5G Overview and predictive Analysis for Latency Optimized Telecommunication Networks

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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

- 300,000+ mobile sites
- 1m+ km of Fibre
- 99m Next-Gen Access homes passed
- 500m customers
- 4bn minutes per day
- 14 petabyte mobile traffic/day
- 30,000 Technology employees in 30 countries
- 273 IP-VPN points of presence in 75 countries
Road to 5G
Evolution of wireless networks

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

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

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

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

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

Main focus of current wireless networks is voice and data.

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

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

Enhancement of Vehicle-to Everything (V2x)
- Autonomous Driving
- safety and non-safety aspects associated with vehicle

Massive Machine Type Communications
- Subway / Station Service
- eHealth
- Wearables
- Inventory Control

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

Source: 3GPP TR 22.891
5G stands for huge capacity, ultra low latency as well as reliability by network slicing.

- **Capacity**
  - >10 Gbps: Peak data rate (theoretical maximum)
  - 0.1 – 1 Gbps: End user experienced data rate
  - 10-100 Mbps/m²: Area traffic capacity

- **Latency**
  - 1 millisecond: End-to-end round trip delay (latency)

- **Slicing**
  - Advanced areas of application: e.g. Robotics, virtual reality, smart cities
  - Edge computing: Applications moved into the network
  - Individual network slices: Enabling of new services and opportunities
  - Customer individual networks: Characteristics based on specific needs
5G comes in multiple releases
5G | Network Architecture Evolution: 4G → 5G

Source: www.netmanias.com
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)
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.

So unterscheidet 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 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.
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 the 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
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
5G capacity gains driven by combination of Active Antenna & huge amount of spectrum

Schematic view on Active Antenna

- Active Antenna
- Dedicated beam per active user or user group
- Beam forming

Vodafone Active Antenna trial results

<table>
<thead>
<tr>
<th>LTE 2x2 MIMO (FDD)</th>
<th>LTE Active Antenna (TDD)</th>
<th>NR Active Antenna (TDD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>150 Mbps</td>
<td>684 Mbps</td>
<td>75 MHz Downlink</td>
</tr>
<tr>
<td>15 MHz Downlink</td>
<td>15 MHz Downlink</td>
<td>75 MHz Downlink</td>
</tr>
<tr>
<td>Downlink + Uplink = 30 MHz</td>
<td>Downlink + Uplink = 20 MHz**</td>
<td>Downlink + Uplink = 100 MHz*</td>
</tr>
<tr>
<td>~4.5 times capacity gain</td>
<td>5 times capacity gain</td>
<td>~3.4 Gbps</td>
</tr>
</tbody>
</table>

- **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
  - 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.
5G Key Technical Dimensions

- Capacity / Speed
- Slicing
- Latency
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

- Mobile Broadband Slice: Well-Known-Business - Hardware+Connectivity
- Massive IoT Slice: Internet of Everything - Products and Solutions (e.g., low cost asset tracking)
- Critical IoT Slice: Ultra Low latency solutions and products with mobile edge cloud.
- Bespoke Slice: Customer individual slice with individual network parameters.

Network Slice Selection Function (NSSF)
Slicing | E2E Network Slice example: Vodafone LTE V2X
5G Key Technical Dimensions

- CAPACITY / SPEED
- SLICING
- LATENCY
• Latency is basically the time it takes for a message, or packet, to travel from point of origin to the point of destination.

• There are many of contributing components for the overall latency:

\[ \text{Latency} = \sum \{ \text{transmission delay}^{1), \text{propagation delay}^{2), \text{processing delay}^{3), \text{queuing delay}^{4)} \} \]
The transmission / serialization delay decrease if the interface bandwidth will be increased.

Basic assumptions:

Ideal source is sending 1250 Byte (10,000Bit) to a receiver at a distance

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

With increasing 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 shortened.
### Latency | Air interface and transport evolution as enabler for ultra low latency

<table>
<thead>
<tr>
<th>Air interface Evolution</th>
<th>Transport Evolution**</th>
<th>Total latency**</th>
</tr>
</thead>
<tbody>
<tr>
<td>4G</td>
<td>LTE</td>
<td>15-20 ms</td>
</tr>
<tr>
<td>4G Evo</td>
<td>LTE Advanced</td>
<td>1-8 ms</td>
</tr>
<tr>
<td>5G</td>
<td>New Radio</td>
<td>1-2 ms</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*MEC = Mobile Edge Computing  ** Transport latency for 5G are estimations
The Planning Tool "Networks"

Predictive latency calculation
What is it used for?

- **Analysis**
  - graphic and table view

- **Calculation**
  - macro for automatic tasks

- **Evolution**
  - high level design network
• **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
Die Berechnung der Latenz basiert auf einer Auswertung der Abhängigkeiten (Routing/Führung) über alle Netzschichten hinweg.

**Routing Stack**
- 4G Network (LTE)
- Packet-based Network (IP/MPLS)
- Eth/WDM Transport Network
- Fiber Network

**Algorithmus**
- Entfernungsberechnung auf Basis des Routing aller darunter liegender Schichten
  - Summe Knotendelay am S1-Interface
  - Summe Routingentfernung am S1-Interface
  - Berechnung der Latenz aus Transitnoten 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**

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Router Analysis

- If there is a Router with Display=MARKED, traffic marks for those nodes will be generated.
- If no Router are marked, full traffic mark will be generated (fallback).

**Graphical Interface:***

- **Options and Parameters:**
  - Edge Group: IP-LOG-LINK
  - Define Potential Connections
  - Use Existing Weights/Lengths
  - Write Lengths of the Created Edges in km
  - Write Existing Value for New Edges
  - Write Common Value for Existing Edges

- **Node Groups:**
  - Node Group 1: SYSTEM-POINT
  - Node Group 2: SYSTEM-POINT
  - Selection: Functions (IP-Router)
  - Parameters: Functions (CE-Router, PE-Router)
<table>
<thead>
<tr>
<th>ID</th>
<th>Region</th>
<th>SecGW</th>
<th>S-GW</th>
<th>Komplett Access</th>
<th>MPS/POS ↔ SecGW</th>
<th>SecGW ↔ S-GW</th>
</tr>
</thead>
<tbody>
<tr>
<td>eNodeB 1</td>
<td>Region 1</td>
<td>SecGW 1</td>
<td>S-GW 1</td>
<td>3.727.89</td>
<td>335.10</td>
<td>3.159.05</td>
</tr>
</tbody>
</table>

**Vodafone NETWORKS Mobile**

**Latency Analysis**

- eNodeB by Latency:
  - 0 ... 3 ms
  - 3 ... 4 ms
  - 4 ... 5 ms
  - 5 ... 5.75 ms
  - 5.75 ... 6.5 ms
  - 6.5 ... 7.25 ms
  - 7.25 ... 8 ms
  - 8 ... 10 ms
  - 10 ... 15 ms
  - 15 ... 25 ms
  - 25 ... 1000 ms
  - invalid
• 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 exact copy of the new E2E Route
  – 2) build your route with partial DWDM routes
• What is the impact for one router rehoming?
  
  – 1) Find an IP-Route which is an exact copy of the new E2E Route

<table>
<thead>
<tr>
<th>route</th>
<th>start location</th>
<th>destination location</th>
<th>latency (µs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>routing 1</td>
<td>router</td>
<td>core</td>
<td>2013,44</td>
</tr>
<tr>
<td>routing 2</td>
<td>router</td>
<td>core</td>
<td>4441,61</td>
</tr>
</tbody>
</table>

  – 2) build your route with partial DWDM routes

<table>
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<th>start location</th>
<th>destination location</th>
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<tr>
<td>routing 1</td>
<td>router</td>
<td>core</td>
<td>2013,44</td>
</tr>
<tr>
<td>routing 2 part 1</td>
<td>router</td>
<td>1st DWDM Hop</td>
<td>3179,3</td>
</tr>
<tr>
<td>routing 2 part 2</td>
<td>1st DWDM Hop</td>
<td>2nd DWDM Hop</td>
<td>871,9</td>
</tr>
<tr>
<td>routing 2 part 3</td>
<td>2nd DWDM Hop</td>
<td>core</td>
<td>319,9</td>
</tr>
<tr>
<td>routing 2</td>
<td>router</td>
<td>core</td>
<td>4371,1</td>
</tr>
</tbody>
</table>

Rehoming is not an option
• Through the embedded predictive latency analysis in networks Vodafone is able to plan a cost optimized network solution during the planning stage.
• Furthermore planned changes in the network design can be investigated in advance 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...

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History of System Architecture

3rd Generation

4th Generation

5G

Rel. 99
Rel. 4
Rel. 5
Rel. 6
Rel. 7
Rel. 8
Rel. 9
Rel. 10
Rel. 11
Rel. 12
Rel. 13
Rel. 14
Rel. 15

UMTS
HSDPA
HSUPA
HSPA+
LTE
LTE-A
ProSe
MTC
LTE-A Pro
NB-IOT
V2X
LTE-A PRO
5G Radio

Core Network based on GSM
IMS – IP Multimedia Subsystem
MMTel – Multimedia Telephony Service
EPC – Evolved Packet Core
MTC Enhancements
Group Comm. Service Enabler
MCPTT
MTC / NB-IOT Networks
V2X Architecture Network Slicing
Next Generation (5G) Networks
• 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.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (IDLE under or Connected to LTE cell not supporting NSA)</td>
<td>4G</td>
<td>4G</td>
<td>4G</td>
<td>4G</td>
</tr>
<tr>
<td>2 (IDLE under or Connected to LTE cell supporting NSA and no detection of NR coverage)</td>
<td>4G</td>
<td>4G</td>
<td>4G</td>
<td>5G</td>
</tr>
<tr>
<td>3 (Connected to LTE only under LTE cell supporting NSA and detection of NR coverage)</td>
<td>4G</td>
<td>4G</td>
<td>5G</td>
<td>5G</td>
</tr>
<tr>
<td>4 (IDLE under LTE cell supporting NSA and detection of NR coverage)</td>
<td>4G</td>
<td>5G</td>
<td>5G</td>
<td>5G</td>
</tr>
<tr>
<td>5 (Connected to LTE + NR under LTE cell supporting NSA)</td>
<td>5G</td>
<td>5G</td>
<td>5G</td>
<td>5G</td>
</tr>
<tr>
<td>6 (IDLE under or connected to NG-RAN while attached to 5GC)</td>
<td>5G</td>
<td>5G</td>
<td>5G</td>
<td>5G</td>
</tr>
</tbody>
</table>

Source: 3GPP RP-172168
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
\( \mu \) = refractive index