Integrating a Broadcast Layer into Cellular Networks – from TOoL+ to FeMBMS

München, 9 May 2019

Structure of my presentation

1. TV on your SmartPhone? Predictions and facts
2. 5G will be there to solve any possible problem
3. Tower Overlay over LTE-A+ (TOoL+): our invention to assist 5G
4. TOoL+ became FeMBMS – results from our measurements here in Bayern
5. Conclusion
The CISCO Visual Networking Index presents a prognosis of the global data traffic over cellular networks (latest version: February 2019)

Cellular networks become video networks – a future they were not designed for.

Cisco: "Video usage tends to occur during evening hours and has a "prime time," unlike general web usage that occurs throughout the day. As a result, more video usage means more traffic during the peak hours of the day."

1 Exabyte = 1000 * 1000 * 1000 GByte, $10^{18}$ Byte

No, cellular networks don’t stand alone
Modern **SmartPhones** and **Tablet-PCs** are the reason for the data avalanche

This iPhone X offers a display resolution of **2436 pixel * 1125 pixel** – which is more than the HDTV-resolution of **1920 pixel * 1080 pixel**

Source: [www.Telekom.de](http://www.Telekom.de), 5 Nov. 2017

---

**The first foldable SmartPhones** were presented at the Mobile World Congress 2019 this year – obviously made for video fanatics
We all experience that SmartPhones are in nearly everybody’s pocket: **Smartphone users in Germany** (total population: 82.2 Mio.)

Let us assume, **people watch TV on their SmartPhones**: What would be the data rate required?

- A first conclusion: Mobile user terminals incorporate ever more powerful hard- and software as well as high-quality displays and are perfectly usable as „personal video terminals“. This is true for SmartPhones and for Tablet PCs

- And what about the **data rate** required for adequate video quality? Assuming the use of the video coding standard **HEVC**, we calculate that the data rate required for an adequate video quality on a Tablet PC or a high-quality Smartphone is approximately **1.3 Mbit/s** (1 Mbit/s for video)

- If a person would watch TV on his Tablet PC or Smartphone for **221 minutes per day** (this number represents the TV consumption of an average German person below 60) this would result in **2.2 GByte/day**. Even if the person would watch just one hour per day, the result would be **0.597 GByte/day**. Today’s average Smartphone user in Germany consumes **0.5 GByte/month**!
Structure of my presentation

1. TV on your Smartphone? Predictions and facts
2. 5G will be there to solve any possible problem
3. Tower Overlay over LTE-A+ (TOoL+): our invention to assist 5G
4. TOoL+ became FeMBMS – results from our measurements here in Bayern
5. Conclusion

5G: What are we talking about?
The vision of one of the vendors

5G targets a large number of applications—from mobile broadband to narrowband connections for Machine to Machine (M2M) or the Internet of Things (IOT)

Source: http://networks.nokia.com/file/28771/5g-white-paper
Available frequencies for the **current spectrum auction** in Germany

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Available Channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 GHz</td>
<td>paired</td>
</tr>
<tr>
<td>3.6 GHz</td>
<td></td>
</tr>
</tbody>
</table>

The German regulator requires significant commitment from participants of the auction: By the end of 2022 at least 100 Mbit/s (aggregate downlink data rate per cell or sector) are to be provided to:

- At least 98% of the homes per Bundesland (regional state),
- All Autobahns, the most significant federal highways, and to the most important railway lines

By the end of 2024 additional requirements are to be met.

In addition each network operator is required to build by the end of 2022 1,000 „5G base stations“, and 500 „5G base stations in „white spots“

---

The result of the frequency auction as of **30 April 2019** (after round 270)

- The German regulator had accepted the companies Drillisch Netz AG, Telefónica Germany GmbH & Co. OHG, Telekom Deutschland GmbH, and Vodafone GmbH

Das letzte Rundenresultat für den 30. April 2019 ist Runde 270.

Frequenzauktion 2019

**Ergebnis der Runde 270**

| Summe | 5.609.590.000 € |

- If you look at the detailed results you will notice: frequencies in the 2 GHz range (2 x 5 MHz) cost app. 211 Mio. €, frequencies in the 3.5 GHz range (1 x 10 MHz) cost app. 110 Mio. €
Why do the higher frequencies cost less?

- The free space attenuation of an electromagnetic wave depends on the frequency
- The first cellular networks in Germany use the 900 MHz frequency range (Telekom „D1“, Vodafone „D2“)
- Now we talk about 3.4 GHz (3400 MHz / 3800 MHz), which is approximately four times 900 MHz
- The free space attenuation grows with the square of the frequency

\[ F = \left( \frac{4\pi r \cdot f}{c} \right)^2 \]

- This results in a factor of 14.3 in comparison to F (900 MHz)
- And the uplink power allowed in a terminal device is limited (SAR limited). What most people forget: If the uplink doesn’t reach the base station, then the device is not connected
- So the density of the base stations needs to increase

As early as 2010 we generated practical experience in a WiMAX-Pilot Trial Niedersachsen operating at 3.5GHz (and we used 800 MHz as a reference)

Base station

Homes covered – yes, only these few

Measurement receiver
The significant difference between 800 MHz and 3.5 GHz were proven by simulation and through measurements during the pilot trial.

The difference between 800 MHz and 3.5 GHz were proven by simulation and through measurements during the pilot trial.

In order to explain the difference, let’s use the following example: At a distance to the base station of 600m, the path loss at 800 MHz is 20 dB smaller, in comparison to that at 3.5 GHz. By the way: We measured in winter and summer to identify the effect of leaves on the trees etc....

What kind of cell radius in a cellular 3.5 GHz network can be driven from our results?

- In order to be able to calculate concrete numbers, the signal format used needs to be defined (the Modulation and Coding Scheme). We chose:
  - MCS 15 (64 QAM) in the downlink which provides a gross data rate of 46.6 Mbit/s brutto in 2x10 MHz using a SISO-Link, and we require a coverage probability at the cell edge of 95%. The result

<table>
<thead>
<tr>
<th>Frequency in MHz</th>
<th>Urban</th>
<th>Suburbia</th>
<th>Rural, flat</th>
<th>Rural, hilly</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>553</td>
<td>1063</td>
<td>2043</td>
<td>1573</td>
</tr>
<tr>
<td>3500</td>
<td>137</td>
<td>264</td>
<td>507</td>
<td>390</td>
</tr>
</tbody>
</table>

This amounts to 1.3 base stations per km². If my Bundesland (Niedersachen) was completely rural flat, each network operator would need to install 61,000 base stations in order to achieve an area coverage of 100%.
The investment in 5G networks (after the cost of the auction has been covered) is not going to be a problem, right?

In its annual report 2017, the German regulator published the following diagram:

Turnover per SIM card per month:

<table>
<thead>
<tr>
<th>Year</th>
<th>Turnover</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>13.8 €</td>
</tr>
<tr>
<td>2013</td>
<td>13.8 €</td>
</tr>
<tr>
<td>2014</td>
<td>13.5 €</td>
</tr>
<tr>
<td>2015</td>
<td>13.6 €</td>
</tr>
<tr>
<td>2016</td>
<td>12.8 €</td>
</tr>
<tr>
<td>2017</td>
<td>13.8 €</td>
</tr>
</tbody>
</table>

- 14%, without taking inflation into account

Structure of my presentation

1. TV on your Smartphone? Predictions and facts
2. 5G will be there to solve any possible problem
3. Tower Overlay over LTE-A+ (TOoL+): our invention to assist 5G
4. TOoL+ became FeMBMS – results from our measurements here in Bayern
5. Conclusion
Our reasoning behind **TOoL+ (Tower Overlay over LTE-A+)**

- If video on the SmartPhone becomes more and more important
- If the whole world wishes to watch popular programmes such as sports etc. live (see the „prime time prediction“ by CISCO)
- If this requires thousands of cells in the various cellular networks to provide identical live content
- If on the other hand a perfect area coverage with these cells is not economically feasible

Then:
- It is perfectly reasonable to offload popular and live video content from the individual cells
- This is how I arrived at the idea of a „Tower Overlay“ over the cells of cellular networks. Fundamentally this defines broadcast to SmartPhones and Tablets – without them needing „non-3GPP-frontends“
- We started our research using LTE (4G) as the 3GPP-layer in the Tower Overlay and embedded it in a DVB-T2 transmission
- In the next step we discarded DVB-T2 and this led to a predecessor of FeMBMS
- Currently, our research concentrates on a Tower Overlay over 5G New Radio (NR) (TOo5G)

---

**Tower Overlay over LTE-A+ (TOoL+): The concept**

- The overlay becomes part of the LTE-A+ network by means of LTE-A+ carrier aggregation to ensure simultaneous provision of unicast, eMBMS, and broadcast services

- The LTE-A+ SmartPhone or Tablet does not have to be equipped with a broadcast frontend to receive the signal

![Diagram of Tower Overlay over LTE-A+](image-url)
We implemented TOoL+ using our „IfN Generic Software Defined Radio Toolkit (IGST)”

The research center of Radio Italiana has tested it in Italy.
In this LTE network 195 sectors are **momentarily** used for unicast (red) and some in addition for eMBMS (blue).

Shown is a snapshot of the live demonstration of a network in Hannover, Germany. A number of users have requested the same HD video. Many LTE cells are momentarily overloaded – despite the presence of eMBMS.

At this moment the **Tower Overlay** (yellow) was added. eMBMS could be switched off.

There are no more overloaded cells. There are still users served via unicast since the Tower Overlay does not reach everybody deep indoor.
A numeric result: requested Mbit/s not served by the networks as a function of the percentage of users requesting a HD video

Data requested and not served

Bundespräsident Joachim Gauck awarded TOoL+ the title „Location of Excellence 2015“
Structure of my presentation

1. TV on your SmartPhone? Predictions and facts
2. 5G will be there to solve any possible problem
3. Tower Overlay over LTE-A+ (TOoL+): our invention to assist 5G
4. TOoL+ became FeMBMS – results from our measurements here in Bayern
5. Conclusion

FeMBMS – an overview

- In March 2017, 3GPP release 14 was published, now specifying a „Further evolved Multimedia Broadcast Multicast Service“ (FeMBMS). Some use the term “5G broadcast” for the system.

- Important additions to the LTE physical layer were introduced:
  - Definition of a dedicated broadcast mode
  - Definition of a new subcarrier spacing (1.25 kHz) providing longer cyclic prefixes of up to 200 µs

- Other additions tackle the service layer, e.g.
  - the pass-through of broadcast data (transparent delivery mode)
  - extended signaling messages
  - support for receiver only devices (receive only mode)
  - free-to-air broadcast
From TOoL+ to its step-sister FeMBMS

- Due to the fact that FeMBMS is so close to TOoL+, we were able to implement the physical layer rapidly – using our IfN Generic Software Defined Radio Toolkit (IGST)

- Together with partners we are trialing FeMBS services in various countries as we speak

- In parallel we are evaluating the performance of FeMBMS in a variety of network configurations again using SiMONE, and here in Bayern

Excerpt from a EBU press release for the European Championships 2018 (31 July 2018)

“RAI Research & Innovation, in cooperation with the Technische Universität Braunschweig, Germany, will demonstrate a stand-alone precursor of 5G broadcast technology deployed on high-power terrestrial broadcast infrastructure. The demonstration is implemented on RAI’s open test network in the Aosta Valley, Italy, which allows up to five broadcast transmitters to operate in a single-frequency-network configuration. Live TV broadcast from the European Championships will be delivered to mobile devices in low and high mobility situations.”
We tested FeMBMS already here in the Munich area during test drives with our measurement receiver: The input power levels

![Map showing transmitters in operation](image1)

Only the transmitter Wendelstein (54 km southeast of this map) is in operation.

![Map showing both transmitters](image2)

Both transmitters Ismaning (as shown) and Wendelstein are in operation.

As predicted*: the short cyclic prefix in the Cell Acquisition Subframe (CAS) results in a performance decrease in an SFN mode.

![Graph showing performance decrease](image3)

PMCH Dataset A (1 TX)  
PBCH Dataset A (1 TX)  
PMCH Dataset B (2 TX)  
PBCH Dataset B (2 TX)

PBCH includes the CAS, PMCH the payload.

*A Richter, L; Ilsen, S: Coverage Evaluation of LTE FeMBMS: A Case Study Based on a DVB-T2 Network. IEEE BMSB 2018

A paper analyzing details, incl. the effect on echo channels will be presented at IEEE BMSB in June.
Conclusion „5G broadcast is FeMBMS“

- I am convinced that with the advent of DVB-T2 (and ATSC 3.0) terrestrial broadcast standards have reached „performance saturation“
- Video consumption on SmartPhones and Tablet PCs is real
- Broadcast frontends in these devices don’t happen (If there was a global standard for terrestrial TV broadcast…)
- LTE-A is a fabulous system, but large scale deployments of eMBMS were never realized
- 5G will undoubtedly be a multi-layer system
- With TOoL+ we have been offering a new layer over LTE networks – a High Power High Tower (HPHT) overlay broadcast network
- TOoL+ works in reality
- The reasoning behind TOoL+ has found its way into 3GPP as FeMBMS (Further evolved Multimedia Broadcast Multicast Service) included in Release 14
- Minister Herrmann pushed the red button this morning – and „5G broadcast“ is now officially on air here in Bayern. Performance evaluation is ongoing
- The next logical step will be a Tower Overlay over 5G (TOo5G)

Thank you very much for your interest and time!

Prof. Dr.-Ing. Ulrich Reimers
reimers@ifn.ing.tu-bs.de