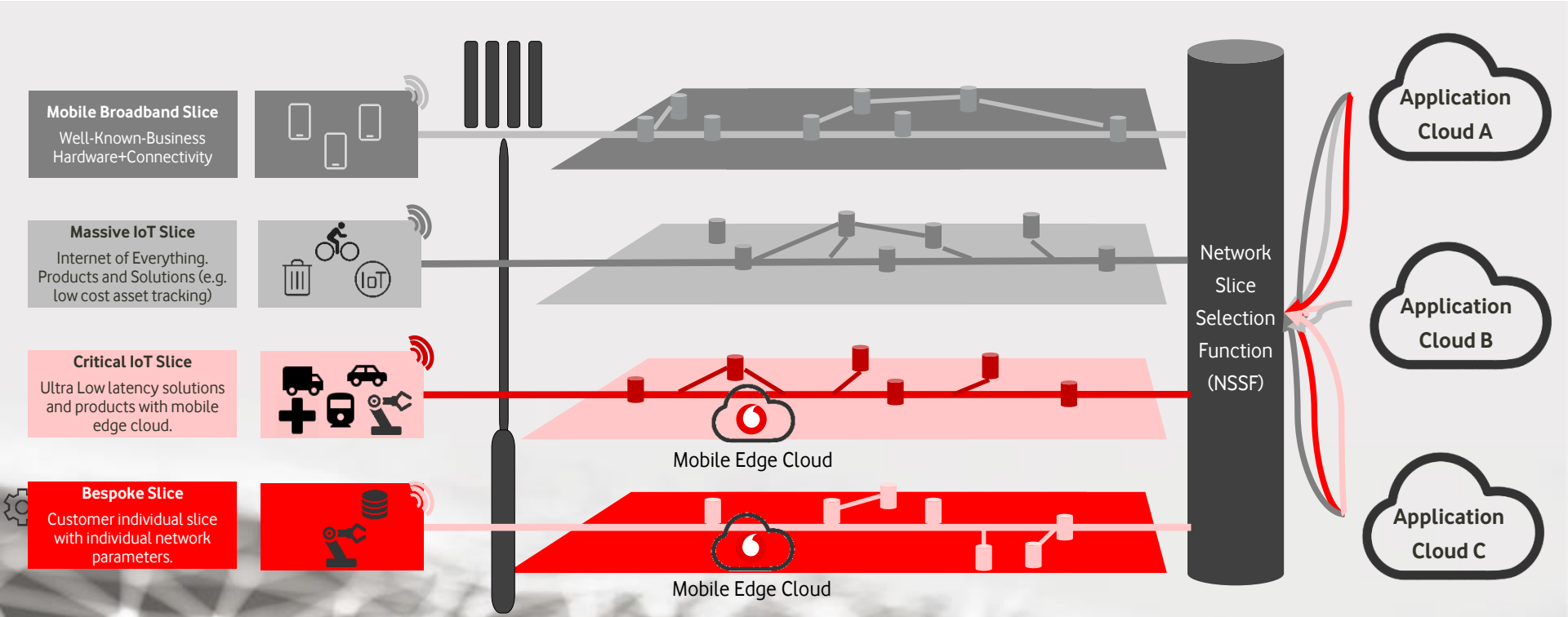
5G Key Technical Dimensions

- CAPACITY / SPEED
- **SLICING**
- LATENCY

Slicing | Customer & application specific networks

- Through Network Slicing operators can offer specific services to different customers with virtual / logic "network slices" over the same physical network.
- Each slice gets the performance characteristics they require, e.g.
  - guaranteed bandwidth
  - Low latency
  - ...
- The full 5G network slicing capabilities will be introduced together with 5G Core.
- The new 5G core will be able to implement the foundation of the network slicing concept in terms of flexibility, elasticity, automation and security.
- Network slicing is expected to play a critical role in 5G networks because of the multitude of use cases and new services 5G will support (e.g. V2X)

Slicing | Customer & application specific networks



Slicing | E2E Network Slice example: Vodafone LTE V2X

5G Key Technical Dimensions

- CAPACITY / SPEED
- SLICING
- LATENCY

Latency | What is latency

- Latency is basically the time it takes for a message, or packet, to travel from is point of origin to the point of destination.
- There are many of contributing components for the overall latency:

Latency = Σ {transmission delay[1)], propagation delay[2)], processing delay[3)], queuing delay[4)]}

Contributors		Typical values			Cure
Transmission (Serialization)	Push bits into link ...0110101100010	**Bandwidth**	**1518 byte**	**9600 byte**	Bandwidth
		1Gbps	12,1 µs	76,8 µs	
		10Gbps	1,21 µs	7,7 µs	
Propagation	Travel from origin to destination	**Medium**	**µs/km**	**km/ms**	Short distance
		Fibre	5	200	
		MW	3,5	300	
Processing	Process header, determine errors and route ...0110101100010 queue	10-30 µs (DWDM, MW) 0...500 µs (IP-NE)			Better HW Low # of NEs
Queuing	Waiting until the packet gets transmitted	0...10 ms			No congestion !!! ➔QOS, network slicing, bandwidth

Latency | What is latency - Transmission / Serialization Delay

The transmission / serialization delay decrease if the interface bandwidth will be increased.

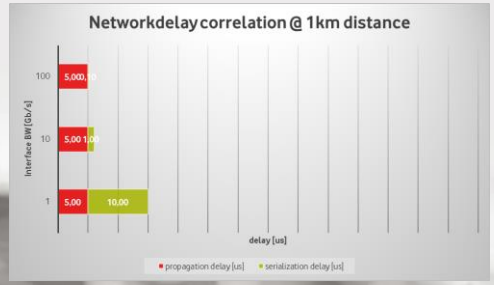
Basic assumptions:

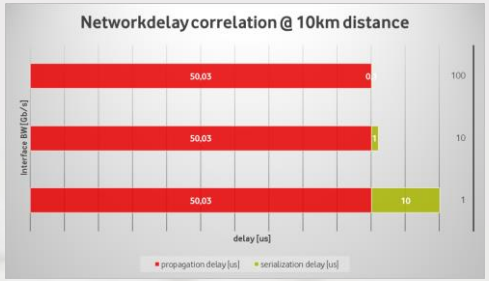
Ideal source is sending 1250 Byte (10.000Bit) to a reciever at a distance

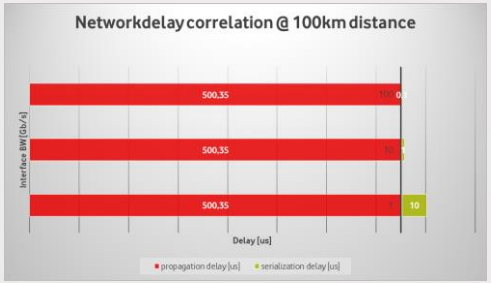
a. 1km
b. 10km
c. 100km

With ingreasing distance the transmission / Serialization delay is negligible.

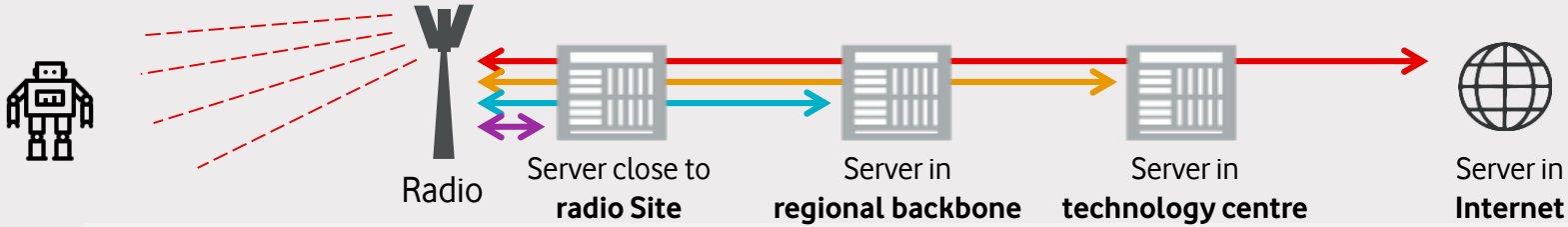
Conclusion:
at one point in time a bandwidth increase will not significantly reduce the latency. To reduce latency the transport distance needs to be shorten.







Latency | Air interface and transport evolution as enabler for ultra low latency



	Air interface Evolution	Transport Evolution**	Total latency**
4G	LTE | 15-20 ms	+ ø 30-35 ms	= 45-55 ms
4G Evo	LTE Advanced | 1-8 ms	+	= 31-43 ms
		+ <10ms	= 11-18 ms
5G	New Radio | 1-2 ms	+	= 11-12ms
		+ 3-4ms	= 4-6 ms
		+ 0 ms	= 1-2 ms

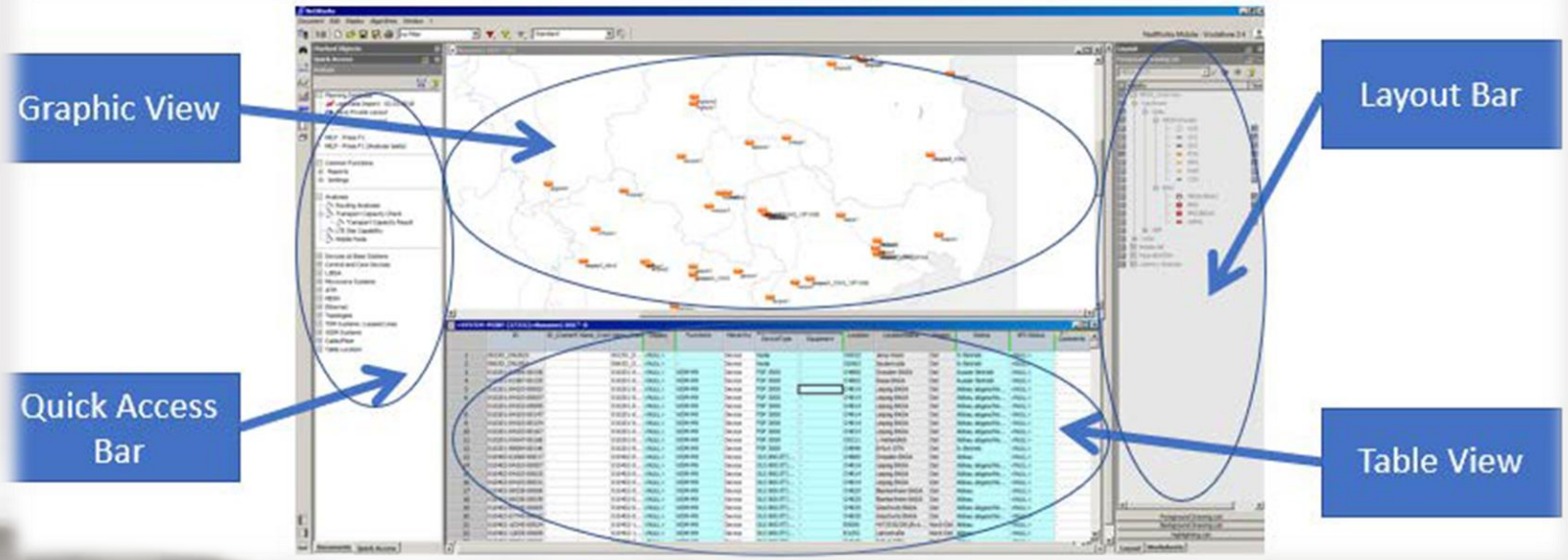
*MEC = Mobile Edge Computing ** Transport latency for 5G are estimations


The Planning Tool "Networks"
Predictive latency calculation

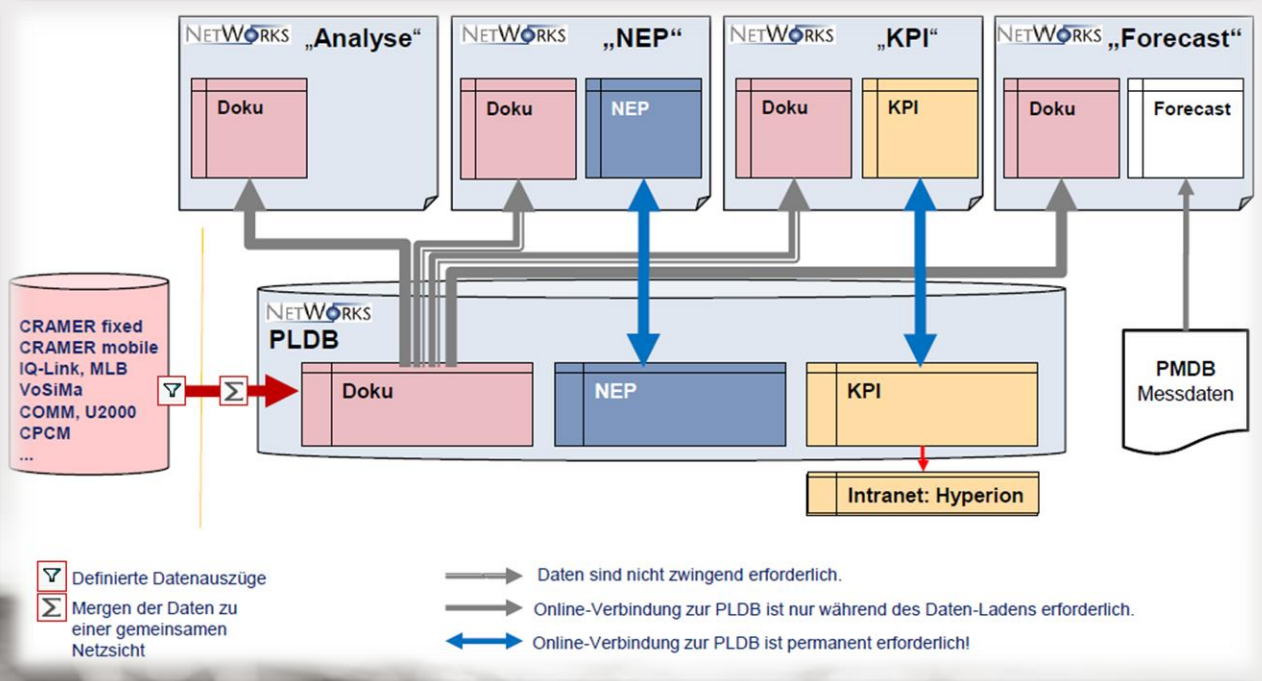
Networks | What is it used for?

- **Analysis**
  - graphic and table view
- **Calculation**
  - macro for automatic tasks
- **Evolution**
  - high level design network

Networks | GUI

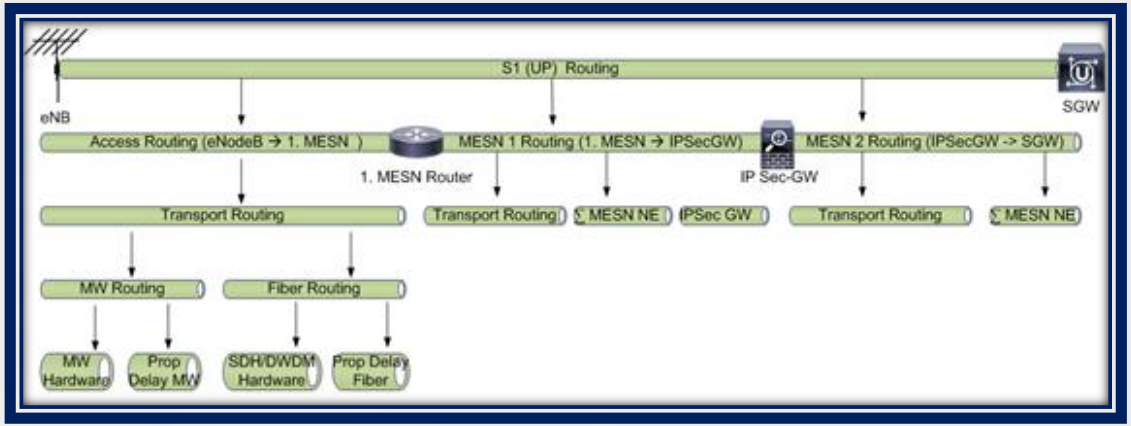


Networks | Architecture



- **Analyse**
  - working with documentation
- **NEP**
  - high level design for a future network
- **KPI**
  - compare KPI with Network
- **Forecast**
  - documentation and measurement database

Networks | Implementation of latency analysis

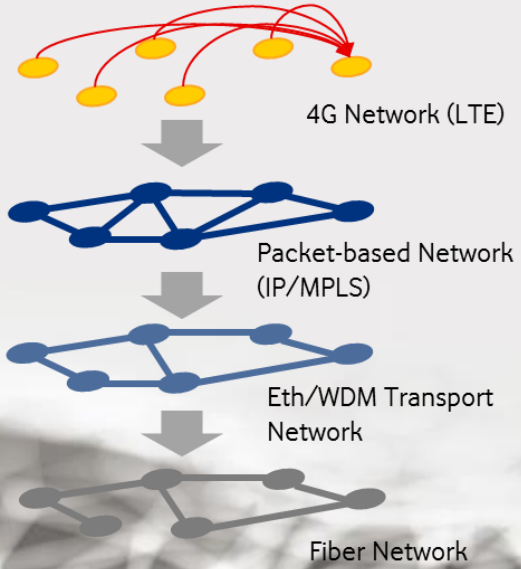


- **Task**
  - calculation of end-to-end-delay from Base Station to S-GW
  - considering used technology
    - microwave transmission
    - fiber cable routing
    - processing delay in nodes

Networks | High level Design of the Framework

- Die Berechnung der Latenz basiert auf einer Auswertung der Abhängigkeiten (Routing/Führung) über alle Netzschichten hinweg.

Routing Stack



Algorithmus

Import Netzdaten

→ Entfernungsberechnung auf Basis des Routing aller darunter liegender Schichten

↓ Summe Knotendelay am S1-Interface

↓ Summe Routingentfernung am S1-Interface

↓ Berechnung der Latenz aus Transitknoten und Ende-zu-Ende Routingentfernung

Eingangsdaten

IP
- Routing over SDH, DWDM or fiber
- Transit and terminating nodes

SDH
- Routing over DWDM or fiber
- Transit and terminating nodes

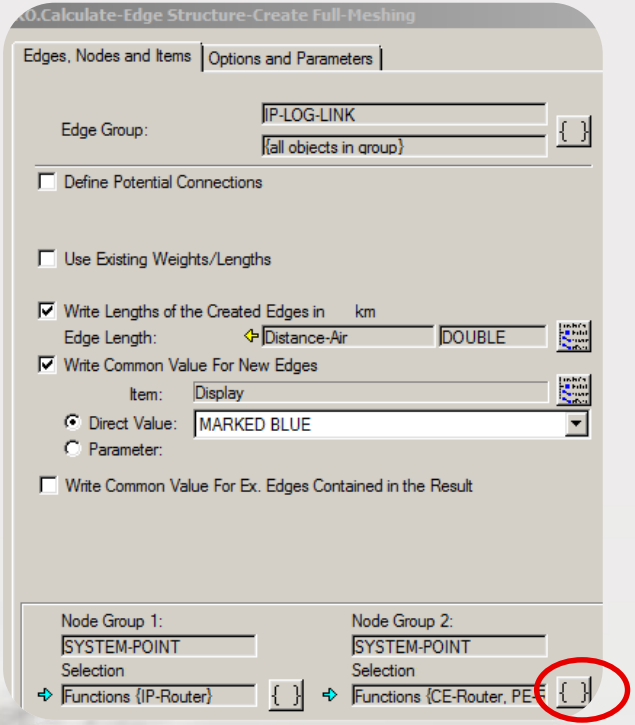
DWDM
- Routing over fiber
- Transit and terminating nodes

Fiber
- Actual fiber length

Microwave
- Coding scheme, bandwidth and distance

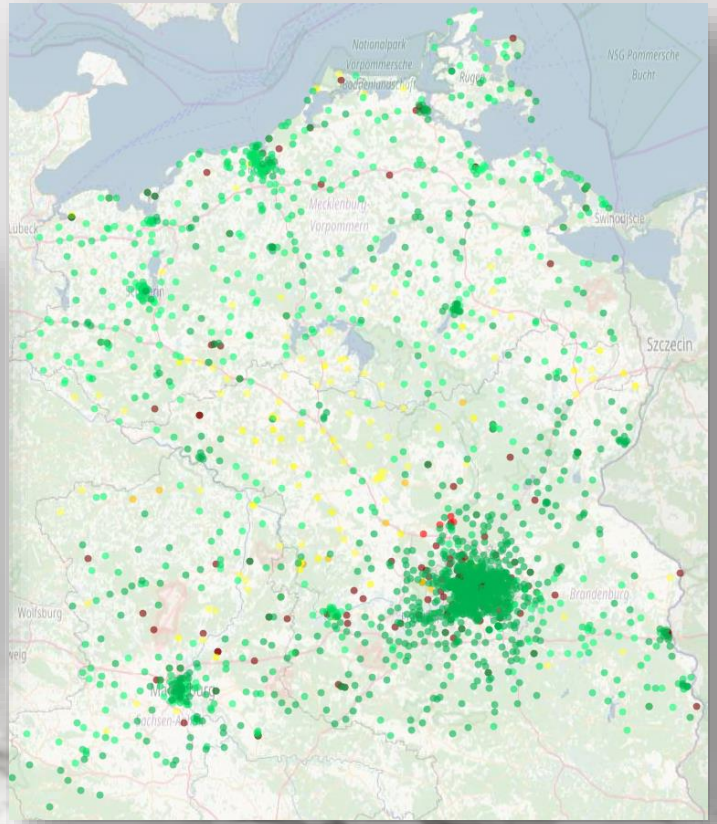
Networks | flexibility within the Latency-Framework

```
Router Analysis
---------------------------------------------------------------

if there are Router with Display=MARKED, traffic marix for those nodes will be generated
if no Router are marked, full traffic marix will be generated (fall back)

Analysis_MESN:
 ==> call macro:  <MESN_defineAreas:End MESN_defineAreas> \\Client\F$\NetWorks\00.Data\Delay_Analyse.mac
 ==> call macro:  <MESNCreateFlows:End MESNCreateFlows> \\Client\F$\NetWorks\00.Data\Delay_Analyse.mac
 ==> call macro:  <MESNRouting:End MESNRouting> \\Client\F$\NetWorks\00.Data\Delay_Analyse.mac
 ==> call macro:  <EvaluateMESN:End EvaluateMESN> \\Client\F$\NetWorks\00.Data\Delay_Analyse.mac
 ==> call macro:  <Report_Latency_MESN:End Report_Latency_MESN> \\Client\F$\NetWorks\00.Data\Delay_Analyse.mac
```



Networks | Output

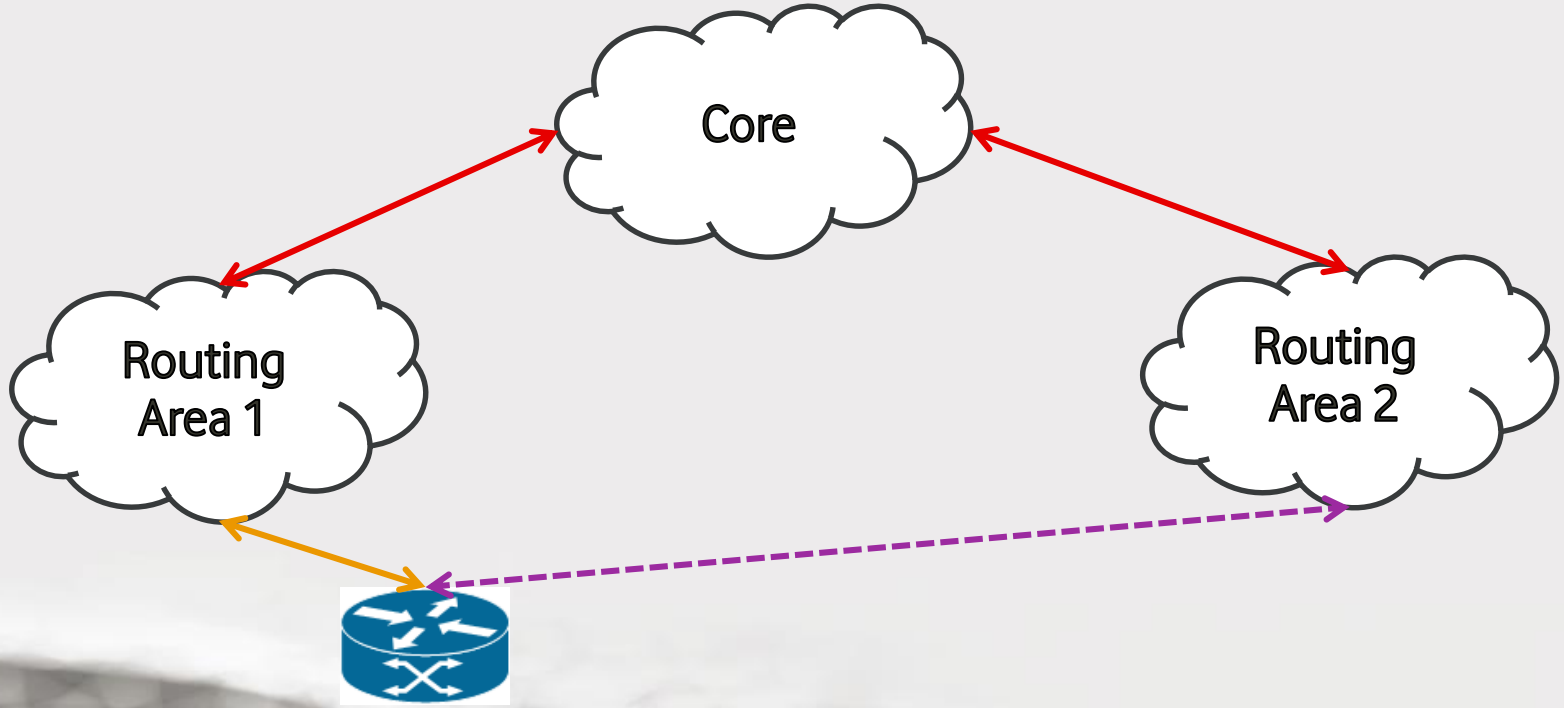
ID	Region	SecGW	S-GW	Latency in µs			
				Komplett	Access	MPS/POS <-> SecGW	SecGW <-> S-GW
				µs	µs	µs	µs
eNodeB 1	Region 1	SecGW 1	S-GW 1	3.727,89	335,10	3.159,05	233,74



Networks | Simulation

- Which impact has a rehoming of a router for the latency?
  - Is it better to rehome a router for a eNodeB site?
  - Are the routing areas up to date?
  - What is the impact for mobile traffic?
- How can Networks support me?
  - 1) Find an IP-Route which is an excact copy of the new E2E Route
  - 2) build your route with partial DWDM routes

Networks | Example



Networks | Example

- What is the impact for one router rehoming ?
  - 1) Find an IP-Route which is an excact copy of the new E2E Route

route	start location	destination location	latency (µs)
routing 1	router	core	2013,44
routing 2	router	core	4441,61

  - 2) build your route with partial DWDM routes

route	start location	destination location	latency (µs)
routing 1	router	core	2013,44
routing 2 part 1	router	1st DWDM Hop	3179,3
routing 2 part 2	1st DWDM Hop	2nd DWDM Hop	871,9
routing 2 part 3	2nd DWDM Hop	core	319,9
routing 2	router	core	4371,1

Rehoming is not an option

Networks | Conclusion

- Through the embeded predective latency analysis in networks Vodafone is able to plan a cost optimized network solution during the planning stage.
- Furthermore planed changes in the network design can be investigated in advanced in terms of latency.
- The included framework can be adapted for various use cases
- The current implementation needs a deep knowledge in macro operation

Outlook

Implementing of wizards for various use cases

Thank you for your attention…

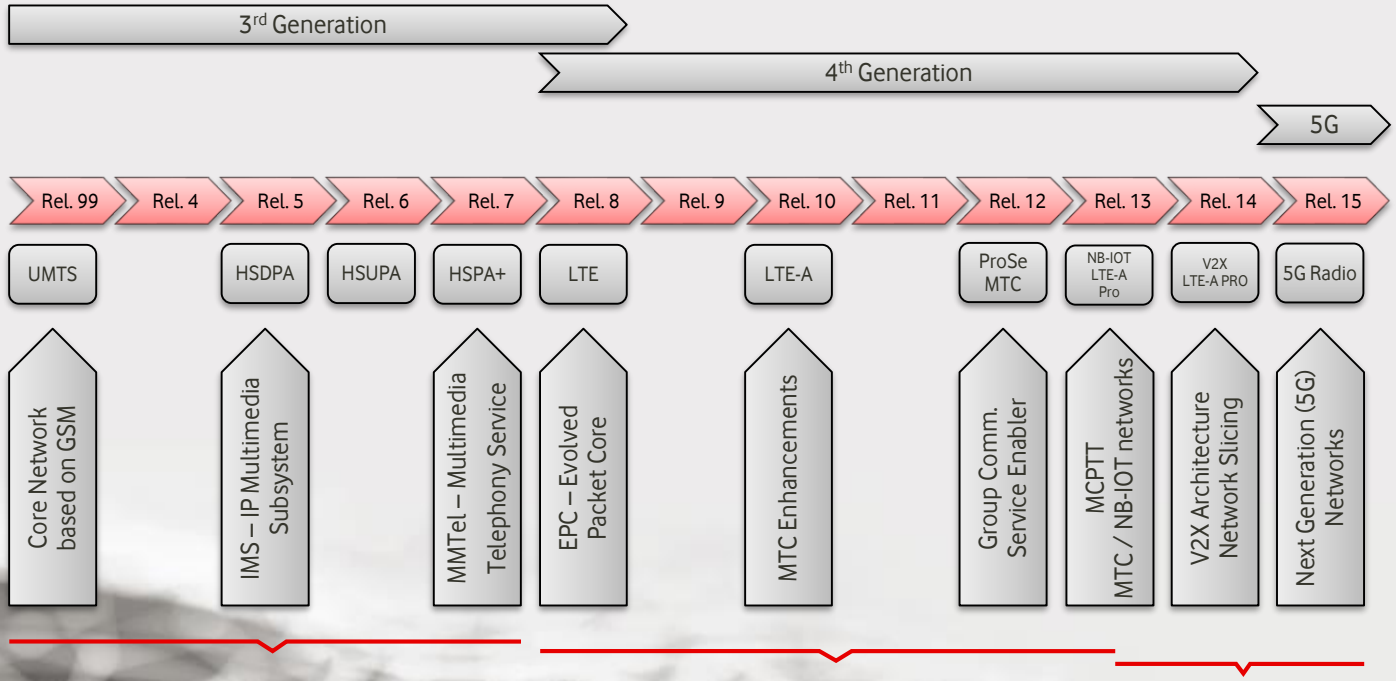
Dennis Lemberg B. Eng.
Network Planning Engineer
MESN & IP Planning

Vodafone GmbH
Kammerstück 17
44357 Dortmund
+49 172 5608155
dennis.lemberg@vodafone.com
vodafone.de

Dipl.- Ing.(FH) Andreas Burk
Gruppenleiter MESN & IP Planning

Vodafone GmbH,
Düsseldorfer Str. 15,
65760 Eschborn
+49 152 2269 5741
andreas.burk@vodafone.com
vodafone.de

History of System Architecture



5G | 5G Ready Network

- When should the 5G logo be shown?
- A survey and discussion among operator members of the 5G introduction project indicates that four configurations should be supported for deciding when to present a 5G logo.
- The configuration are presented from most restrictive to most relaxed configuration.
- Adoption is decided according to operator and regional regulatory requirement.

State	Config. A	Config. B	Config. C	Config. D
1 (IDLE under or Connected to LTE cell not supporting NSA)	4G	4G	4G	4G
2 (IDLE under or Connected to LTE cell supporting NSA and no detection of NR coverage)	4G	4G	4G	5G
3 (Connected to LTE only under LTE cell supporting NSA and detection of NR coverage)	4G	4G	5G	5G
4 (IDLE under LTE cell supporting NSA and detection of NR coverage)	4G	5G	5G	5G
5 (Connected to LTE + NR under LTE cell supporting NSA)	5G	5G	5G	5G
6 (IDLE under or connected to NG-RAN while attached to 5GC)	5G	5G	5G	5G

Source: 3GPP RP-172168

Latency | What is latency - Propagation delay as function of distance

$$T_{\text{prop delay}} = \frac{l}{c_0 \mu}$$

l = length in km
c_0 = speed of light
μ = refractive index