



THE GREAT 2020 MOBILE NETWORK TEST



Together with our longtime network testing partner umlaut we have investigated in the 26th year which mobile operators and mobile networks lead the field in Germany, Austria and Switzerland.

Even in the 26th year of our mobile network tests there is much news to report. It starts with our network testing partner who was formerly known under the name P3 communications, but now has repositioned its business and will henceforth operate under the name umlaut. Of course, this does not change anything regarding its unrestricted competence and neutrality. Maybe the new situation even still enhances these virtues: According to its new motto “to always put something on top”, umlaut’s network testing teams couldn’t resist the opportunity to also perform first measurements in the new 5G networks. You can read about their findings from page 20 on.

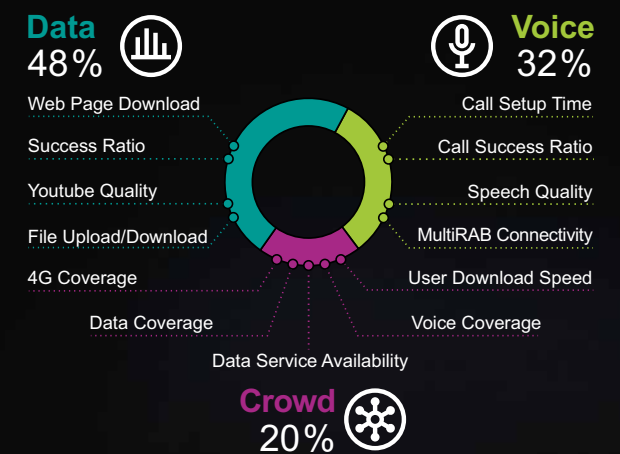
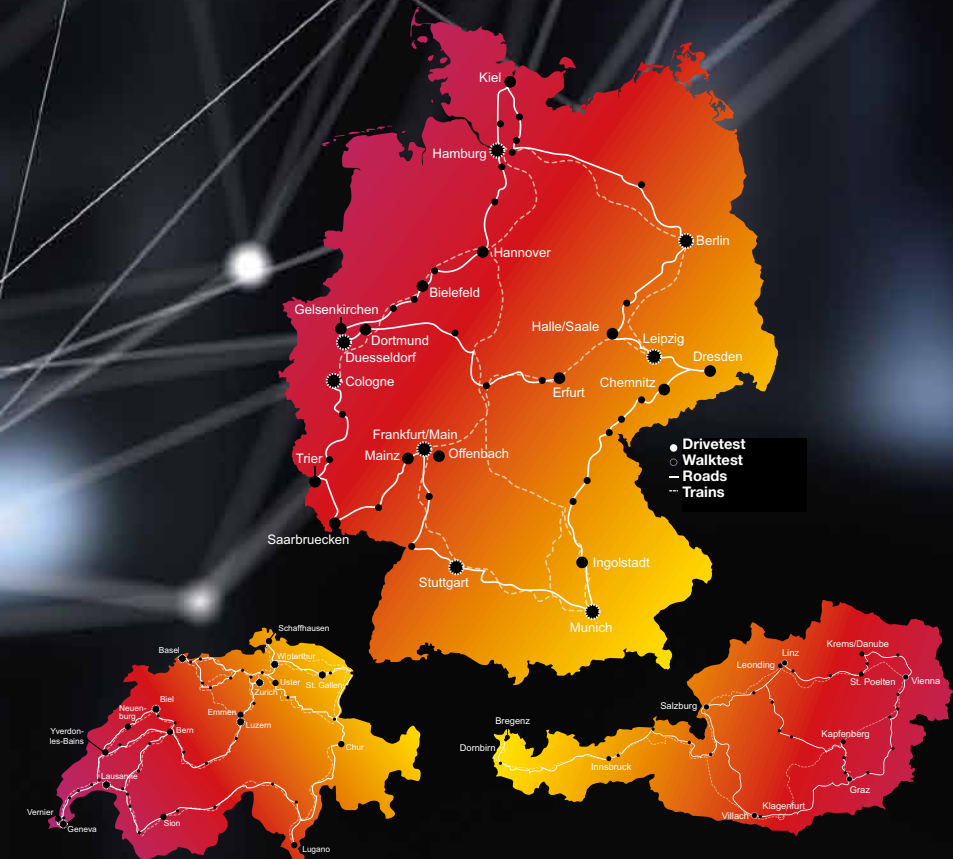
But there is more: We further refined our crowdsourcing methodology, which we had included into our assessments for the first time last year – now making it even more significant. Crowdsourcing complements the results of our drivetests and walktests with long-term observations from a large number of mobile communications users.

Refined Crowdsourcing Results
With our latest refinements to the crowdsourcing aggregations, we now also include uploads into our data throughput assessments. Furthermore, we also made the descriptions about coverage more granular and meaningful (for details please see “Methodology” on pages 16/17).

What did not change was the great effort which we put into the gathering of our results and the safeguarding of its statistical relevance. The key figures presented below notably prove this once again this year.

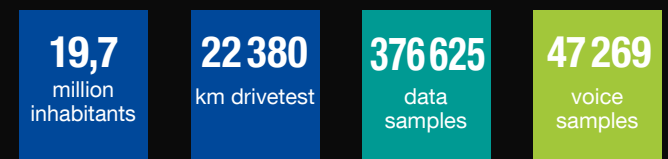
Yet, this effort definitely pays dividends as our relevance is confirmed each and every year by the operator’s reactions. Regardless whether they won or lost – each of them makes quite clear that they attach much greater importance to our sophisticated evaluations than to the growing number of other parties’ attempts to gain attention in the marketplace with their own flavours of “network tests”.

Hannes Rügheimer



A 360 degree view at network quality
As part of our constant advancement of our testing methodology, we have increased the share of our refined crowdsourcing results in the total result to 20 percent. The weighting of the voice and data measurements reflects that data communications plays a more important role than telephony today for many users. But in those cases when it is needed, the latter function still does have to be available without any limitations.

DRIVETESTS AND WALKTESTS



CROWDSOURCING



Indicated are the combined values for Germany, Austria and Switzerland. See the separate values per country under „Methodology“ on pages 16/17.

Germany

Voice

The quality of mobile voice telephony incorporates 32 percent of our total score. Indeed, telephony nowadays is only one of many smartphone applications – but when it is needed, it has to work.

► For a couple of years now, the German mobile networks have supported VoLTE (“Voice over LTE”). Thus, they do not have to switch back to 3G or 2G in order to make a phone call. Instead they transport the voice information contained in data packets via LTE.

The improvements gained with this technology can be clearly seen in the measurement values of our drivetests and walktests: Call setup times in the Telekom and Vodafone networks are on average significantly below 2 seconds. In the Telefónica/O2 network, the determined average values also stay comfortably short – ranging

between 2.2 seconds (walktests in bigger cities) and 2.6 seconds (drivetests in smaller towns).

The measured voice quality is also impressive: Average MOS values between 4.4 and 4.5 mark high-quality connections, which are realized in many cases via the higher bandwidth EVS codec (Enhanced Voice Services).

MultiRAB Connectivity, which we measured for the first time in 2019, states whether a smartphone can hold contact to more than one “Radio Access Bearers” during telephony – practically handling data communication

| Operator | Telekom | Vodafone | Telefónica |
|----------------------------------|---------|----------|------------|
| Voice Cities (Drivetest) | | | |
| Call Success Ratio (%) | 99.3 | 99.0 | 98.4 |
| Call Setup Time Ø (s) / P90 (s) | 1.5/1.8 | 1.5/2.0 | 2.3/2.6 |
| Speech Quality Ø / P10 (MOS-LQO) | 4.6/4.3 | 4.5/4.2 | 4.5/3.9 |
| MultiRAB Connectivity (%) | 99.0 | 99.6 | 99.0 |
| Voice Cities (Walktest) | | | |
| Call Success Ratio (%) | 99.6 | 99.4 | 99.1 |
| Call Setup Time Ø (s) / P90 (s) | 1.5/1.8 | 1.4/1.9 | 2.2/2.5 |
| Speech Quality Ø / P10 (MOS-LQO) | 4.6/4.5 | 4.6/4.5 | 4.6/4.3 |
| MultiRAB Connectivity (%) | 99.7 | 99.3 | 99.8 |
| Voice Towns (Drivetest) | | | |
| Call Success Ratio (%) | 99.6 | 98.9 | 97.7 |
| Call Setup Time Ø (s) / P90 (s) | 1.5/1.8 | 1.5/2.1 | 2.6/4.0 |
| Speech Quality Ø / P10 (MOS-LQO) | 4.6/4.3 | 4.5/4.2 | 4.3/3.4 |
| MultiRAB Connectivity (%) | 99.8 | 98.8 | 97.9 |
| Voice Roads (Drivetest) | | | |
| Call Success Ratio (%) | 99.5 | 98.2 | 94.3 |
| Call Setup Time Ø (s) / P90 (s) | 1.6/1.9 | 1.6/2.2 | 2.7/4.9 |
| Speech Quality Ø / P10 (MOS-LQO) | 4.5/4.1 | 4.4/3.8 | 4.3/3.2 |
| MultiRAB Connectivity (%) | 99.3 | 95.1 | 91.2 |
| Voice Trains (Walktest) | | | |
| Call Success Ratio (%) | 94.3 | 94.4 | 87.8 |
| Call Setup Time Ø (s) / P90 (s) | 1.8/2.1 | 1.8/2.4 | 2.8/4.9 |
| Speech Quality Ø / P10 (MOS-LQO) | 4.3/3.4 | 4.4/3.6 | 4.1/3.0 |
| MultiRAB Connectivity (%) | 99.6 | 98.1 | 93.3 |

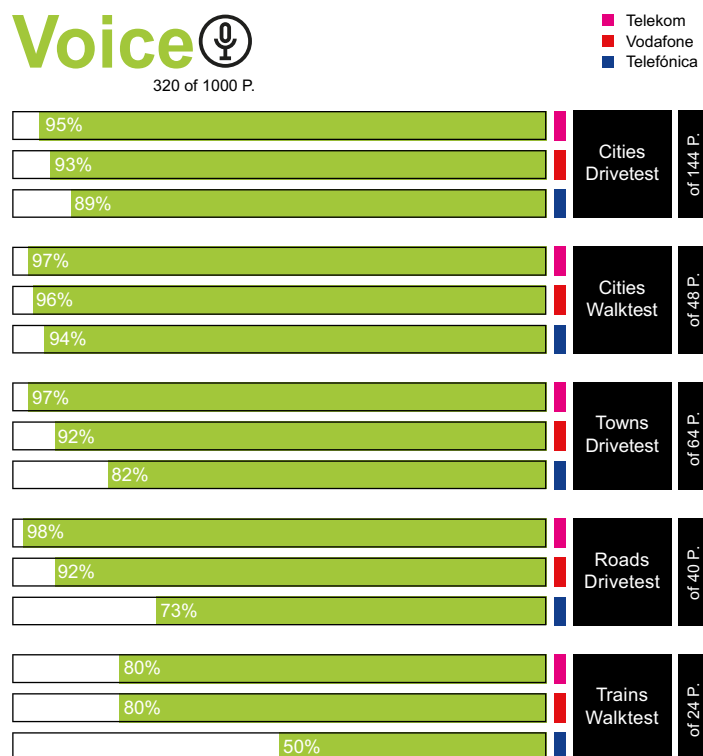


at the same time. The success rates determined for this feature are also overall very good.

Improvements at O2

The operator Telefónica or O2 respectively, which was busy in the last years with the ongoing merging of its formerly own network infrastructure

with the one of E-Plus, shows clear signs of progress: In the bigger cities, the operator can almost close the gap to the leading duo Telekom and Vodafone. In smaller towns and on the connecting roads, it still follows at some distance, but was able to improve its results here as well.



Data

Surfing the Web, conducting uploads and downloads or enjoying video streams – the measurement results from the data discipline incorporate 48 percent of the total score.

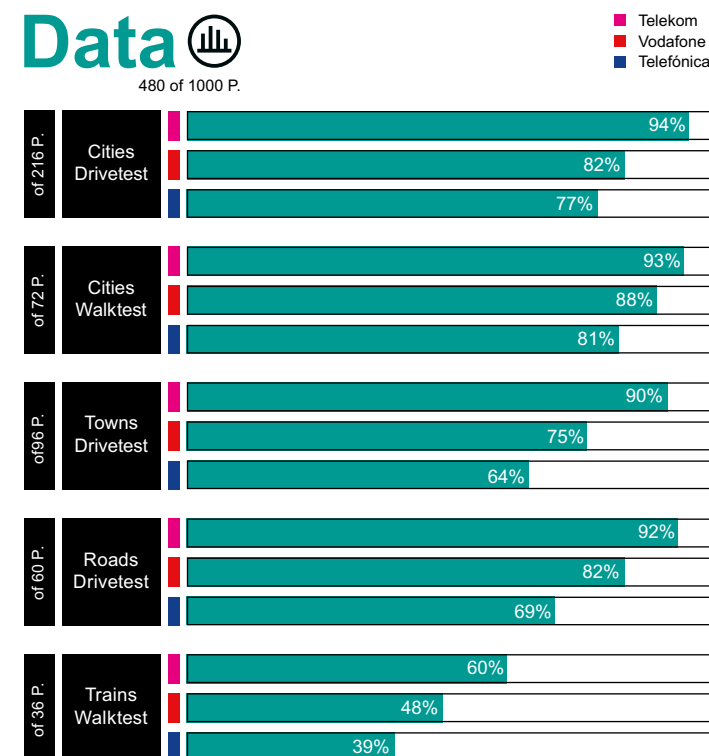
► This year’s ranking among the German operators can be clearly read from all data disciplines: Telekom leads, Vodafone follows at some distance, and Telefónica/O2 ranks third, again with some distance behind the second rank. Still, O2 managed to improve in some areas over its results from the previous year. In other areas it at least managed to keep its performance constant.

Telekom leads data discipline

This ranking is also valid for almost all applications – such as surfing the web, conducting downloads and uploads or playing back videos from Youtube. Especially mobile video playback in difficult scenarios illustrates where there are still deficits: For example, Vodafone only achieves success

ratios around 95 percent in the drivetests conducted in the cities – in other words: five percent of video requests stall. In smaller towns, this KPI sinks to 93 percent at Vodafone and to 92 percent at OS. Only Telekom manages to keep it constantly above 98 percent.

The download and upload measurements especially in the cities clearly show that all operators continue to extend the “carrier aggregation” in their networks. Vodafone and Telefónica/O2 combine up to four LTE carrier frequencies per connection, Telekom currently up to three. Thus, data rates at Telekom and Vodafone raise above 150 Mbps in the 10 percent of the fastest measurements. This may still leave room for improvement, but goes into the right direction.



| Operator | Telekom | Vodafone | Telefónica |
|------------------------------------|------------|------------|------------|
| Data (Cities; Drivetest) | | | |
| Web Page Download | | | |
| Success Ratio (%) | 99.7 | 99.2 | 98.6 |
| Total Session Time (s) | 1.0 | 1.1 | 1.2 |
| File Download (5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 99.9/1.7 | 99.7/3.3 | 99.5/4.5 |
| 90%/10% faster than (Mbps) | 17.5/90.3 | 5.6/84.2 | 3.9/70.5 |
| File Upload (2.5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 99.9/1.2 | 99.7/2.2 | 99.6/2.5 |
| 90%/10% faster than (Mbps) | 11.3/41.4 | 4.5/36.4 | 4.2/31.9 |
| File Download (7 seconds) | | | |
| Success Ratio (%) | 99.7 | 99.6 | 98.8 |
| Ø Throughput (Mbps) | 86.3 | 66.3 | 40.5 |
| 90%/10% faster than (Mbps) | 24.0/168.7 | 6.4/152.1 | 4.1/92.0 |
| File Upload (7 seconds) | | | |
| Success Ratio (%) | 99.5 | 99.3 | 98.9 |
| Ø Throughput (Mbps) | 37.8 | 22.4 | 21.5 |
| 90%/10% faster than (Mbps) | 12.7/58.6 | 4.9/50.8 | 4.1/44.2 |
| Youtube Videos | | | |
| Success Ratio/Start Time (%/s) | 98.9/1.0 | 95.2/1.2 | 94.4/1.4 |
| Ø Video Resolution (p) | 918 | 905 | 889 |
| Youtube Live | | | |
| Success Ratio/Start Time (%/s) | 98.7/1.3 | 95.4/1.4 | 94.5/1.6 |
| Ø Video Resolution (p) | 1038 | 1022 | 995 |
| Data (Cities; Walktest) | | | |
| Web Page Download | | | |
| Success Ratio (%) | 99.8 | 99.7 | 99.1 |
| Total Session Time (s) | 1.0 | 1.0 | 1.2 |
| File Download (5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 100.0/1.7 | 99.9/2.2 | 99.1/3.5 |
| 90%/10% faster than (Mbps) | 18.3/99.9 | 14.1/94.1 | 5.4/76.2 |
| File Upload (2.5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 99.7/1.3 | 99.6/1.8 | 99.1/1.9 |
| 90%/10% faster than (Mbps) | 11.3/41.4 | 6.1/38.8 | 6.1/34.5 |
| File Download (7 seconds) | | | |
| Success Ratio (%) | 99.9 | 99.9 | 99.1 |
| Ø Throughput (Mbps) | 85.5 | 78.7 | 52.9 |
| 90%/10% faster than (Mbps) | 21.2/173.3 | 15.0/165.6 | 6.1/119.7 |
| File Upload (7 seconds) | | | |
| Success Ratio (%) | 99.1 | 99.1 | 98.5 |
| Ø Throughput (Mbps) | 35.4 | 29.7 | 27.4 |
| 90%/10% faster than (Mbps) | 10.9/56.1 | 6.3/54.1 | 5.4/50.8 |
| Youtube Videos | | | |
| Success Ratio/Start Time (%/s) | 98.8/1.0 | 97.8/1.1 | 96.2/1.3 |
| Ø Video Resolution (p) | 916 | 910 | 898 |
| Youtube Live | | | |
| Success Ratio/Start Time (%/s) | 98.8/1.3 | 96.1/1.4 | 95.0/1.5 |
| Ø Video Resolution (p) | 1035 | 1031 | 1005 |
| Daten (Towns; Drivetest) | | | |
| Web Page Download | | | |
| Success Ratio (%) | 99.7 | 98.8 | 98.0 |
| Total Session Time (s) | 1.0 | 1.4 | 1.5 |
| File Download (5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 100.0/2.3 | 99.5/6.5 | 98.0/6.1 |
| 90%/10% faster than (Mbps) | 8.3/78.9 | 2.8/57.7 | 3.1/59.4 |
| File Upload (2.5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 99.8/1.7 | 100.0/2.4 | 99.0/4.3 |
| 90%/10% faster than (Mbps) | 6.2/37.9 | 4.4/25.3 | 1.7/25.1 |
| File Download (7 seconds) | | | |
| Success Ratio (%) | 99.5 | 98.1 | 97.4 |
| Ø Throughput (Mbps) | 62.3 | 26.9 | 30.2 |
| 90%/10% faster than (Mbps) | 15.3/118.3 | 3.2/74.0 | 3.3/78.9 |
| File Upload (7 seconds) | | | |
| Success Ratio (%) | 99.8 | 99.8 | 96.3 |
| Ø Throughput (Mbps) | 33.0 | 17.0 | 15.0 |
| 90%/10% faster than (Mbps) | 6.6/56.7 | 4.1/30.5 | 1.9/32.8 |
| Youtube Videos | | | |
| Success Ratio/Start Time (%/s) | 98.3/1.1 | 92.7/1.6 | 92.0/1.7 |
| Ø Video Resolution (p) | 913 | 876 | 853 |
| Youtube Live | | | |
| Success Ratio/Start Time (%/s) | 98.5/1.3 | 95.5/1.6 | 92.3/1.7 |
| Ø Video Resolution (p) | 1030 | 973 | 972 |

Connecting Roads

► The demands on data connectivity when driving on the roads have considerably risen in recent years – Internet-connected satnav system or streaming apps in on-board infotainment systems boost the expectations and requirements of the users. Traveling between the cities and towns considered in our benchmark (see map on page 4) umlaut's therefore captured the quality of data connections on a total of 6,300 kilometres of roads.

Clear ranking on the roads

The results of these measurements confirm the ranking which was already determined in the other data disciplines:

Telekom is clearly ahead, Vodafone follows in a good middle position and was able to increase its performance compared to last year. O2 keeps the third rank and basically maintains the level determined in the previous year.

This picture is constant for all investigated categories: We determined the highest success ratios and throughputs in the Telekom network, Vodafone follows at some distance and O2 ranks third with a still larger gap. Drivers looking for powerful mobile connections on the autobahn and on rural roads get on best with Telekom, according to our benchmark results.

Internet connectivity in the car becomes ever more important. What is the state of data connectivity on German roads in the year 2019?

| Operator | Telekom | Vodafone | Telefónica |
|------------------------------------|-----------|----------|------------|
| Data (Roads; Drivetest) | | | |
| Web Page Download | | | |
| Success Ratio (%) | 99.6 | 98.7 | 95.8 |
| Total Session Time (s) | 1.1 | 1.3 | 1.4 |
| File Download (5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 99.7/3.1 | 99.8/5.1 | 97.2/5.9 |
| 90%/10% faster than (Mbps) | 5.5/79.3 | 3.7/59.1 | 2.9/50.7 |
| File Upload (2.5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 99.7/2.1 | 99.2/2.7 | 96.8/4.1 |
| 90%/10% faster than (Mbps) | 5.4/36.4 | 3.8/25.0 | 2.1/24.6 |
| File Download (7 seconds) | | | |
| Success Ratio (%) | 99.9 | 97.8 | 96.0 |
| Ø Throughput (Mbps) | 49.0 | 31.1 | 23.4 |
| 90%/10% faster than (Mbps) | 7.6/118.3 | 3.3/82.1 | 3.2/54.8 |
| File Upload (7 seconds) | | | |
| Success Ratio (%) | 98.8 | 98.5 | 93.3 |
| Ø Throughput (Mbps) | 25.0 | 16.2 | 15.1 |
| 90%/10% faster than (Mbps) | 5.4/52.8 | 4.0/27.1 | 2.0/30.3 |
| Youtube Videos | | | |
| Success Ratio/Start Time (%/s) | 97.7/1.3 | 91.8/1.5 | 87.1/1.7 |
| Ø Video Resolution (p) | 906 | 880 | 862 |
| Youtube Live | | | |
| Success Ratio/Start Time (%/s) | 96.2/1.4 | 92.3/1.6 | 90.0/1.7 |
| Ø Video Resolution (p) | 1020 | 994 | 971 |

Crowd

The crowdsourcing shows the same ranking already familiar from the other categories. But in this discipline, Telefónica scores surprisingly high.

► We find the ranking determined in the previous categories once more in the overall crowdsourcing results: Telekom ranks first, Vodafone in the middle and Telefónica/O2 third.

Even for the stronger contenders Telekom and Vodafone, 4G coverage in the cities shows a certain room for improvement. It is even more pronounced at Telefónica/O2 and in this case also concerns data coverage (which includes the provisioning of 3G as well) in non-urban areas. It is however noteworthy that according to the crowdsourcing results, O2 customers experienced the highest download and also upload data rates in the cities.

The analysis of network stability during our six-month observation period identified one day with anomalies in the Telekom network, two such days at Telefónica and three at Vodafone. Keeping in mind that this observation spans over half a year, its result is however still tolerable.

| Operator | Telekom | Vodafone | Telefónica |
|---|---------|----------|------------|
| Crowd Country – Operational Excellence | | | |
| Number of degraded days (d) | 1 | 3 | 2 |
| Number of degraded hours (h) | 2 | 7 | 4 |
| Crowd urban | | | |
| Voice Coverage (%) | 99.4 | 99.3 | 99.5 |
| Data Coverage (%) | 98.2 | 98.1 | 97.9 |
| 4G Coverage (%) | 93.0 | 92.2 | 88.8 |
| Download data speed (Mbps) | 48.9 | 51.3 | 52.8 |
| Upload data speed (Mbps) | 7.9 | 11.9 | 16.7 |
| Crowd non-urban (Benchmark view) | | | |
| Voice Coverage (%) | 99.9 | 99.9 | 99.9 |
| Data Coverage (%) | 99.3 | 98.5 | 93.9 |
| 4G Coverage (%) | 99.1 | 97.9 | 85.1 |
| Download data speed (Mbps) | 24.3 | 23.2 | 23.2 |
| Upload data speed (Mbps) | 3.4 | 3.9 | 4.6 |
| Crowd non-urban (Own network view) | | | |
| Voice Coverage (%) | 99.9 | 99.9 | 99.9 |
| Data Coverage (%) | 99.1 | 98.3 | 92.9 |
| 4G Coverage (%) | 98.7 | 97.6 | 84.1 |
| Download data speed (Mbps) | 22.4 | 21.4 | 22.2 |
| Upload data speed (Mbps) | 3.2 | 3.5 | 4.0 |

Data on Railways

► The long-time problem child of our mobile benchmarks are connections in German long-distance trains. Although this did not essentially change much, our walktest teams still determined some improvements over the results from the previous year. This is quite distinct for voice telephony (see measurement values and results on page 4), but also for data communications.

Minor improvements, but still much to do

A direct comparison to the connectivity on the roads shows that there is still much need for improvements on the railways. Success ratios of 93

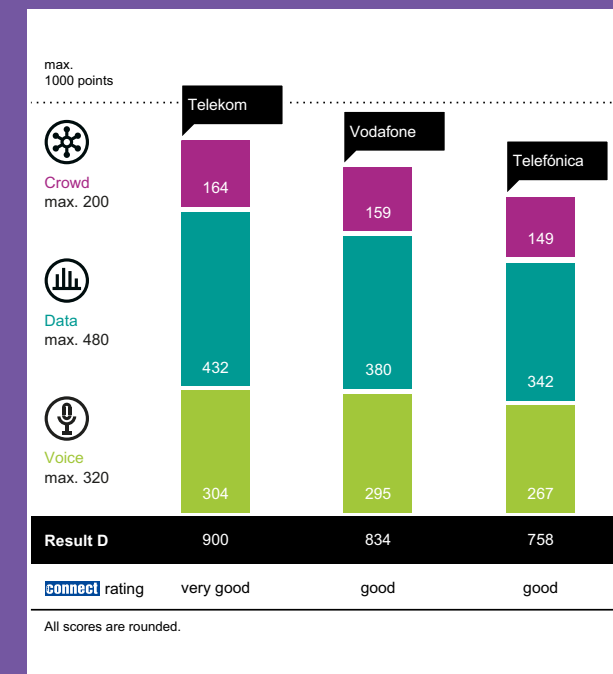
to 88 percent when trying to access a web page or to download a file give a clear indication of what travelers in the trains may expect when using their notebooks, tablets and smartphones – and what they should better not expect. Travelers who would even like to kill time with watching web videos, are bound to succeed with this endeavour only in 60 to 80 percent of the cases.

All lamenting aside, we still would like to acknowledge that the results and degrees of fulfillment went up for all three candidates compared to last year. We hope this trend continues for the customers of German railways.

Working on your notebook, tablet or smartphone while traveling via train – or just watching a Youtube video. How well does this actually work today? Our test results are disillusioning.

| Operator | Telekom | Vodafone | Telefónica |
|------------------------------------|-----------|-----------|------------|
| Data (Trains; Walktest) | | | |
| Web Page Download | | | |
| Success Ratio (%) | 93.1 | 87.1 | 88.0 |
| Total Session Time (s) | 2.0 | 2.2 | 2.2 |
| File Download (5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 97.8/14.6 | 92.8/16.0 | 89.3/13.0 |
| 90%/10% faster than (Mbps) | 1.0/30.9 | 0.8/24.0 | 1.3/25.0 |
| File Upload (2.5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 98.7/4.3 | 98.4/3.3 | 91.3/5.7 |
| 90%/10% faster than (Mbps) | 2.0/24.5 | 3.3/20.0 | 1.3/18.0 |
| File Download (7 seconds) | | | |
| Success Ratio (%) | 93.3 | 86.7 | 90.0 |
| Ø Throughput (Mbps) | 13.6 | 11.0 | 9.8 |
| 90%/10% faster than (Mbps) | 1.6/32.3 | 1.0/23.0 | 1.2/23.6 |
| File Upload (7 seconds) | | | |
| Success Ratio (%) | 97.2 | 96.3 | 84.7 |
| Ø Throughput (Mbps) | 13.4 | 9.7 | 9.9 |
| 90%/10% faster than (Mbps) | 2.8/27.1 | 2.1/19.3 | 1.5/20.3 |
| Youtube Videos | | | |
| Success Ratio/Start Time (%/s) | 73.9/2.0 | 60.2/2.4 | 64.3/2.3 |
| Ø Video Resolution (p) | 804 | 759 | 761 |
| Youtube Live | | | |
| Success Ratio/Start Time (%/s) | 74.5/2.1 | 73.9/2.6 | 79.7/2.5 |
| Ø Video Resolution (p) | 880 | 820 | 843 |

Single Review



Already for the ninth time in a row, Telekom wins connect's mobile network test in Germany. In comparison to the previous year, the operator managed to improve once again in the voice discipline and in the crowdsourcing. Its performance in data communications basically remained constant. Compared with the competition, the Bonn-based company however leads in all partial disciplines.



The comparison with last year's results shows that Vodafone also managed to improve – a little more pronounced in the voice discipline and in the crowdsourcing, to a smaller extent also in the data discipline. As we tighten our requirements year over year, this is an achievement which would not have been possible without great efforts of the technicians and without extensive investments.



The improvement is clearly visible: From the grade "sufficient" two years ago, via "satisfactory" in the previous year, Telefónica now has fought its way up to the grade "good". Of all three German operators, O2's advance is the most pronounced. This is also reflected by very good crowdsourcing results. However, in rural areas and on the railways, the gap to the competitors is still distinct.

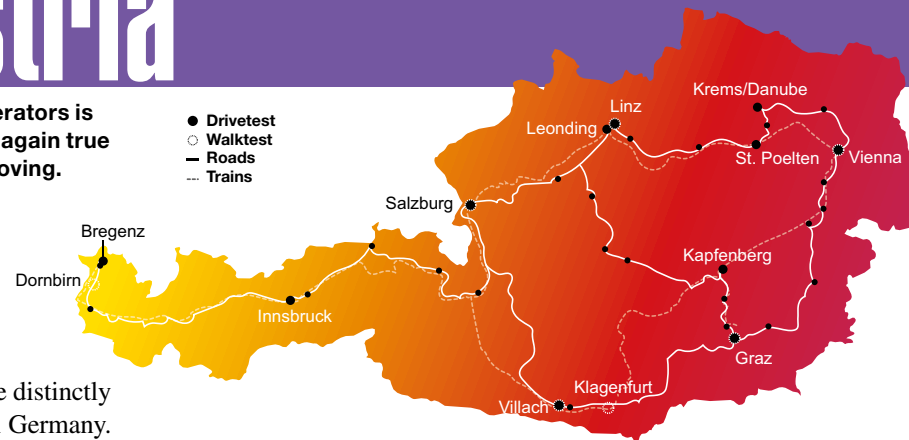
Austria

In the Alpine Republic, the contest between the operators is always battled out on a very high level. This is once again true for this year – with all three candidates clearly improving.

Traditionally, the operators in Austria score at a very high level in our network test – in recent years, they have regularly achieved a significantly higher number of points than their German peers. Nonetheless, they had to admit defeat to the even stronger providers from Switzerland at a pronounced score distance. While we're already at hinting to the fact that the gaps in the top group somewhat shrank this year, we also would like to reveal that this development did not mean any disadvantages for Austrian customers.

Another cause for joy for Austrian mobile communications subscribers is already well known: Still, the mobile

tariffs in Austria are distinctly lower than those in Germany. A constant annoyance however are the high roaming charges which all Austrian providers demand for mobile phone usage in the non-EU neighbouring country Switzerland. At least they seem to have invested a good part of the money gained this way into network upgrades. As otherwise the once more notable improvements of all three Austrian operators over their results from the previous year would be hard to explain.



Voice connections

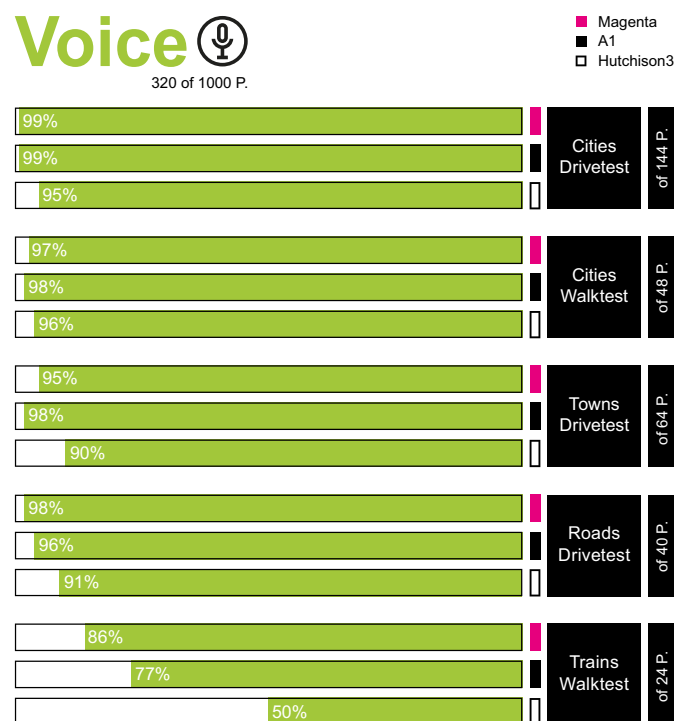
The measurement values clearly emphasize that all three operators in Austria have been supporting and continuously expanded the fast and high-quality voice telephony via VoLTE (Voice over LTE) since 2018. Especially Magenta convinces with very short call setup times. Their average was well below one second – not only in the big cities, but also in smaller towns and on the connecting roads.

The success rates are also on a good level – even on the connecting roads, they range distinctly above 99 percent at

Magenta – and only slightly below this value in the networks of the two competitors A1 and Three. To criticize that in the Three network only 98.6 percent of all test phone call came through, would only be complaining on a very high level.

The values for voice quality gathered during our drivetests and walktests in larger Austrian cities and smaller Austrian towns as well as on the connecting roads are beyond any doubt anyway. And the MultiRAB connectivity which we examined for the first time this year, proves that in most of

| Operator | Magenta | A1 | Hutchison3 |
|----------------------------------|---------|---------|------------|
| Voice Cities (Drivetest) | | | |
| Call Success Ratio (%) | 99.9 | 99.9 | 99.3 |
| Call Setup Time Ø (s) / P90 (s) | 0.9/1.0 | 1.5/1.7 | 2.3/3.2 |
| Speech Quality Ø / P10 (MOS-LQO) | 4.6/4.3 | 4.5/4.2 | 4.5/4.2 |
| MultiRAB Connectivity (%) | 99.9 | 99.8 | 99.8 |
| Voice Cities (Walktest) | | | |
| Call Success Ratio (%) | 99.5 | 99.7 | 99.5 |
| Call Setup Time Ø (s) / P90 (s) | 1.0/1.1 | 1.6/1.8 | 2.3/2.8 |
| Speech Quality Ø / P10 (MOS-LQO) | 4.6/4.5 | 4.6/4.4 | 4.6/4.4 |
| MultiRAB Connectivity (%) | 99.6 | 99.9 | 98.5 |
| Voice Towns (Drivetest) | | | |
| Call Success Ratio (%) | 99.2 | 99.7 | 98.6 |
| Call Setup Time Ø (s) / P90 (s) | 0.9/1.0 | 1.5/1.7 | 2.3/3.1 |
| Speech Quality Ø / P10 (MOS-LQO) | 4.6/4.4 | 4.5/4.2 | 4.5/4.2 |
| MultiRAB Connectivity (%) | 100.0 | 99.4 | 97.4 |
| Voice Roads (Drivetest) | | | |
| Call Success Ratio (%) | 99.5 | 98.9 | 98.5 |
| Call Setup Time Ø (s) / P90 (s) | 0.9/1.0 | 1.6/1.8 | 2.5/4.4 |
| Speech Quality Ø / P10 (MOS-LQO) | 4.5/4.2 | 4.4/4.0 | 4.4/3.8 |
| MultiRAB Connectivity (%) | 100.0 | 98.6 | 97.5 |
| Voice Trains (Walktest) | | | |
| Call Success Ratio (%) | 96.0 | 93.3 | 87.3 |
| Call Setup Time Ø (s) / P90 (s) | 1.1/1.2 | 1.7/2.0 | 2.7/4.8 |
| Speech Quality Ø / P10 (MOS-LQO) | 4.4/3.9 | 4.4/3.9 | 4.2/3.1 |
| MultiRAB Connectivity (%) | 97.7 | 98.9 | 93.3 |



the cases simultaneous voice and data communication were also conveniently available.

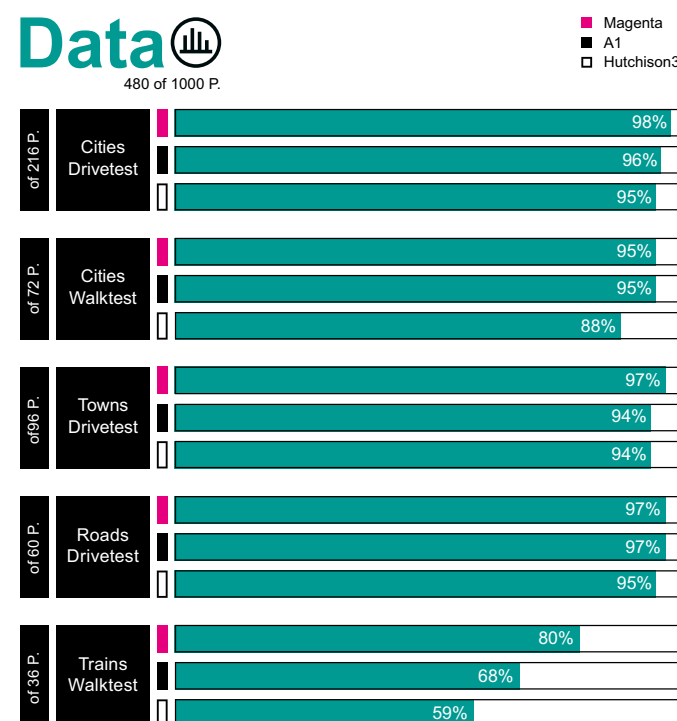
Data connections

Convincing results can also be seen in the data measurements. With the recent rollout of 4CA in its LTE network (combination of four carrier frequen-

cies), Magenta is one step ahead in this respect. A1 also offers 4CA in its network – but the firmware of the Samsung Galaxy S9 which we used for our measurements could not fully support the specific frequency combination employed by this operator. In larger cities and smaller towns, Magenta

achieves average data throughputs above 100 Mbps, in ten percent of the cases even above 200 Mbps. The values achieved by A1 only range slightly behind, with Three also offering high data rates and reliable connections to its customers. Only when it came to surveying uploads as part of

the walktests, we still found some room for improvement in the Three network. In turn, this operator achieves a narrow lead in the category of accessing Youtube videos in smaller towns. But all in all, the results of all three Austrian operators in the data discipline leave very little to be desired.



| Operator | Magenta | A1 | Hutchison3 |
|------------------------------------|------------|------------|------------|
| Data (Roads; Drivetest) | | | |
| Web Page Download | | | |
| Success Ratio (%) | 99.6 | 99.7 | 99.5 |
| Total Session Time (s) | 0.8 | 0.9 | 0.9 |
| File Download (5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 99.4/1.3 | 99.8/1.5 | 99.6/1.3 |
| 90%/10% faster than (Mbps) | 18.6/104.9 | 16.5/111.0 | 18.3/102.6 |
| File Upload (2.5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 99.8/1.3 | 99.6/1.7 | 99.2/2.2 |
| 90%/10% faster than (Mbps) | 10.3/42.8 | 8.1/39.5 | 6.4/30.4 |
| File Download (7 seconds) | | | |
| Success Ratio (%) | 99.8 | 99.8 | 99.8 |
| Ø Throughput (Mbps) | 89.1 | 83.3 | 84.0 |
| 90%/10% faster than (Mbps) | 21.9/173.5 | 20.2/166.8 | 23.6/155.0 |
| File Upload (7 seconds) | | | |
| Success Ratio (%) | 99.6 | 99.8 | 99.2 |
| Ø Throughput (Mbps) | 32.8 | 31.3 | 27.2 |
| 90%/10% faster than (Mbps) | 9.5/57.9 | 9.9/51.8 | 6.7/41.8 |
| Youtube Videos | | | |
| Success Ratio/Start Time (%/s) | 99.6/0.9 | 99.8/1.1 | 99.4/1.0 |
| Ø Video Resolution (p) | 918 | 916 | 916 |
| Youtube Live | | | |
| Success Ratio/Start Time (%/s) | 99.2/1.3 | 97.2/1.7 | 98.7/1.5 |
| Ø Video Resolution (p) | 1040 | 1034 | 1038 |



| Operator | Magenta | A1 | Hutchison3 |
|------------------------------------|-----------|----------|------------|
| Data (Trains; Walktest) | | | |
| Web Page Download | | | |
| Success Ratio (%) | 96.1 | 94.6 | 91.5 |
| Total Session Time (s) | 1.1 | 1.3 | 1.4 |
| File Download (5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 97.5/2.9 | 95.3/2.8 | 94.2/3.3 |
| 90%/10% faster than (Mbps) | 7.9/70.3 | 6.7/74.9 | 7.2/70.5 |
| File Upload (2.5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 95.9/2.9 | 95.3/4.8 | 90.7/3.8 |
| 90%/10% faster than (Mbps) | 5.4/31.2 | 1.6/21.5 | 2.9/23.3 |
| File Download (7 seconds) | | | |
| Success Ratio (%) | 96.1 | 93.0 | 93.2 |
| Ø Throughput (Mbps) | 50.3 | 38.3 | 39.6 |
| 90%/10% faster than (Mbps) | 8.4/109.9 | 6.1/90.1 | 7.4/85.5 |
| File Upload (7 seconds) | | | |
| Success Ratio (%) | 93.6 | 89.3 | 85.2 |
| Ø Throughput (Mbps) | 20.7 | 12.7 | 14.8 |
| 90%/10% faster than (Mbps) | 4.7/38.8 | 2.0/29.3 | 2.5/28.8 |
| Youtube Videos | | | |
| Success Ratio/Start Time (%/s) | 92.1/1.2 | 91.2/1.6 | 88.3/1.6 |
| Ø Video Resolution (p) | 884 | 906 | 900 |
| Youtube Live | | | |
| Success Ratio/Start Time (%/s) | 97.8/1.6 | 90.9/1.8 | 83.5/1.8 |
| Ø Video Resolution (p) | 992 | 1029 | 1030 |

Mobile communications on railways

The most difficult discipline of our benchmark are mobile phone calls and data communication while travelling on a train. Here again, the values determined by umlaut, fit the long-time overall picture: The three Austrian providers are ahead of their German counterparts but behind the Swiss operators. However, in comparison to last year, they still managed to improve their results.

This improvement is considerable in terms of voice telephony – at least for Magenta and A1. Both contenders were able to increase their success rates and voice

quality. Three ranges on the same level as in the previous year in this discipline.

In the data measurements conducted in trains, Magenta achieves the best overall result. Here again, Magenta and A1 distinctly improved their performances over the previous year. Three also managed to improve by some percent. However, all in all, the tests performed on the railways show the most potential for the Austrian operators to improve. But once again the result emphasizes: In comparison to Germany, Austrian users can be very satisfied with the performance of mobile communications in their trains.

| Operator | Magenta | A1 | Hutchison3 |
|------------------------------------|------------|------------|------------|
| Data (Cities; Drivetest) | | | |
| Web Page Download | | | |
| Success Ratio (%) | 100.0 | 99.9 | 99.8 |
| Total Session Time (s) | 0.7 | 0.9 | 0.9 |
| File Download (5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 100.0/1.0 | 100.0/1.2 | 99.8/1.3 |
| 90%/10% faster than (Mbps) | 28.8/120.1 | 25.2/114.6 | 21.1/106.7 |
| File Upload (2.5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 100.0/0.9 | 99.8/1.2 | 99.9/1.4 |
| 90%/10% faster than (Mbps) | 15.9/46.0 | 12.4/42.1 | 11.7/31.3 |
| File Download (7 seconds) | | | |
| Success Ratio (%) | 100.0 | 100.0 | 99.8 |
| Ø Throughput (Mbps) | 113.9 | 94.8 | 85.9 |
| 90%/10% faster than (Mbps) | 36.6/207.3 | 28.5/175.5 | 23.1/166.3 |
| File Upload (7 seconds) | | | |
| Success Ratio (%) | 99.9 | 99.8 | 99.7 |
| Ø Throughput (Mbps) | 43.9 | 37.9 | 30.3 |
| 90%/10% faster than (Mbps) | 17.2/60.6 | 14.0/56.1 | 14.4/42.0 |
| Youtube Videos | | | |
| Success Ratio/Start Time (%/s) | 100.0/0.9 | 99.9/1.1 | 99.6/1.0 |
| Ø Video Resolution (p) | 920 | 919 | 920 |
| Youtube Live | | | |
| Success Ratio/Start Time (%/s) | 99.5/1.2 | 98.5/1.6 | 99.0/1.5 |
| Ø Video Resolution (p) | 1039 | 1039 | 1039 |
| Data (Cities; Walktest) | | | |
| Web Page Download | | | |
| Success Ratio (%) | 99.8 | 99.9 | 99.2 |
| Total Session Time (s) | 0.8 | 0.9 | 1.0 |
| File Download (5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 99.8/1.0 | 99.8/1.5 | 99.5/1.6 |
| 90%/10% faster than (Mbps) | 31.7/104.4 | 22.1/116.4 | 18.0/103.9 |
| File Upload (2.5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 99.6/1.1 | 99.5/1.7 | 98.8/2.1 |
| 90%/10% faster than (Mbps) | 11.3/43.7 | 7.6/42.5 | 6.0/30.9 |
| File Download (7 seconds) | | | |
| Success Ratio (%) | 99.8 | 99.8 | 99.5 |
| Ø Throughput (Mbps) | 107.2 | 98.1 | 78.4 |
| 90%/10% faster than (Mbps) | 34.2/202.3 | 30.8/174.2 | 18.4/143.5 |
| File Upload (7 seconds) | | | |
| Success Ratio (%) | 99.3 | 99.5 | 97.7 |
| Ø Throughput (Mbps) | 37.1 | 35.9 | 27.7 |
| 90%/10% faster than (Mbps) | 9.4/59.4 | 11.9/56.1 | 8.4/41.2 |
| Youtube Videos | | | |
| Success Ratio/Start Time (%/s) | 99.8/0.9 | 99.8/1.0 | 98.8/1.1 |
| Ø Video Resolution (p) | 921 | 918 | 916 |
| Youtube Live | | | |
| Success Ratio/Start Time (%/s) | 98.1/1.2 | 99.4/1.6 | 100.0/1.6 |
| Ø Video Resolution (p) | 1036 | 1037 | 1033 |
| Data (Towns; Drivetest) | | | |
| Web Page Download | | | |
| Success Ratio (%) | 100.0 | 99.9 | 99.8 |
| Total Session Time (s) | 0.7 | 0.9 | 0.9 |
| File Download (5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 100.0/1.0 | 100.0/1.5 | 100.0/1.3 |
| 90%/10% faster than (Mbps) | 29.5/112.7 | 16.0/106.7 | 21.4/95.6 |
| File Upload (2.5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 100.0/1.0 | 100.0/1.7 | 99.7/1.3 |
| 90%/10% faster than (Mbps) | 14.7/43.6 | 7.3/36.0 | 12.6/30.5 |
| File Download (7 seconds) | | | |
| Success Ratio (%) | 100.0 | 100.0 | 99.7 |
| Ø Throughput (Mbps) | 103.1 | 78.3 | 84.1 |
| 90%/10% faster than (Mbps) | 33.7/188.0 | 17.6/143.4 | 26.0/151.9 |
| File Upload (7 seconds) | | | |
| Success Ratio (%) | 100.0 | 100.0 | 98.8 |
| Ø Throughput (Mbps) | 40.9 | 29.4 | 28.4 |
| 90%/10% faster than (Mbps) | 14.9/59.8 | 9.3/49.9 | 12.6/41.2 |
| Youtube Videos | | | |
| Success Ratio/Start Time (%/s) | 99.7/0.9 | 99.4/1.1 | 99.7/1.0 |
| Ø Video Resolution (p) | 920 | 915 | 920 |
| Youtube Live | | | |
| Success Ratio/Start Time (%/s) | 99.4/1.3 | 99.4/1.6 | 100.0/1.5 |
| Ø Video Resolution (p) | 1040 | 1035 | 1040 |

Crowd

All three operators perform very well in the crowdsourcing. Three manages to achieve the most distinct gain.

► As in the year before, the results of our crowdsourcing analysis identify an advance for A1. But also Magenta and Three score quite well in this category.

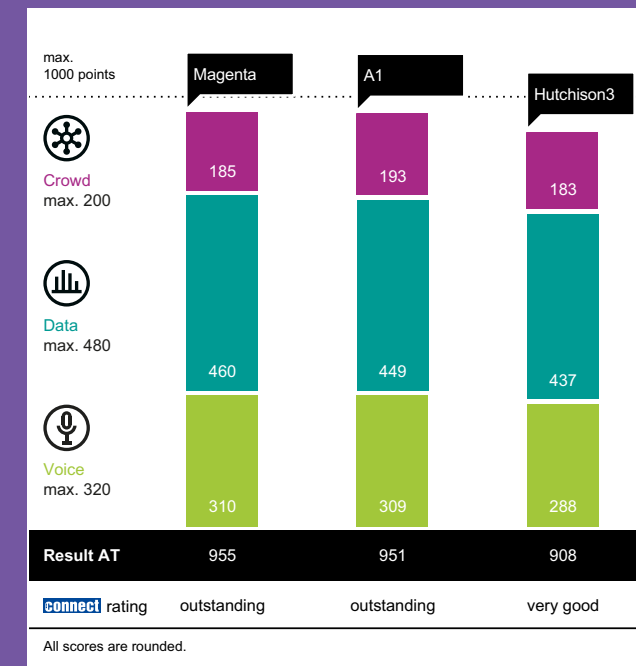
In the coverage figures determined this way, all three operators achieve very good results for voice telephony. Magenta leads the field in data coverage (which includes 3G and 4G reception). At small distances each follows A1 and then Three. When it comes to 4G coverage, the lag of Three behind the leading two operators is a little more obvious.

In contrast, Three is ahead regarding data throughputs in urban areas. But when we look closer at the rural areas, A1 is ahead both in the download and upload disciplines.

And while we observed some smaller anomalies at Three and somewhat more extensive ones at Magenta in the six-month evaluation period, we could not identify any degradations in the A1 network during this period of time.

| Operator | Magenta | A1 | Hutchison3 |
|---|---------|-------|------------|
| Crowd Country – Operational Excellence | | | |
| Number of degraded days (d) | 3 | 0 | 1 |
| Number of degraded hours (h) | 14 | 0 | 2 |
| Crowd urban | | | |
| Voice Coverage (%) | 99.7 | 99.9 | 99.9 |
| Data Coverage (%) | 99.8 | 99.0 | 98.5 |
| 4G Coverage (%) | 98.2 | 97.8 | 97.0 |
| Download data speed (Mbps) | 104.2 | 129.4 | 135.0 |
| Upload data speed (Mbps) | 29.8 | 34.7 | 39.7 |
| Crowd non-urban (Benchmark view) | | | |
| Voice Coverage (%) | 99.7 | 99.9 | 99.7 |
| Data Coverage (%) | 99.6 | 99.5 | 95.1 |
| 4G Coverage (%) | 98.4 | 98.9 | 93.6 |
| Download data speed (Mbps) | 37.8 | 51.1 | 48.8 |
| Upload data speed (Mbps) | 7.8 | 12.4 | 11.7 |
| Crowd non-urban (Own network view) | | | |
| Voice Coverage (%) | 99.5 | 99.8 | 99.6 |
| Data Coverage (%) | 99.3 | 98.8 | 94.5 |
| 4G Coverage (%) | 97.4 | 97.6 | 92.7 |
| Download data speed (Mbps) | 36.0 | 47.4 | 47.1 |
| Upload data speed (Mbps) | 7.2 | 10.4 | 10.7 |

Single Review



Magenta As in the previous year, Magenta (formerly T-Mobile Austria) takes the overall win in Austria. The winner owes its narrow lead of four points ahead of its pursuer A1 to obtaining the best results both in the voice and in the data category of our comparison. With distinct improvements over the previous year, Magenta receives the overall grade "outstanding".

A1 A1 Telekom also performs "outstanding" and follows in a neck-and-neck race for the overall win at a distance of only four points behind Magenta. In order to reach this level, this operator clearly managed to improve over its performance from the previous year too. Among the convincing results is also the excellent reliability which we could identify in the six-month crowdsourcing observation period.

3 In the overall assessment, the smallest contender in Austria achieved the most distinct improvement over last year's results. Its performance in the voice and data categories range slightly above the level shown in the previous year – in spite of tighter criteria. In the crowdsourcing assessment, Three shows a clear advance. The operator also deserves recognition for the best Youtube performance in smaller towns.

Switzerland

In Helvetia, traditionally, the air is getting particularly thin up there. Which Swiss operators makes it to the winner's podium this time?

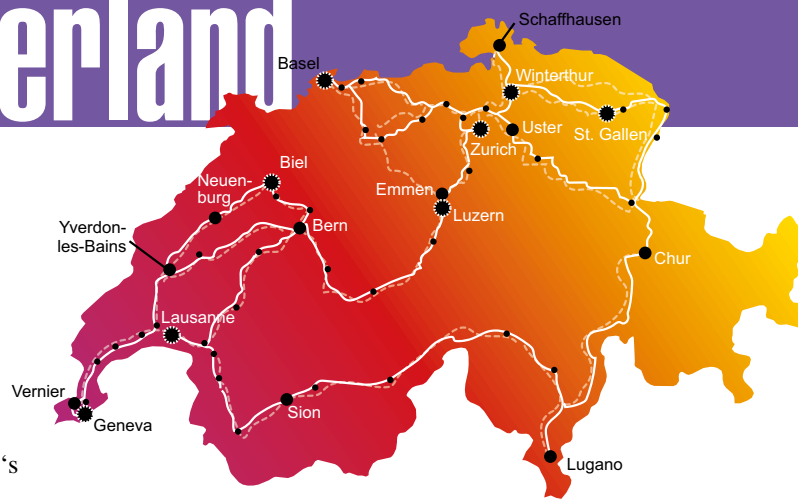
► Here comes another long-time tradition: When we compare the performances in Germany, Austria and Switzerland, the Swiss operators demonstrate where the forefront can be found. While our evaluation scheme delivers a wide dispersion of results in other countries, the Swiss contenders regularly achieve the grade "outstanding" – which connect issues only rarely.

Still, this fierce combat on the highest level is exciting again and again: Which Swiss network manages to collect the total win? How distinct is the lead over the best operators in Germany and Austria? And how does the smallest Swiss operator Salt fare in comparison to its bigger competitors

Swisscom and Sunrise? Let's have a closer look.

Voice connections

After recently also Salt introduced the modern telephony mode VoLTE (Voice over LTE) in its network, conducting voice calls over data packets and without the „circuit-switched fallback“ to 3G or 2G connections is now standard in all three Swiss networks. And it pays off: The smallest operator Salt now comes much closer to its two strong competitors when we look at the call



setup times or voice quality – even if it does not absolutely reach their very high levels. Especially in smaller towns, the gap is still a little more distinct. But also there as well as on the Swiss roads, Salt managed to improve its performance over the previous year.

Also noteworthy are the high success ratios achieved by Sunrise and Swisscom in cities and towns as well as on the connecting roads. In the Sunrise network, literally a 100 percent of the test calls conducted during the walktests in cities and towns succeeded.

Swisscom accomplishes the same in the larger cities and only narrowly misses the 100 percent mark in the smaller towns. Possibly record-breaking as well are Sunrise's call setup times ranging clearly below one second in all tested scenarios – including Swiss trains.

Data connections

What was already apparent in the voice discipline, becomes clear again in the data category: Swisscom and Sunrise have a neck-and-neck race on the highest level, Salt follows at a relatively close distance.



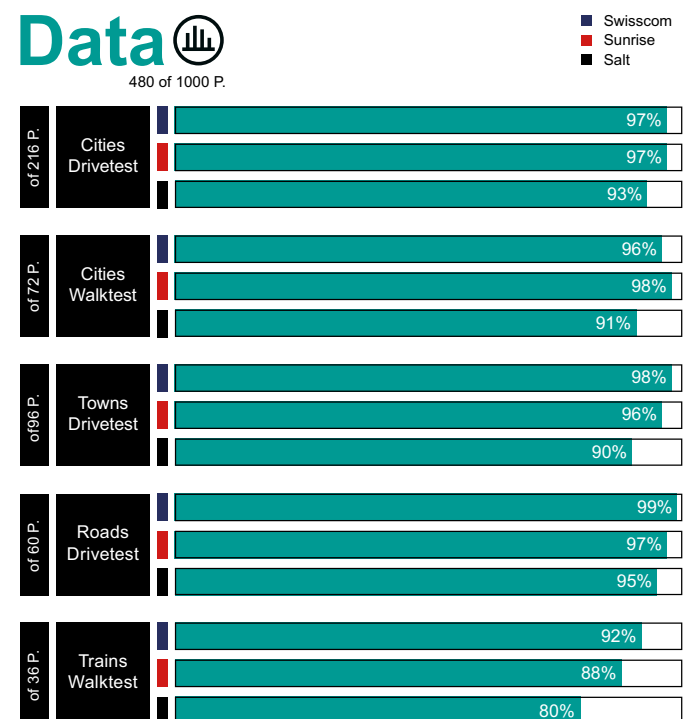
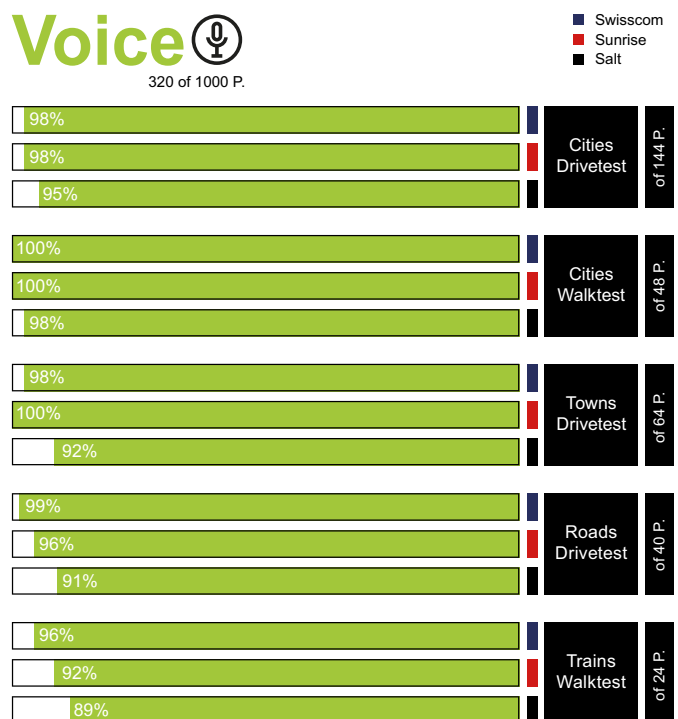
Almost complete LTE coverage at all locations visited by unlaut's teams and a high share of data connections with 4CA („4 carrier aggregation“ – the combination of four LTE carrier frequencies on suitable devices) in the larger cities – this is what characterizes the measurement

results of Swisscom and Sunrise. In bigger cities and smaller towns as well as on the connecting roads, the two Swiss operators with the largest customer numbers achieve top success rates for all data tests. But also the smaller contender Salt does not have to hide its results.

The tight distance at which the battle for the top position is fought at becomes apparent when we take a closer look at the test results in the individual categories: In the drivetests conducted in larger cities, Sunrise and Swisscom practically share the same high rank. In the big-city walktests

Swisscom takes a narrow lead, while in the drivetests in smaller towns an on the connecting roads, it is Swisscom's turn to achieve the top score. Again, also Salt shows convincing results in the data measurements conducted on the roads. All in all, Swiss drivers get on very well with all three operators.

| Operator | Swisscom | Sunrise | Salt |
|----------------------------------|----------|---------|---------|
| Voice Cities (Drivetest) | | | |
| Call Success Ratio (%) | 99.7 | 99.6 | 99.3 |
| Call Setup Time Ø (s) / P90 (s) | 1.1/1.3 | 0.7/0.7 | 1.7/1.9 |
| Speech Quality Ø / P10 (MOS-LQO) | 4.5/4.2 | 4.5/4.3 | 4.4/4.0 |
| MultiRAB Connectivity (%) | 99.9 | 99.9 | 99.9 |
| Voice Cities (Walktest) | | | |
| Call Success Ratio (%) | 100.0 | 100.0 | 99.8 |
| Call Setup Time Ø (s) / P90 (s) | 1.1/1.3 | 0.7/0.7 | 1.6/1.8 |
| Speech Quality Ø / P10 (MOS-LQO) | 4.6/4.5 | 4.7/4.6 | 4.5/4.2 |
| MultiRAB Connectivity (%) | 100.0 | 100.0 | 99.8 |
| Voice Towns (Drivetest) | | | |
| Call Success Ratio (%) | 99.6 | 100.0 | 98.8 |
| Call Setup Time Ø (s) / P90 (s) | 1.1/1.3 | 0.7/0.8 | 1.9/3.0 |
| Speech Quality Ø / P10 (MOS-LQO) | 4.5/4.2 | 4.5/4.3 | 4.4/3.7 |
| MultiRAB Connectivity (%) | 100.0 | 100.0 | 100.0 |
| Voice Roads (Drivetest) | | | |
| Call Success Ratio (%) | 99.6 | 98.9 | 97.6 |
| Call Setup Time Ø (s) / P90 (s) | 1.1/1.4 | 0.7/0.7 | 1.9/2.6 |
| Speech Quality Ø / P10 (MOS-LQO) | 4.5/4.2 | 4.5/4.2 | 4.4/3.8 |
| MultiRAB Connectivity (%) | 100.0 | 99.9 | 99.6 |
| Voice Trains (Walktest) | | | |
| Call Success Ratio (%) | 98.8 | 97.7 | 96.9 |
| Call Setup Time Ø (s) / P90 (s) | 1.2/1.5 | 0.7/0.8 | 1.8/2.0 |
| Speech Quality Ø / P10 (MOS-LQO) | 4.4/3.8 | 4.4/3.8 | 4.4/3.7 |
| MultiRAB Connectivity (%) | 100.0 | 100.0 | 100.0 |



| Operator | Swisscom | Sunrise | Salt |
|------------------------------------|------------|------------|------------|
| Data (Roads; Drivetest) | | | |
| Web Page Download | | | |
| Success Ratio (%) | 100.0 | 99.6 | 99.5 |
| Total Session Time (s) | 0.7 | 0.7 | 0.7 |
| File Download (5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 100.0/0.9 | 99.8/1.2 | 99.4/1.6 |
| 90%/10% faster than (Mbps) | 30.3/125.0 | 20.9/114.3 | 15.3/109.2 |
| File Upload (2.5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 100.0/1.0 | 99.8/1.2 | 99.8/1.5 |
| 90%/10% faster than (Mbps) | 14.6/47.4 | 10.4/43.7 | 9.8/39.6 |
| File Download (7 seconds) | | | |
| Success Ratio (%) | 100.0 | 99.8 | 99.6 |
| Ø Throughput (Mbps) | 123.0 | 84.6 | 72.2 |
| 90%/10% faster than (Mbps) | 33.6/215.1 | 22.7/159.6 | 17.7/139.3 |
| File Upload (7 seconds) | | | |
| Success Ratio (%) | 100.0 | 99.6 | 99.6 |
| Ø Throughput (Mbps) | 44.4 | 32.6 | 35.0 |
| 90%/10% faster than (Mbps) | 20.1/62.1 | 9.0/55.4 | 11.6/57.7 |
| Youtube Videos | | | |
| Success Ratio/Start Time (%/s) | 100.0/0.8 | 99.2/0.9 | 97.8/0.9 |
| Ø Video Resolution (p) | 921 | 919 | 918 |
| Youtube Live | | | |
| Success Ratio/Start Time (%/s) | 99.6/1.1 | 98.4/1.2 | 97.2/1.3 |
| Ø Video Resolution (p) | 1036 | 1034 | 1027 |



| Operator | Swisscom | Sunrise | Salt |
|------------------------------------|----------|-----------|----------|
| Data (Trains; Walktest) | | | |
| Web Page Download | | | |
| Success Ratio (%) | 99.2 | 98.7 | 97.0 |
| Total Session Time (s) | 1.0 | 1.1 | 1.1 |
| File Download (5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 99.3/3.3 | 99.3/3.9 | 98.3/4.4 |
| 90%/10% faster than (Mbps) | 6.2/81.8 | 5.5/62.9 | 4.9/62.0 |
| File Upload (2.5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 99.7/1.7 | 100.0/2.2 | 98.0/2.2 |
| 90%/10% faster than (Mbps) | 5.9/36.9 | 4.9/32.1 | 6.5/32.6 |
| File Download (7 seconds) | | | |
| Success Ratio (%) | 99.7 | 98.0 | 96.9 |
| Ø Throughput (Mbps) | 45.6 | 38.9 | 28.7 |
| 90%/10% faster than (Mbps) | 7.1/94.0 | 8.0/77.8 | 4.0/59.2 |
| File Upload (7 seconds) | | | |
| Success Ratio (%) | 99.0 | 98.3 | 96.9 |
| Ø Throughput (Mbps) | 25.5 | 22.6 | 23.2 |
| 90%/10% faster than (Mbps) | 6.9/44.4 | 5.0/40.4 | 7.0/39.6 |
| Youtube Videos | | | |
| Success Ratio/Start Time (%/s) | 97.4/1.3 | 95.7/1.5 | 90.1/1.3 |
| Ø Video Resolution (p) | 912 | 910 | 900 |
| Youtube Live | | | |
| Success Ratio/Start Time (%/s) | 96.6/1.4 | 95.3/1.5 | 93.1/1.4 |
| Ø Video Resolution (p) | 1020 | 1030 | 1026 |

Top mobile connectivity in Swiss trains

With only minor limitations, this also applies to Swiss railways. Here the helvetic operators show their neighbours (Austria to some extent, but first of all Germany), how the provision of mobile communications in trains should really look like. In the telephony category, the best contender Swisscom convinces with gathering 96 percent of the available points. The weakest candidate, Salt, still achieves 89 percent. When it comes to data connections, the overall level is even higher. When we look at success ratios between 90 percent and 99 percent for

accessing websites or receiving video streams, it would seem almost silly to mention a “potential for improvement” in the light of the results from Austria and Germany.

Still, we do not want to miss the opportunity to mention that on the overall utterly high level, in a direct comparison between the competitors, Swisscom is slightly ahead. Sunrise scores in the middle field, and Salt last. But even this third-ranking operator achieves results which would easily suffice for a category win in other countries. Sorry, but we simply could not help mentioning this fact once again ...

| Operator | Swisscom | Sunrise | Salt |
|------------------------------------|------------|------------|------------|
| Data (Cities; Drivetest) | | | |
| Web Page Download | | | |
| Success Ratio (%) | 99.9 | 99.8 | 99.8 |
| Total Session Time (s) | 0.7 | 0.7 | 0.7 |
| File Download (5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 100.0/1.2 | 100.0/1.1 | 99.9/2.0 |
| 90%/10% faster than (Mbps) | 24.2/115.9 | 22.9/116.6 | 10.5/98.4 |
| File Upload (2.5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 100.0/0.8 | 100.0/1.0 | 99.9/1.1 |
| 90%/10% faster than (Mbps) | 19.2/47.8 | 13.1/45.1 | 13.5/39.6 |
| File Download (7 seconds) | | | |
| Success Ratio (%) | 99.9 | 100.0 | 99.9 |
| Ø Throughput (Mbps) | 110.7 | 101.5 | 59.9 |
| 90%/10% faster than (Mbps) | 30.8/208.1 | 26.0/195.7 | 13.3/128.9 |
| File Upload (7 seconds) | | | |
| Success Ratio (%) | 99.9 | 99.9 | 99.9 |
| Ø Throughput (Mbps) | 48.4 | 38.2 | 38.7 |
| 90%/10% faster than (Mbps) | 21.1/62.4 | 13.7/58.7 | 13.3/58.9 |
| Youtube Videos | | | |
| Success Ratio/Start Time (%/s) | 99.7/0.8 | 99.6/0.9 | 99.5/0.9 |
| Ø Video Resolution (p) | 920 | 918 | 917 |
| Youtube Live | | | |
| Success Ratio/Start Time (%/s) | 99.0/1.1 | 99.6/1.1 | 98.1/1.2 |
| Ø Video Resolution (p) | 1033 | 1032 | 1032 |
| Data (Cities; Walktest) | | | |
| Web Page Download | | | |
| Success Ratio (%) | 99.7 | 99.9 | 99.8 |
| Total Session Time (s) | 0.7 | 0.6 | 0.8 |
| File Download (5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 99.8/1.1 | 100.0/1.1 | 99.6/2.1 |
| 90%/10% faster than (Mbps) | 22.0/133.4 | 24.8/124.6 | 11.2/89.5 |
| File Upload (2.5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 99.6/0.8 | 100.0/0.9 | 99.8/1.2 |
| 90%/10% faster than (Mbps) | 23.0/47.9 | 14.0/45.6 | 14.8/39.7 |
| File Download (7 seconds) | | | |
| Success Ratio (%) | 99.8 | 100.0 | 99.8 |
| Ø Throughput (Mbps) | 118.5 | 106.8 | 53.2 |
| 90%/10% faster than (Mbps) | 25.0/240.5 | 29.6/204.2 | 12.1/110.7 |
| File Upload (7 seconds) | | | |
| Success Ratio (%) | 99.6 | 99.8 | 99.6 |
| Ø Throughput (Mbps) | 49.6 | 39.4 | 38.2 |
| 90%/10% faster than (Mbps) | 26.4/62.5 | 15.6/58.5 | 15.5/58.5 |
| Youtube Videos | | | |
| Success Ratio/Start Time (%/s) | 99.8/0.8 | 100.0/0.9 | 98.5/1.0 |
| Ø Video Resolution (p) | 920 | 920 | 915 |
| Youtube Live | | | |
| Success Ratio/Start Time (%/s) | 99.2/1.1 | 100.0/1.1 | 97.4/1.3 |
| Ø Video Resolution (p) | 1038 | 1039 | 1037 |
| Data (Towns; Drivetest) | | | |
| Web Page Download | | | |
| Success Ratio (%) | 99.9 | 99.8 | 99.5 |
| Total Session Time (s) | 0.7 | 0.7 | 0.8 |
| File Download (5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 100.0/0.9 | 100.0/1.1 | 99.3/1.9 |
| 90%/10% faster than (Mbps) | 30.3/113.9 | 23.7/106.8 | 10.8/95.5 |
| File Upload (2.5MB) | | | |
| Success Ratio/Ø Session Time (%/s) | 100.0/0.7 | 100.0/1.2 | 99.6/1.2 |
| 90%/10% faster than (Mbps) | 20.0/47.7 | 11.3/44.3 | 11.6/39.4 |
| File Download (7 seconds) | | | |
| Success Ratio (%) | 100.0 | 100.0 | 99.8 |
| Ø Throughput (Mbps) | 107.1 | 88.6 | 57.8 |
| 90%/10% faster than (Mbps) | 34.0/195.2 | 27.8/152.1 | 13.7/119.9 |
| File Upload (7 seconds) | | | |
| Success Ratio (%) | 100.0 | 100.0 | 98.9 |
| Ø Throughput (Mbps) | 47.8 | 35.1 | 33.8 |
| 90%/10% faster than (Mbps) | 23.9/62.4 | 10.6/56.1 | 9.7/56.0 |
| Youtube Videos | | | |
| Success Ratio/Start Time (%/s) | 100.0/0.9 | 99.8/1.0 | 99.1/1.0 |
| Ø Video Resolution (p) | 921 | 920 | 912 |
| Youtube Live | | | |
| Success Ratio/Start Time (%/s) | 99.1/1.1 | 99.1/1.1 | 98.6/1.2 |
| Ø Video Resolution (p) | 1034 | 1034 | 1028 |

Crowd

In the crowdsourcing, the three Swiss networks show top results again. Still, Swisscom takes a narrow lead once more.

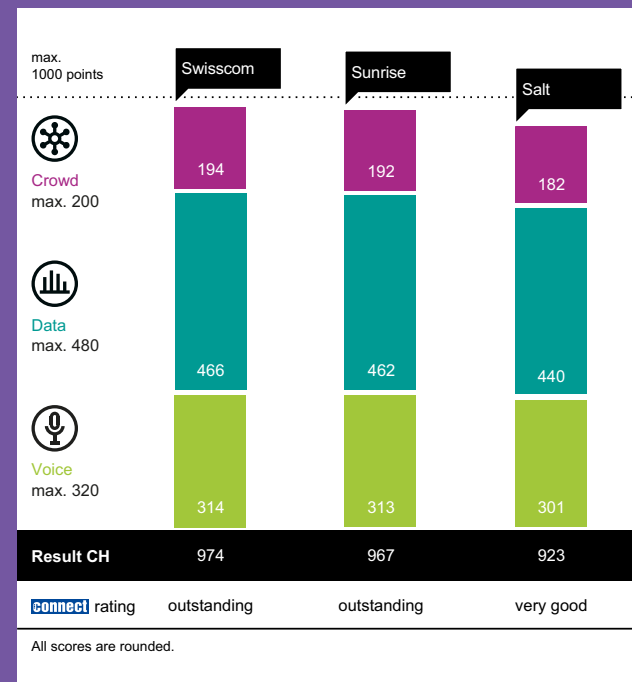
In the results of our crowdsourcing analysis, Swisscom and Sunrise once again rank at a very close distance. There is a gap of just two points separating Swisscom, which also leads in this category, from its pursuer Sunrise. In contrast, the ten point lag of Salt behind Sunrise is already a bit more pronounced.

The determined coverage rates are very high for Swisscom and Sunrise in urban as well as rural areas. Salt shows convincing coverage results in the rural areas, but lags a little behind its competitors when it comes to 4G and data (3G + 4G) coverage. The data rates of downloads and uploads identified for Swisscom are a little ahead of the competition both in urban and rural areas, and wrap up the operator’s overall win.

Concerning service availability, we can only report that none of the three Swiss networks showed any degradations whatsoever during the half-year observation period.

| Operator | Swisscom | Sunrise | Salt |
|---|----------|---------|-------|
| Crowd Country – Operational Excellence | | | |
| Number of degraded days (d) | 0 | 0 | 0 |
| Number of degraded hours (h) | 0 | 0 | 0 |
| Crowd urban | | | |
| Voice Coverage (%) | 99.7 | 99.8 | 99.8 |
| Data Coverage (%) | 99.4 | 99.7 | 97.5 |
| 4G Coverage (%) | 98.0 | 98.2 | 94.5 |
| Download data speed (Mbps) | 112.0 | 92.7 | 74.5 |
| Upload data speed (Mbps) | 36.5 | 26.5 | 24.5 |
| Crowd non-urban (Benchmark view) | | | |
| Voice Coverage (%) | 100.0 | 100.0 | 100.0 |
| Data Coverage (%) | 100.0 | 100.0 | 99.9 |
| 4G Coverage (%) | 100.0 | 99.9 | 99.3 |
| Download data speed (Mbps) | 60.0 | 38.4 | 36.7 |
| Upload data speed (Mbps) | 13.5 | 6.9 | 5.8 |
| Crowd non-urban (Own network view) | | | |
| Voice Coverage (%) | 99.9 | 99.9 | 100.0 |
| Data Coverage (%) | 99.7 | 99.9 | 99.9 |
| 4G Coverage (%) | 99.6 | 99.8 | 99.1 |
| Download data speed (Mbps) | 52.7 | 36.5 | 35.6 |
| Upload data speed (Mbps) | 10.1 | 6.1 | 5.2 |

Single Review



Among the two “outstanding” Swiss operators, this year the market leader Swisscom takes the overall win once again – for the second time in a row. In doing so, the operator outperforms its pursuer Sunrise in all three test categories – in some cases with a gap of only one point as in the voice evaluation, yet overall at some distance.



“Outstanding” is also Sunrise’s grade – even if the gap behind the overall winner is not quite as narrow as last year (when it was just one point). Overall, Sunrise stepped it up a notch in the crowd assessment. The drivetest and walktest results range basically at the same level as in the previous year. In the face of our tighter methodology, thus Sunrise has improved at least to some extent.



The third rank in Switzerland would still be the first in Germany. But analogies like this are actually not needed for this operator which is awarded with the overall grade “very good”. More interesting for the company and its customers: Salt achieved the biggest score improvement of all Swiss operators over the previous year. It derives from a clear increase in the voice discipline and also in the crowdsourcing.

SERVICE TEST

SERVICE TEST

Methodology

■ The tests in Germany took place from October 1st to November 1st, 2019, the ones in Austria from October 3rd to 18th, and the ones in Switzerland from October 10th to 30th, 2019. For each country, connect's partner for the network measurements, umlaut, used two vehicles for drivetesting the chosen cities, towns and roads. Each car carried a total of six Samsung Galaxy S9 smartphones. One per operator was used for the voice tests and another one for the data measurements. In addition to the drivetest, in each country a walktest team took measurements by foot. For this effort, the teams visited so-called "areas of interest" with a strong visitor frequency like train stations, airport terminals, coffee shops, museums and also local public transport. Travelling from city to city allowed the assessment of cellular network quality within long distance trains. The walktest teams also utilised Samsung Galaxy S9 smartphones that were installed in trolleys and backpacks with additional strong batteries. The devices' firmware was each operator's current firmware version. If such software was not available, the



Each drivetest vehicle carried six Samsung Galaxy S9 smartphones.

most current firmware from Samsung was used.

Logistics

All drivetests and walktests were done between 8 am and 10 pm. During the drivetests, two cars were present in the same cities, but on different routes to avoid any interference of one car's measurement by the other car's. On the connecting roads, both vehicles drove a given route, but followed each other at a small temporal and spatial distance. In Germany, the measurements included 20 larger cities and 24 smaller towns, while the walktests frequented ten cities. The measurement cars drove a total of approx. 9,780 kilometers. With their drivetests, they covered about 14.4 million inhabitants which equals about 1715 percent of the German population. In Austria, the drivetests covered 11 big cities and 20 smaller towns, the walktest team visited seven cities. Here, the vehicles covered about 6,010 km equalling 3.1 million inhabitants or 35.3 percent of the population. In Switzerland, the drivetests covered 18 big cities and 33 smaller towns, the walktests took place in eight cities. The test route in Switzerland was about 6,590 km long, equalling about 2.2 million inhabitants or approximately 26.1 percent of the population. For the definition of the test routes umlaut generates four independent plans, from which connect then randomly chooses one.

Voice telephony

Voice services were measured with the smartphones performing calls alternating between the measurement cars ("mobile to mobile"). The walktest teams



Professional and critical: Bernd Theiss, head of test and technology at connect (on the left), and Hakan Ekmen, CEO of umlaut (on the right).

called a stationary counterpart for all voice tests. In the assessment of call setup times we also rate the so-called P90 value. Such values specify the threshold in a statistical distribution, below which 90 percent of the gathered values are ranging. For speech quality, we publish the P10 value (10 percent of the values are lower than the specified threshold), because in this case higher values are better. Background data traffic was transmitted by one of the smartphones simultaneously in order to reflect a realistic usage scenario. As a new KPI in 2019, we also evaluate the so-called MultiRAB (Multi Radio Access Bearer) Connectivity. This value denominates whether data connectivity is available during the phone calls. Audio quality was assessed by using the HD-Voice capable POLQA wide band scoring. All devices were configured in "LTE preferred" mode.

Data connectivity

To assess cellular data performance, top websites (according to the Alexa ranking) were dynamically downloaded. Additionally a static website was tested, the industry standard ETSI (European Telecommunications Standards Institute) Kepler refe-

rence page. HTTP downloads and uploads were conducted with 5 MB and 2.5 MB files, simulating small file transfers. The networks' peak performance was tested with a seven second download and upload of a single, very large file. Youtube measurements considered the "adaptive resolution" feature of this video platform. In order to offer a persistent video experience, Youtube adapts the video streams' resolution dynamically to the bandwidth that is currently available. Our scoring therefore considers the success ratio, the time until the playback starts as well as the videos' average resolution.

Crowdsourcing

The results of the crowdsourcing analysis performed by umlaut contribute 20 percent to the total score. For this purpose, in all three countries samples collected from mid-May until end of October 2019 were evaluated. For Germany, a total of 2.8 billion single measurement values from von 476,000 users was analyzed. This represents about 99.3 percent of the built-up area in urban surroundings and 91.5 percent of the rest of the country's built-up area. For Austria, umlaut considered approx. 902 million values from a total of 99,800 users – represen-



ting a 100 percent of the built-up area in cities and 92.1 percent of the built-up area outside of them. The figures for Switzerland: 41,400 users contributed 200 million samples. This covers a 100 percent of the built-up area in cities, and 88.4 percent outside of them.

The data base for these analysis is obtained by more than 800 popular apps. They log in the background whether there is a network connections, which mobile network technologies are available and what download and upload data rates can be achieved – provided that the user has before agreed to this completely anonymous data collection. These values are gathered every 15 minutes and transmitted once a day to umlaut's servers. The reports only comprise of a small number of bytes so that they do not put a substantial strain to the users'

data volumes. Readers who wish to actively support our network test can do this by installing and using the connect app (see box below). However, it is only one of many apps containing the described background functionality.

Network coverage

In order to determine the coverage with 4G, "data" (3G and 4G) as well as telephony, umlaut applies a grid of 2 by 2 km tiles to the test area. These "evaluation areas" are then sub-divided into 16 smaller tiles. In order to ensure the statistical relevance of the results, each tile must deliver a minimum number of users and measurement data. In our 2019 benchmark framework, we differentiate between a „Benchmark View“ and an „Own Network View“: For the Benchmark View, only those evaluation areas are considered for which we have

determined valid results for all operators who are considered in the benchmark. In the Own Network View an evaluation area will also be considered if there is none of the competitors present. Above that, we now distinguish urban and non-urban areas in our crowd evaluations – respecting that the coverage with mobile services is usually higher in urban than in rural areas.

Data Throughputs

For each "evaluation area" umlaut determines the maximum download and upload speeds reached by each participating user with 15 minutes time slices. Then, the maximum value of these slices with a 4 week grid is calculated, and of these eventually the P90 value (as explained earlier).

Network stability

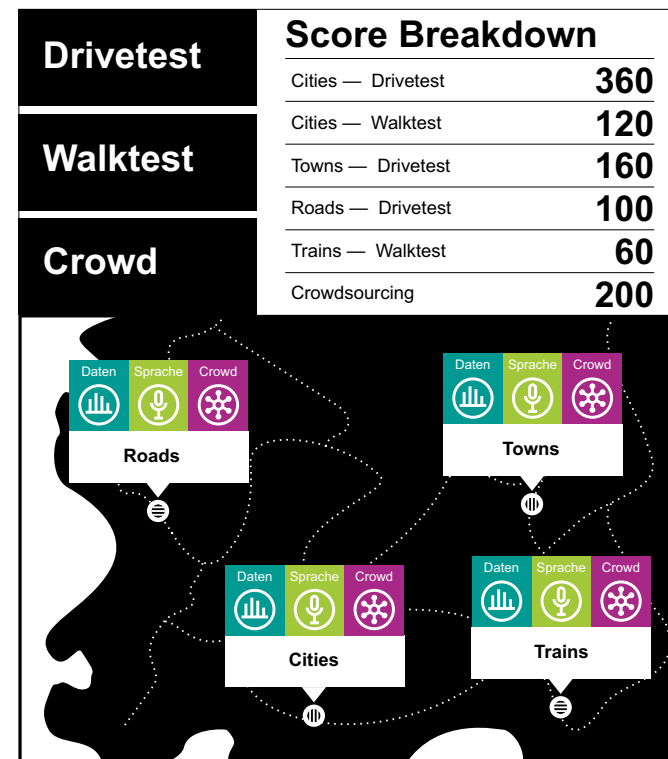
Another aspect determined in the crowdsourcing are degra-



Boxes mounted to the rear and side windows of the cars contain the smartphones used for testing.

dations or anomalies in the (data) network connectivity. A sophisticated algorithm distinguishes simple loss of network coverage (such as in elevators, car parks or buildings with poor indoor reception) from actual degradations. Incidents that occur at night between 10 pm and 8 am are not considered. Points will be deducted for the number of days and the number of hours with recognized service degradations.

A even more detailed description of our methods and the results for other countries can be found online at www.connect-testlab.com. >>



Participate in our crowdsourcing

The connect app not only allows you to take part in our crowdsourcing. Above that, you receive latest telecommunications news and you can also check the speed of your network with an informative speed test. The Android version additionally reveals interesting details like data consumption and usage time per app.

Only if you agree, the app will also perform completely anonymous connection tests in the background. The required data is less than 2 MB per month.



Android version



iOS version



Connectivity at a glance: The "history" shows when and with which technology and speed you were online.

You will find the according downloads in the app stores of Google or Apple with the adjacent QR codes.

Fairness and Transparency

The process of our mobile network test starts long before the actual execution of the measurements. In doing so, the longtime experience of connect and umlaut helps us to adequately look into even last-minute allegations.

■ To ensure fair and transparent testing, in recent years certain routines proved to be helpful. This includes connect and umlaut informing the operators at an early stage about the basic parameters of our tests.

Among other details, this so-called framework consists of the smartphones used for testing and the firmware installed on them, the KPIs gathered during the measurements and being considered in the evaluation, the basic scoring scheme and the exact timing. connect and umlaut defined these frame conditions for this year's mobile network test early in 2019 and subsequently informed the CTOs of the

operators about them. We are then open for feedback and suggestions, but critically check every single one and also have to reject many of them.

But the competitors also eye each other suspiciously. Thus, shortly before our editorial deadline, one operator confronted us with the allegation that a competitor had provided us with SIM cards which would assign their users a larger share of bandwidth than the most powerful tariff of the operator in question would normally allow for. We investigated this accusation – but controlling the terms and conditions of the affected tariff at first re-

mained inconclusive. However, the comparison of the borrowed test SIMs with a regularly bought one, which is part of our standard testing procedure, revealed that both SIMs operated identically – even in situations with heavy network utilisation. This implied the conclusion that there was no attempt of fraud, but that the suspect had not clearly communicated the respective contract conditions.

The fact that such discussions and disputes are fought very intensively and also until the last second, is once again proof that the operators take our methodology and also our results very seriously.

Conclusion

Hannes Rügheimer,
connect author



The fact that the rankings in all three tested countries did not change compared to the previous year, proves again the very high level that the competition of the operators takes place on.

Because in order to make sure that our network test stays the de-facto industry standard also in its 26th year, we regularly update or testing and evaluation methods to the advancing technological development. Part of this is that umlaut and connect raise our thresholds and requirements from year to year. If under these conditions really all operators manage to improve over their results from the previous year, as is was the case this time, we are particularly happy. For this proves that our demanding network test ultimately helps to improve the networks – to the

advantage of all customers.

In Germany, a strong Telekom gains the overall victory for the ninth time in a row. The Bonn company even managed to once again improve its scores in the voice discipline and in the crowdsourcing. Also Vodafone which ranks second improved its results. But definitely the greatest leap forward in Germany is achieved by Telefónica/O2. Overall good measurement results but also good marks in the crowdsourcing show that the Munich-based operator made notable headway in the last year in integrating the formerly separate networks of E-Plus and O2.

But the performance level which overall ranks below those from the two neighbouring countries and particularly the poor results of our measurement in the

trains make quite clear that there is still much to do for the German operators.

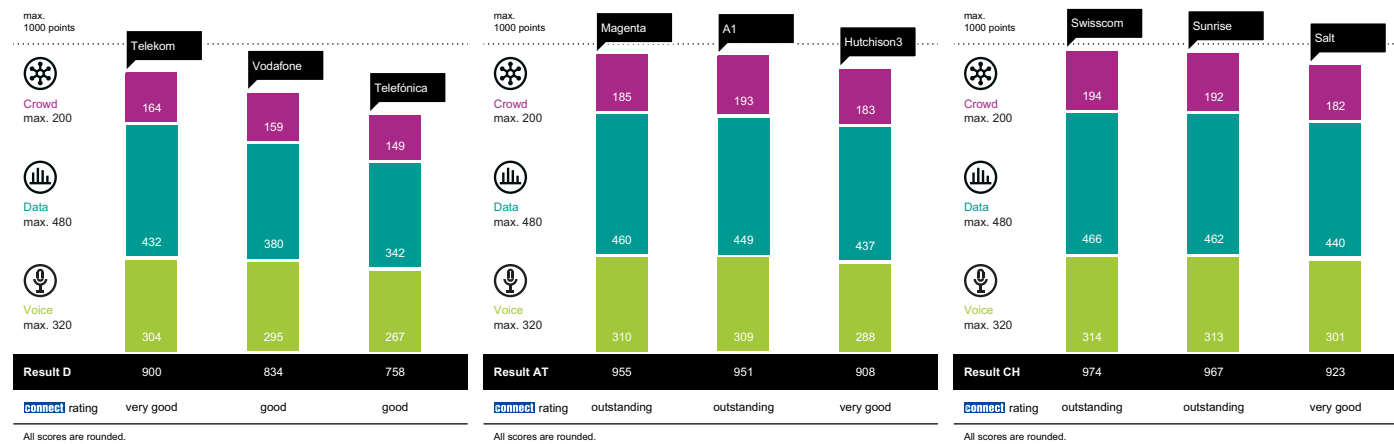
In Austria, Magenta (the former T-Mobile Austria) takes the overall win again this year – and gains the top grade “outstanding” for the first time. The effects of the very close run at the top are well felt by A1 Telekom – which also receives the grade “outstanding” but ranks second at a distance of only four points to the test winner. The smallest network operator in the Alp republic, Hutchison's brand Three, achieves the overall grade “very good” which still designates the most distinct improvement over the previous year among the Austrian providers.

On a still somewhat higher level the neck-and-neck race in Switzerland is fought. But there,

the result shows a somewhat larger distance. Swisscom defends its top position and gains the overall grade “outstanding”. Sunrise scores seven points behind but is also rated to be



“outstanding”. Salt, the smallest operator in Switzerland, achieves the grade “very good” – but can be pleased about achieving the highest growth in points over the previous year.



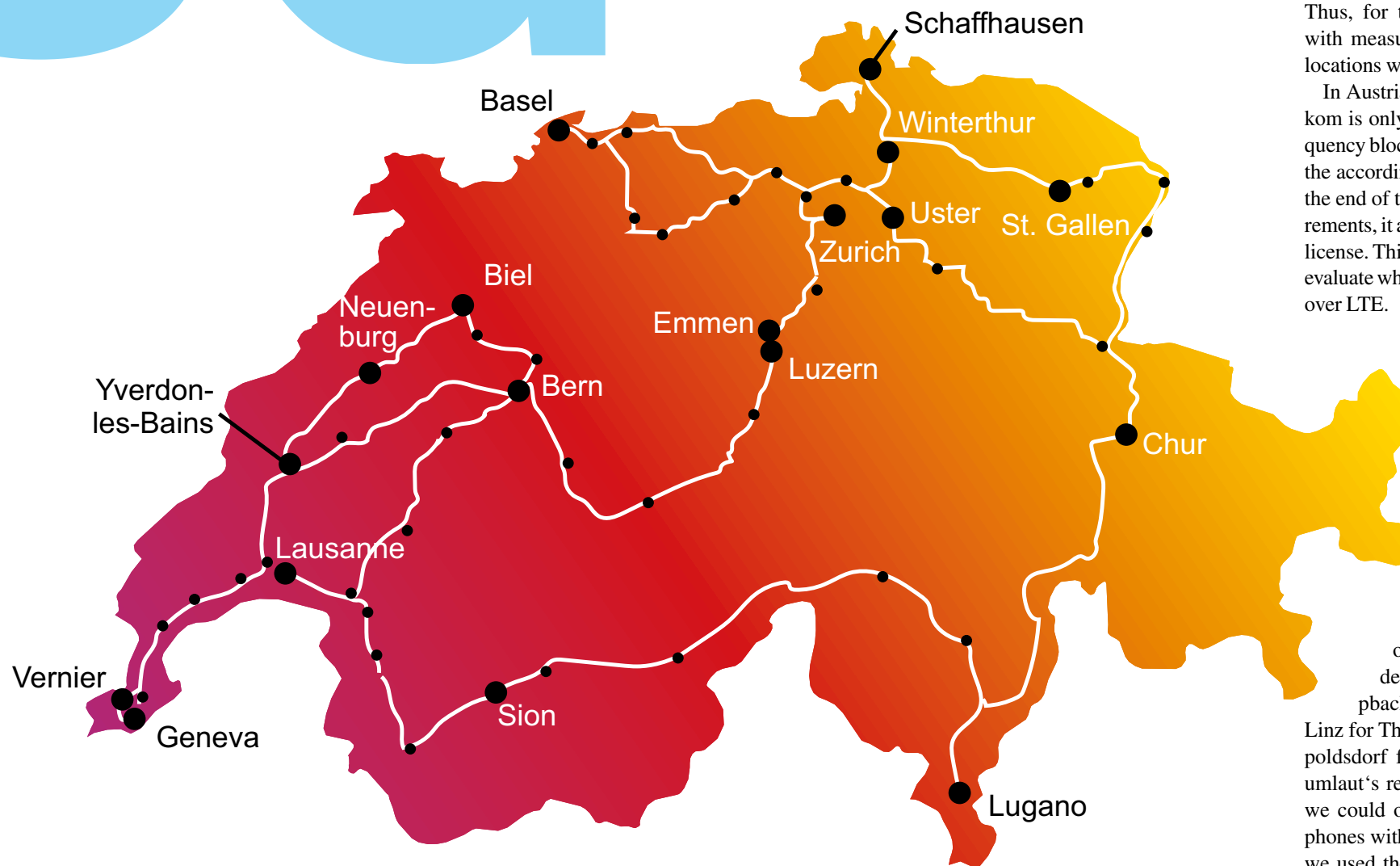
| GERMANY | | | | AUSTRIA | | | SWITZERLAND | | |
|-------------------------------------|-----------|----------|------------|-------------|-------------|------------|-------------|-------------|-----------|
| Overall Results Voice, Data & Crowd | Telekom | Vodafone | Telefónica | Magenta | A1 | Hutchison3 | Swisscom | Sunrise | Salt |
| Voice max. 320 points | 304 | 295 | 267 | 310 | 309 | 288 | 314 | 313 | 301 |
| Cities Drivetest 144 | 95% | 93% | 89% | 99% | 99% | 95% | 98% | 98% | 95% |
| Cities Walktest 48 | 97% | 96% | 94% | 97% | 98% | 96% | 100% | 100% | 98% |
| Towns Drivetest 64 | 97% | 92% | 82% | 95% | 98% | 90% | 98% | 100% | 92% |
| Roads Drivetest 40 | 98% | 92% | 73% | 98% | 96% | 91% | 99% | 96% | 91% |
| Trains Walktest 24 | 80% | 80% | 50% | 86% | 77% | 50% | 96% | 92% | 89% |
| Data max. 480 points | 432 | 380 | 342 | 460 | 449 | 437 | 466 | 462 | 440 |
| Cities Drivetest 216 | 94% | 82% | 77% | 98% | 96% | 95% | 97% | 97% | 93% |
| Cities Walktest 72 | 93% | 88% | 81% | 95% | 95% | 88% | 96% | 98% | 91% |
| Towns Drivetest 96 | 90% | 75% | 64% | 97% | 94% | 94% | 98% | 96% | 90% |
| Roads Drivetest 60 | 92% | 82% | 69% | 97% | 97% | 95% | 99% | 97% | 95% |
| Trains Walktest 36 | 60% | 48% | 39% | 80% | 68% | 59% | 92% | 88% | 80% |
| Crowd max. 200 points | 164 | 159 | 149 | 185 | 193 | 183 | 194 | 192 | 182 |
| Country | 60 | 97% | 90% | 93% | 88% | 100% | 97% | 100% | 100% |
| Urban | 84 | 71% | 71% | 69% | 95% | 94% | 93% | 94% | 95% |
| Non-urban (Benchmark View) | 44 | 84% | 81% | 62% | 93% | 96% | 85% | 99% | 95% |
| Non-urban (Own Network View) | 12 | 81% | 79% | 59% | 90% | 93% | 83% | 96% | 94% |
| Total max. 1000 points | 900 | 834 | 758 | 955 | 951 | 908 | 974 | 967 | 923 |
| connect rating | very good | good | good | outstanding | outstanding | very good | outstanding | outstanding | very good |



All values have been rounded to integer numbers. The internal calculation of points and percentages was based on three decimal places. Intermediate results therefore can slightly deviate from the specified values.

EARLY MEASUREMENTS

Many operators talk loudly about their 5G network upgrades. Still, the new standard is not yet completely ready for our network test. However, umlaut conducted measurements for connect which reveal what the fifth generation of mobile communications can already offer today.



Wherever we look, we see 5G in the starting blocks. Our longtime network testing partner umlaut and we are also ready to evaluate the 5G network extensions with according measurements. The devices needed for this are available – as well as the necessary knowledge. However, 5G implementations stand only at their very begin-

ning in Austria and Germany, whereas in Switzerland one operator – Sunrise – has already started a large-scale 5G rollout. But the implementation of the still young mobile communications standard is accompanied by dependencies and problems. It is not a given that the young networks' functions are fully compatible with all new smartphones. And not every

tuning approach in the networks is met by a mobile phone available on the market which supports this exact feature. Therefore, the early rollouts can not yet be fully evaluated. Consequently, we have excluded it from the setup of this year's network test. But as Vodafone and Telekom assiduously build 5G network cells and gather their first experiences with them, we were also keen on

getting a first impression about what 5G is able to offer under the conditions of our network testing. But as the many tens of thousands of network cells in Germany only include a few hundred which are already supporting 5G, umlaut's drivetest cars would have only gathered a very small share of 5G measurements. Thus, for the moment we settled with measurements at a few fixed locations which already offer 5G.

In Austria, the operator A1 Telekom is only allowed to use the frequency blocks which it purchased in the according auction starting from the end of this year. For our measurements, it activated a site with a test license. This allowed us to precisely evaluate which advantages 5G offers over LTE.

The Measurements

So, Austria only allowed for a limited view, as 5G was not yet commercially available in all networks. As the result of consultations with the operators, we had to consider further peculiarities on top of visiting the pre-determined locations in Alpbach for A1 Telekom, in Linz for Three and in Klausen Leopoldsdorf for Magenta. Instead of umlaut's regular benchmark setup, we could only use specific smartphones with speedtest apps. For A1 we used the Samsung S10 5G, for Magenta the Huawei Mate 20X 5G and for Three the ZTE Axon 10 Pro 5G as their preferred devices. In the measurements, 5G convinced with download data rates between 500 and 1100 Mbps. On average, this is five times faster than the smartphones which we used for comparative 4G measurements – and also particularly faster than what can be commonly expected in the fixed-line network.

| Switzerland | | Sunrise | | Swisscom | |
|-------------------------|--------|-----------|-----------|-----------|-----------|
| Number of Measurements | | | | | |
| 5G | | 778 | | 69 | |
| Mixed | | 372 | | 965 | |
| 4G | | 15028 | | 14970 | |
| Percentage 5G only | | 4,80% | | 0,43% | |
| Percentage including 5G | | 7,10% | | 6,50% | |
| | | 5G | 4G | 5G | 4G |
| Download | | | | | |
| Reliability | | 100,0% | 99,9% | 100,0% | 100,0% |
| Average Throughput | (Mbps) | 405 | 86 | 219 | 107 |
| 90%/10% faster than | (Mbps) | 226/571 | 23,2/166 | 144/253 | 27,5/204 |
| Session Time | (s) | 0,4 | 1,1 | 0,5 | 0,9 |
| Upload | | | | | |
| Reliability | | 98,4% | 99,8% | 100,0% | 99,8% |
| Average Throughput | (Mbps) | 51,3 | 33,6 | 30,6 | 46,3 |
| 90%/10% faster than | (Mbps) | 22,6/83,1 | 8,6/56,8 | 11,5/61,9 | 21,0/61,5 |
| Session Time | (s) | 0,7 | 1,2 | 1,5 | 0,7 |
| Website Access | | | | | |
| First 500 kilobits | (s) | 0,53 | 0,67 | 0,51 | 0,63 |

Even considering that the resources of an LTE network are distributed over more users, this is a significant speed advantage for 5G.

In Germany, the network test experts of umlaut could already dig a little deeper. With a measurement car retrofitted with Samsung S10 5G, a drivetest team visited three suggested municipalities per operator. For Telekom they were located in Berlin, Cologne and Darmstadt, while Vodafone recommended places in Ratingen, Düsseldorf and Offenbach/Main. Telefónica is obviously dedicated to optimize its LTE network and did not yet take part in the 5G comparison.

In the average of all throughput measurements, 5G showed more than three times the speed of LTE – again a remarkable performance boost. However, the advance shrank when we compared the maximum throughput rates. Here, the newest generation of mobile communications reached 695 Mbps – which is not quite as far ahead of LTE. The latter partially owes its good result of 401 Mbps to the very effective so-called carrier aggregation – the bundling of more than one frequency bands. This works well especially in not too crowded network cells.

An interesting observation is that the new mobile communication standard lags a little behind LTE when it comes to uploads. One of the reasons is that in the current implementation, non-standalone 5G always requires a 4G connection which controls the 5G data transfers. Currently, according to a Telekom specialist, only the downloads actually make use of 5G. Uploads are still executed via 4G, but with additional protocol overhead. When 5G will also support uploads – and even more with „stand-alone 5G“ which does not require a 4G link any more, the speeds of data uploads are definitely bound to change.

In Switzerland which currently precedes Europe in terms of mobile communications, we went all the way. Simultaneously to our network test, we sent an additional drivetest car carrying Samsung Galaxy S10 5G on the way. It drove the same

| Germany* | | 5G | 4G |
|--------------------|--------|------|------|
| Download | | | |
| Average Throughput | (Mbps) | 516 | 164 |
| Maximum Throughput | (Mbps) | 695 | 401 |
| Upload | | | |
| Average Throughput | (Mbps) | 49,2 | 58 |
| Maximum Throughput | (Mbps) | 61,2 | 86,8 |

*Telekom and Vodafone, average results from locations suggested by the operators

Generational Conflict

Each time a new mobile communications standard is introduced, this is also a wake-up call for the opponents of this technology. This is true again for the fifth generation, which stirs up the debate due to its new properties – a debate which was believed to be already resolved.

■ Among the arguments which opponents of mobile communication invoke against 5G, are the growing numbers of radio cells, the use of higher frequencies and the so called „beam forming“ – which means directing the radio signals straight onto the users.

However, critics often ignore that radio exposure is actually reduced with a growing number of network cells. The reason is that the intensity of a radio signal rapidly decreases with growing distances. In order to compensate for this, the transmitter has to tune up its power the farther it is positioned from the receiver.

In order to save battery power and energy in the base station, the transmitter and the smartphone both reduce their transmission power for each connection as far as possible. The closer they are together, the less power they use for the transmis-

sion. Therefore, a tighter network of base stations actually leads to lower radio exposures – both for the user caused by his smartphone as well as for bystanders caused by the radio cells.

The higher frequencies of millimeter waves are currently beside the point, because the first 5G implementations start in the sub 6 GHz spectrum, in Germany at around 3.6 GHz. These frequencies are part of the well-tried range between 2.6 GHz for LTE and 5 GHz for WiFi. Concerning millimeter waves, research was intensified. But it is evident already that higher frequencies penetrate human tissue less deeply. Thus, for example the human brain is better shielded against millimeter waves.

It is understandable that beamforming – the focusing of signals to the recipient – can be viewed as a threat. But here



again the output level is reduced so largely that only the necessary minimum reaches the receiver. The maximum radio exposition of a single user stays about the same. And bystanders are exposed at a much lower level reaching down to practically nothing, when they are situated outside the directed beam.

Even after almost 20 years in which more than 50 percent of the population in Europa have used mobile phones, the accurately recorded official cancer registers show no evidence of rising cancer figures due to mobile communications. This should give even the critics something to think about.

routes as our official network test cars. In doing so, the distance between the 5G and the 4G measurement cars was always wide enough to make sure that one car would not affect the transmissions of the other. Thus, the measurements in the 5G model country were executed according to connect's network test standards. In this context, Swisscom claims to have commercially launched 5G in eight cities on April 17th, 2019. Sunrise specified that it already reached 152 cities with 5G by March 30th, 2019.

Of all the measurements, in the Sunrise network already 4.8 percent were completely conducted in the 5G network. For Swisscom the number was substantially lower with a share of 0.43 percent. When taking into account those measurements that contain a partial share of 5G, the percentages came closer together with 7.1% over 6.5%. The lead of Sunrise is all the more surprising as

this operator focuses its 5G implementation to smaller cities and even villages as a fixed-line substitution – while the network test has a larger share in the more densely populated urban areas in order to represent a sufficient share of the total population. In any case, the determined data rates are remarkable, particularly regarding the expectable minimum download speeds (90 percent faster than). In this KPI, Sunrise shows a speed increase by a factor of 10. And even in the slowest it is still 10 percent faster than the maximum speed of many DSL lines in Germany. The minimum speed in the Swisscom network is also faster by a factor of 5, although it already marks the top at 4G within the test area of Germany, Austria and Switzerland. Sunrise also shows an increase in the upload data rates with a minimally reduced 5G reliability in comparison to LTE. In the Swisscom network, we observe the same slowdown as in Germany.

This is only an intermediate result of the 5G implementations in Switzerland which were recently somewhat slowed down due to the flare-up of protests by opponents of mobile communication (see box above). But now it gains momentum again, especially as Swisscom plans to re-allocate parts of the LTE spectrum for 5G on demand via Dynamic Spectrum Sharing (DSS) by the end of the year. Provided that DSS capable phones are soon available, this way a 5G coverage of all of Switzerland could become possible quickly. Sunrise also observes this technology, but currently upgrades its network the conventional way. At the time of writing, it was claimed to cover 331 municipalities – and counting.

And this is good, as unlaut and connect plan to re-visit Switzerland soon again in order to measure a complete 5G network. As for Germany, we are keenly observing the development. **Hakan Ekmen, Bernd Theiss**