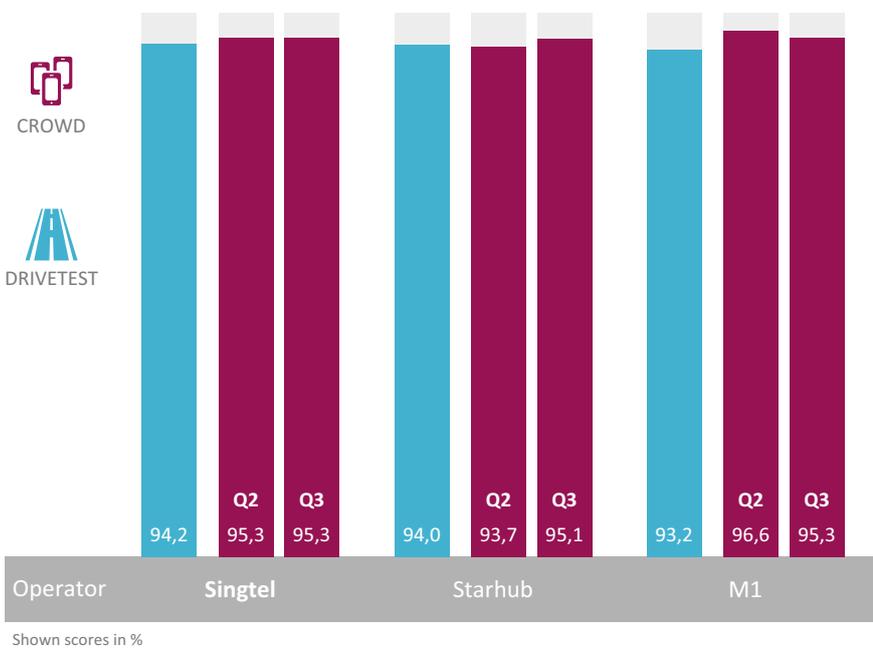# THE
2018
MOBILE REVIEW
FOR SINGAPORE

For the first time, the network bench-marking expert P3 and connect magazine have tested the mobile networks in the city-state of Singapore. We have conducted a drivetest as well as a crowd based analysis over six months resulting in the following comprehensive Mobile Review.

Thanks to strict regulatory require-ments, the network quality of all Singapore operators is very high. This makes it very intersting to compare their performance with that of other leading world capitals. Also, we have taken a detailed look into the perfor-mance of each Singapore operator.

Operator	**Singtel**			Starhub			M1		
	94,2	**Q2** 95,3	**Q3** 95,3	94,0	**Q2** 93,7	**Q3** 95,1	93,2	**Q2** 96,6	**Q3** 95,3

Shown scores in %

All three Singapore operators deliver a high level of data performance while ranking very closely. However, in the drivetest results, Singtel is slightly ahead, The crowd results are good overall, but show a slight lead of M1 in some of the KPIs.

RESULTS IN A NUTSHELL

The Singapore market is known for its high network quality. Thus, it is not surprising that the three operators considered in this review rank closely. And still, our holistic network testing approach, comprised of a data-centric drivetest and sophisticated crowdsourcing analyses, reveals specific strenghts of each operator.

As this Mobile Review for the networks in Singapore does not use the full methodology of our regular Network Benchmarks, we abstained from ranking or grading the operators. However, the results of our data-centric drivetest and crowdsourcing analysis provides a good indication of their achievements. The drivetest result shows the maximum performance of the networks, whereas the crowd evaluation reflects the actual user experience.

The drivetest results confirm that all three Singapore operators deliver a high level of data performance and rank closely. However, in our drivetest, Singtel shows a slight advantage over its competitors. In the detailed analysis, each operator demonstrates specific strenghts: M1 is ahead in the web browsing tests and also takes a narrow lead in the file uploads. Singtel provides the fastest file downloads, while StarHub scores best in the YouTube measurements.

The extensive crowdsourcing analysis, based on 344 million samples collected in two consecutive 3-month-periods from April to June and July to September 2018, overall validates these findings. The results show the high performance level of all three networks. The quality of 4G coverage was a little lower in the first evaluation period. Singtel and StarHub improved regarding this KPI in the second period, only M1 fell a little behind. On the other hand, the average data rates dropped in all networks in the second observation period. In some of the KPIs, M1 showed a slight advantage. The examination of the Data Service Availability showed minor degradations in the StarHub network in March and in the M1 network in September.

DRIVE-TEST FACTS

99.5%
of population covered

31,003
samples

2,100
km drivetest

CROWD-SOURCING FACTS

19,257
users

344
million samples

97.8%
of the built-up area

OPERATORS IN SINGAPORE

According to the Singapore Info-Communications Media Development Authority's (IMDA) statistics, Singapore's mobile market has a penetration rate of almost 150 per cent. A total of 5.6 million inhabitants hold about 8.5 million mobile subscriptions – comprising of roughly 60 per cent postpaid and 40 per cent prepaid subscriptions.

Singapore Telecommunications Limited (Singtel) was founded in 1992 and today employs more than 23,000 staff worldwide. Headquartered in Singapore, Singtel is also the parent company of the renowned Australian operator Optus. Additionally, Singtel is invested in leading companies in Asia and Africa, including Bharti Airtel (India, South Asia and Africa), Telkomsel (Indonesia), Globe Telecom (the Philippines) and Advanced Info Service (Thailand). With an operating revenue of 17.5 billion Singapore Dollars (about 12.5 billion US Dollars) in the fiscal year 2018, Singtel is one of the largest telecommunications companies in Asia. The group specifies over 650 million customers in 21 countries. In Singapore, Singtel has 4.1 million mobile subscribers, which equals a share in the mobile market of about 48 per cent.

In the course of the liberalisation of the Singapore telecommunications market, StarHub was awarded the licence to provide fixed network and mobile services in 1998. The company was officially launched in April 2000 and has been listed on the Singapore stock exchange since 2004. StarHub currently counts about 2,500 employees. For its fiscal year 2017, the Group published a mobile revenue of 1.2 billion Singapore Dollars (about 0.9 billion US Dollars). When also taking Pay TV, broadband, fixed line and other revenues into account, the company achieved a total revenue of 2.4 billion Singapore Dollars (about 1.7 billion US Dollars) in 2017. For Singapore, StarHub specifies 2.3 million mobile subscribers which equals a mobile market share of about 27 per cent.

M1 Limited (previously known as MobileOne) was formed in 1994, launched its mobile service in 1997 and became a publicly listed company at the end of 2002. M1 now employs over 1,500 people. The company prides itself to have launched South East Asia's first commercial LTE network in June 2011 and to have become the first operator in South East Asia to offer nationwide 4G services from September 2012. For its fiscal year 2017, M1 published an operating revenue of 1.1 billion Singapore Dollars (about 0.8 billion US Dollars). Additionally, the company specified a fixed services revenue of 130 million Singapore Dollars (about 94 million US Dollars). At the end of 2017, M1 had a total of 2.2 million mobile customers and 189,000 fibre subscribers. Its mobile customer base equals a market share of about 26 per cent.

A STUDY INTO THE SINGAPORE MOBILE MARKET

P3, headquartered in Aachen, Germany, is a world leader in mobile network testing. The company has over 3,500 employees worldwide and a turnover of more than 350 million Euros. P3 is partnering with the international telecommunications magazine connect, which has more than 20 years of editorial expertise and is one of the leading test authorities in Europe for telecommunications products and services. Together, P3 and connect have been conducting the most important network benchmark test in Germany for more than 15 years, extending it to other European countries since 2009. Above that, P3 has been conducting its authoritative Mobile Benchmarking in Australia since 2014 where it is well known and respected. P3 and connect also examined many other mobile networks all over the world including those the USA.

In 2017 alone, P3 compiled more than 60,000 measurement hours in more than 80 countries across five continents, with its test vehicles covering almost one million kilometres. Recently, P3 has expanded its testing scope by amending the drivetests and walktests with a sophisticated and statistically highly reliable crowdsourcing approach. As the de-facto industry standard, the P3 benchmarking methodology focuses on customer-perceived network quality. P3's network benchmarks are widely accepted as a completely objective authority.

DRIVETEST AND CROWDSOURCING REFLECT HIGH PERFORMANCE OF THE SINGAPORE NETWORKS

In 2018, P3 and connect have extended the scope of their network assessments to the city-state of Singapore. This market is particularly interesting with its very large market penetration of almost 150 per cent (see the previous page) as well as its very high standard of network quality which is also ensured by strict regulatory requirements.

This year, P3 and connect have started their qualified look into the Singapore mobile market by mainly concentrating on the data quality of the networks – taking into account the typical usage patterns of mobile subscribers as well as the importance of mobile data availability and performance for future applications such as IoT or automotive connectivity. To achieve this, P3 have conducted a data-centric drivetest in May 2018. In order to validate and supplement its results and analyse trends in the development of the networks' performance, we have also performed an extensive crowdsourcing analysis covering two periods of three months each in order to be able to also. The results of both approaches clearly reflected the high performance level of the mobile networks in Singapore.

> "Singapore's mobile operators are among the best in a global comparison with very smart results. Our review confirms that all three Singapore operators deliver high quality while Singtel is showing a slight advantage over its competitors. Our crowd-based benchmarking also reveals that particularly Sydney, Australia, achieves comparably high data throughputs. Therefore, we are looking forward to the certainly very interesting results of our upcoming Mobile Benchmark in Australia."
>
> Hakan Ekmen,
> CEO of P3 communications

⬆⬇ DATA DRIVETESTS

FOR THIS MOBILE REVIEW, WE HAVE CONDUCTED A DATA-CENTRIC DRIVETEST, TAKING INTO ACCOUNT THE TYPICAL USAGE PATTERNS OF MOBILE SUBSCRIBERS AS WELL AS THE IMPORTANCE OF MOBILE DATA AVAILABILITY AND PERFORMANCE FOR FUTURE APPLICATIONS SUCH AS IOT OR AUTOMOTIVE CONNECTIVITY.

SINGTEL IS CLOSELY AHEAD OF A VERY STRONG COMPETITION

In order to assess the performance and reliability of data connections in the Singapore networks, two drivetest cars drove a total of 2,100 kilometres, covering 99.5 per cent of Singapore's population.

Each of P3's drivetest cars was equipped with arrays of Galaxy S8 Smartphones capable of supporting 300 Mbit/s download and 50 Mbit/s upload speeds. All data measurements were done in 4G preferred mode. Each car carried one smartphone per operator.

P3's drivetesting considers fast throughputs as well as the networks' availability and stability. Web page and file downloads or file uploads reward fast speeds, while recording success ratios and assessing YouTube playouts concentrate on reliability aspects. As YouTube streams videos at adaptive bitrates, the average value of the received video resolution is another important performance indicator.

OVERALL HIGH DATA PERFORMANCE

The drivetests show the high performance level of all three mobile operators in Singapore. Determining their overall scores for the data drivetests, all competitors are close together: Singtel achieves 94.2 per cent of the total possible points, StarHub follows with 94.0 per cent and M1 with 93.2 per cent. Although we see some differences in their detailed performances, this is a very good result for all three of them. ▶

Data in Cities - Drivetest	Singtel	Starhub	M1
Web-Page Download (Live/Static)			
Success Ratio (%)	99,6	99,8	99,9
Time to First Byte (ms)	506	425	419
KBytes First Second (kB)	566	561	538
HTTP Static Page DL Qualifier (%)	99,8	97,7	98,8
HTTP Static Page DL Overall Session Time (s)	1,2	1,1	1,0
File Download (3 MB)			
Success Ratio/Avg. Session Time (%/s)	99,8/1,0	99,8/1,2	100,0/2,2
90%/10% faster than (kbit/s)	15938/72948	15669/45810	9073/46083
File Upload (1 MB)			
Success Ratio/Avg. Session Time (%/s)	99,5/0,7	99,7/0,6	99,7/0,7
90%/10% faster than (kbit/s)	10012/ 28369	11512/ 27397	10599/ 31873
File Download (7 Seconds)			
Success Ratio (%)	99,7	99,8	100,0
Avg. Throughput (kbit/s)	66526	60963	39350
90%/10% faster than (kbit/s)	19927/128676	20433/113872	14370/70779
File Upload (7 Seconds)			
Success Ratio (%)	100,0	100,0	99,5
Avg. Throughput (kbit/s)	25708	27293	36076
90%/10% faster than (kbit/s)	13432/47602	15931/36323	13923/57709
Youtube Video			
Success Ratio/Start Time (%/s)	99,0/1,8	99,4/1,8	98,9/1,9
Playouts without Interruptions (%)	99,8%	100,0%	99,7%
Average Video Resolution (p)	1080	1080	1058

WEB BROWSING

M1 AHEAD IN WEB BROWSING

When it comes to accessing live web pages from the widely acknowledged Alexa ranking and the static Kepler test page, M1 is closely ahead of the other two operators. M1's success rates are slightly higher and the download times slightly shorter. This results in a fulfillment rate of 96 per cent in this category. However, Singtel with 94 per cent and StarHub with 93 per cent follow at close distance.

FILE DOWNLOADS & UPLOADS

SINGTEL PROVIDES THE FASTEST DOWNLOADS, ALL THREE ALMOST ON PAR REGARDING UPLOADS

In the download tests, Singtel is one step ahead due to faster average data rates and a higher top speed (P90). StarHub ranks second and M1 third in the download evaluation. Examining their upload performance, all three operators are almost on par with a slight advantage for M1 due to slightly higher average upload data rates.

YOUTUBE

STARHUB SCORES BEST IN THE YOUTUBE MEASUREMENTS

In our tests of YouTube playbacks, StarHub showed a slight advantage over its competitors. This operator achieves a 100 per cent playout without interruptions (Singtel: 99.8 per cent, M1: 99.7 per cent). Also, the overall success ratio is slightly higher in the StarHub network. Still, the mobile reception of YouTube videos provides a very good user experience in all three Singapore mobile networks.

DATA RESULTS AT A GLANCE

Although all three Singapore operators deliver a high level of data performance and rank closely together, in the overall assessment, Singtel shows a slight advantage over its competitors. In the detailed analysis, each operator shows specific strenghts: M1 is ahead in the web browsing tests and is closely ahead of the competition when it comes to file uploads. Singtel provides the fastest file downloads, and StarHub scores best in the YouTube measurements.

CROWD

19,257 users have contributed 344 million samples to our crowd-sourcing analysis of the Singapore networks over two consecutive periods spanning three months each. The evaluation area of our crowd-sourcing represents 97.8 per cent of the built-up area of Singapore.
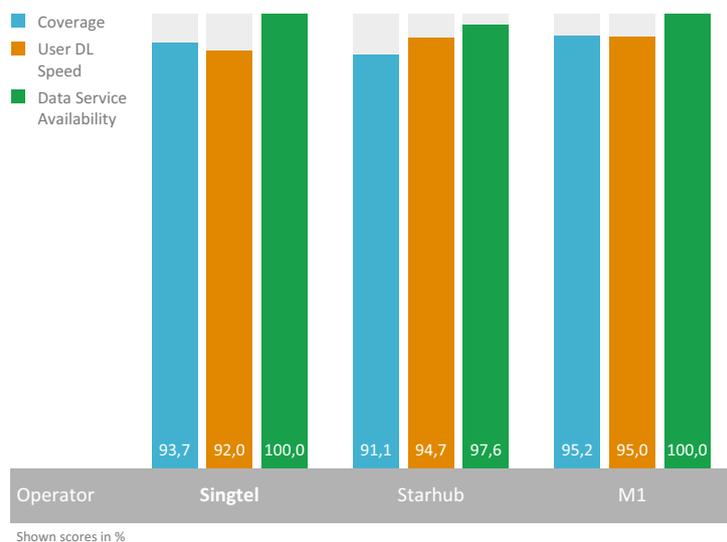
In order to validate and supplement the results of the drivetest, we have also performed an extensive crowd-sourcing analysis of the mobile market in Singapore. This analysis is based on crowd data that has been gathered in two periods of three months each. P3 decided to follow this approach because our crowdsourcing metrics are based on three-month periods. As the drivetests were conducted in May 2018, we wanted to factor in crowdsourcing data from this period as well — resulting in including the measurement period April to June 2018. On the other hand, we also wanted to present data that is as current as possible. This is why we also included a second period ranging from July to September 2018. Considering two consecutive three-month crowdsourcing periods allows us to also have a look at trends and developments between the two compared periods.

The results are based on usage data that have been collected from smartphone users who are utilising one or more of 800+ apps in which P3 has integrated background diagnosis processes determining relevant usage data 24/7, 365 days a year. Quarterhourly reports are generated daily and sent to P3's servers for a thorough analysis (see detailed description of the methodology on pages 9 and 10). This way, more 19,257 users have contributed a total of 344 million samples in the described six-month period. Based on the total population count of 4.6 million people, one of 308 inhabitants of Singapore has contributed to our crowd data. The evaluation area of our crowdsourcing represents 97.8 per cent of the built-up area of Singapore.
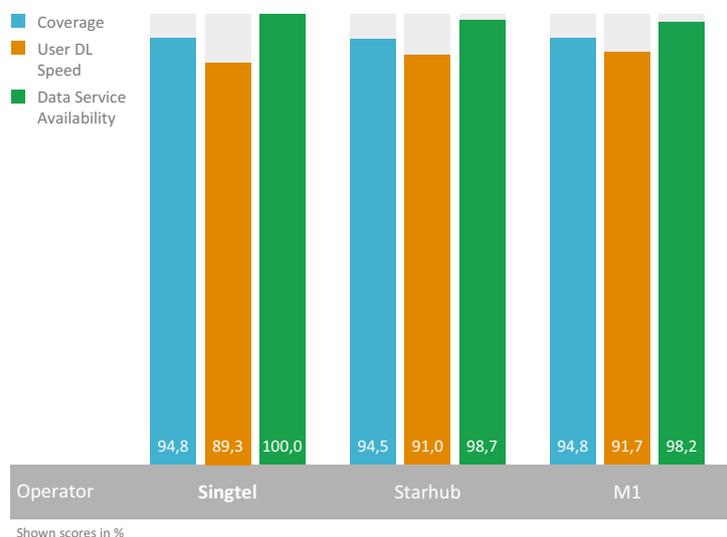
ALL OPERATORS SHOW HIGH PERFORMANCE, BUT THERE ARE STILL SOME VARIATIONS IN THEIR CROWD RESULTS

The overall results of our crowd tests confirm the drivetest results in so far as all three Singapore operators show respectable performance. In an overall assessment, M1 leads the field with a narrow margin in the April to June period. In the July to September period, Singtel and M1 are on par. StarHub follows at close distance in both cases. A direct comparison of both periods shows that Singtel's performance stayed the same, StarHub was able to improve by some percentage points, whereas M1 lost a couple of percentage points. However, these variances are minor all in all.

Overview Score (April - June)

Legend: ■ Coverage ■ User DL Speed ■ Data Service Availability

Operator	**Singtel**			Starhub			M1		
Coverage	93,7			91,1			95,2		
User DL Speed		92,0			94,7			95,0	
Data Service Availability			100,0			97,6			100,0

Shown scores in %

Overview Score (July - September)

Legend: ■ Coverage ■ User DL Speed ■ Data Service Availability

Operator	**Singtel**			Starhub			M1		
Coverage	94,8			94,5			94,8		
User DL Speed		89,3			91,0			91,7	
Data Service Availability			100,0			98,7			98,2

Shown scores in %

P3 connect
MOBILE REVIEW

ALMOST PERFECT VOICE AND DATA COVERAGE FOR ALL OPERATORS AND ALSO HIGH 4G COVERAGE

For all Singapore operators, we observed 100 per cent coverage within our test area for both voice and data services during both observation periods. Even the demanding 4G coverage is very high with values between 97 and 99 per cent. Also, the results for the so called Quality of Coverage (the percentage of actual availability of the mobile network services) were high for voice and data. An examination of the Quality of 4G Coverage shows that these values were a little lower in the first evaluation period with Singtel and StarHub improving in the second period, while M1 received a slightly better result in the first period than in the second one.

When it comes to data rates, M1 shows a slight advantage in the average as well as the top values (P90) of each Users' Best Throughput within the observation time. These averages were 11.2 Mbit/s in the first evaluation period and 10.5 Mbit/s in the second one. StarHub and SingTel each follow at close distance with StarHub achieving 11.1 Mbit/s in the first and 10.3 Mbit/s in the second period, SingTel's results are 10.6 Mbit/s in the first and 10.1 Mbit/s in the second observation period. A possible explanation for the overall drop in these values between the April to June and the July to September period could be a higher number of users in the networks leading to a higher utilisation of the network cells and their capacities.

Stil, SingTel delivers the highest values for the top speeds (P90) observed per evaluation area ("EA"). This applies to both observation periods. The difference to the User's Best Throughput is that these top speeds have been achieved by varying users.
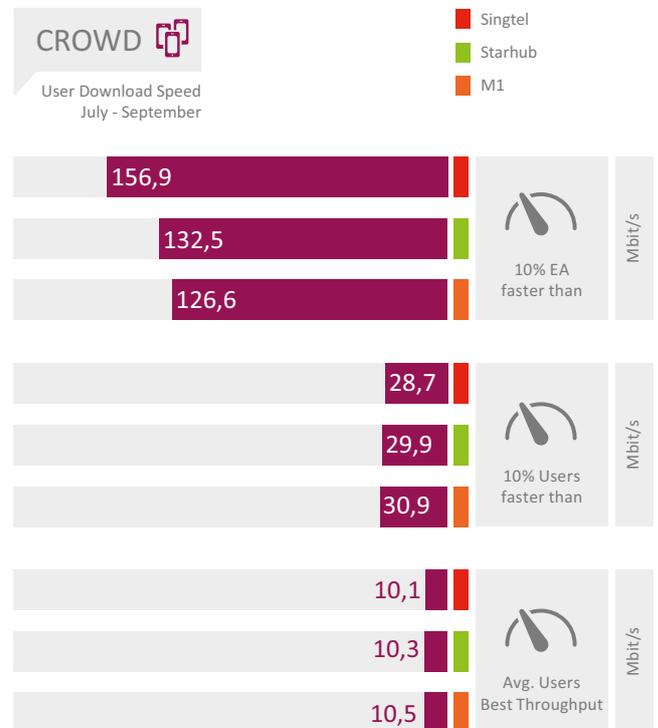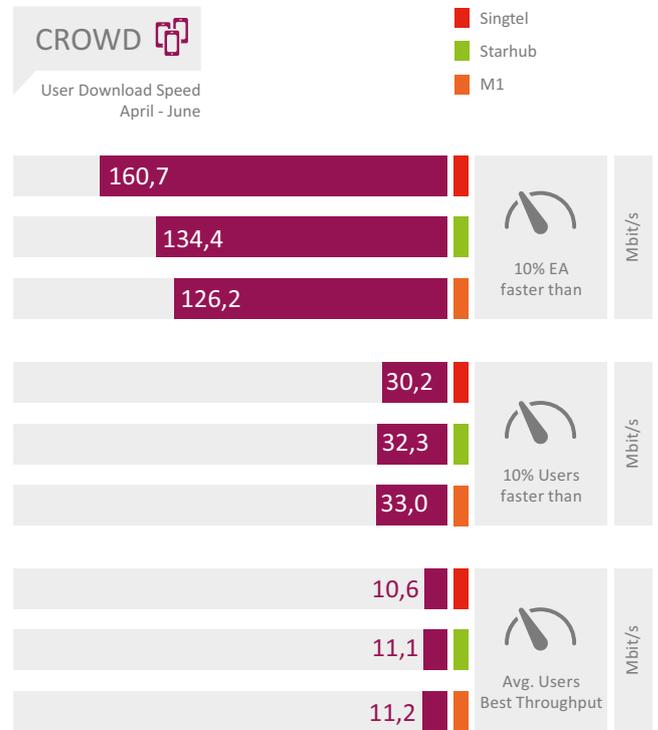
Occasional drops especially in some coverage KPIs between the first and the second three-month period can be explained by user fluctuations – the number of users within a particular observation area is typically not constant between evaluation periods.

SINGTEL SHOWED NO DEGRADATIONS IN BOTH CONSIDERED PERIODS

In the evaluation for Data Service Availability, also all three competitors shows generally pleasing results. Our analysis identified one hour with limited service availabilty in the StarHub network in March and also a two hour degradation in the M1 network in September. Both incidents only had a very limited impact on the users' experience of network availability and stability.

CROWD
User Download Speed
April - June

Singtel
Starhub
M1

	Mbit/s
160,7	
134,4	10% EA faster than
126,2	

	Mbit/s
30,2	
32,3	10% Users faster than
33,0	

	Mbit/s
10,6	
11,1	Avg. Users Best Throughput
11,2	

CROWD
User Download Speed
July - September

Singtel
Starhub
M1

	Mbit/s
156,9	
132,5	10% EA faster than
126,6	

	Mbit/s
28,7	
29,9	10% Users faster than
30,9	

	Mbit/s
10,1	
10,3	Avg. Users Best Throughput
10,5	

DATA SERVICE AVAILABILITY
Affected hours (h) and days (d) (2018)

	March	April	May	June	July	August	September
Singtel							
Starhub	1h over 1d						
M1							2h over 1d

P3 connect
MOBILE REVIEW

CROWD RESULTS AT A GLANCE

The crowdsourced results for the coverage of voice and data services is exceptionally high in the Singapore networks. The Quality of 4G Coverage was a little lower in the first evaluation period, SingTel and Starhub improved regarding this KPI in the second one. On the other hand, the average data rates dropped in all netwoks in the second observation period. In some of the KPIs, M1 showed a slight advantage. The examination of Data Service Availability showed only minor degradations in the StarHub and M1 networks.

HOW DOES SINGAPORE COMPARE TO OTHER WORLD CAPITALS?

As a successful business capital, Singapore is competing with metropolitan areas on a global scale. Therefore we have compared our crowdsourced throughput results gathered in Singapore with those achieved in Berlin, Cape Town, Jakarta, London and Sydney.

A look at the average values of the best throughputs achieved by each individual user participating in our crowdsourcing (see chart below) shows that the Singapore operators deliver considerably high performance also when compared to their global competitors.

HIGHEST OBSERVED DATA RATES IN SINGAPORE AND SYDNEY

M1, StarHub and Singtel provide high data rates to their customers, which in this comparison are only matched by the performances of the Australian operators Telstra, Optus and Vodafone in Sydney.
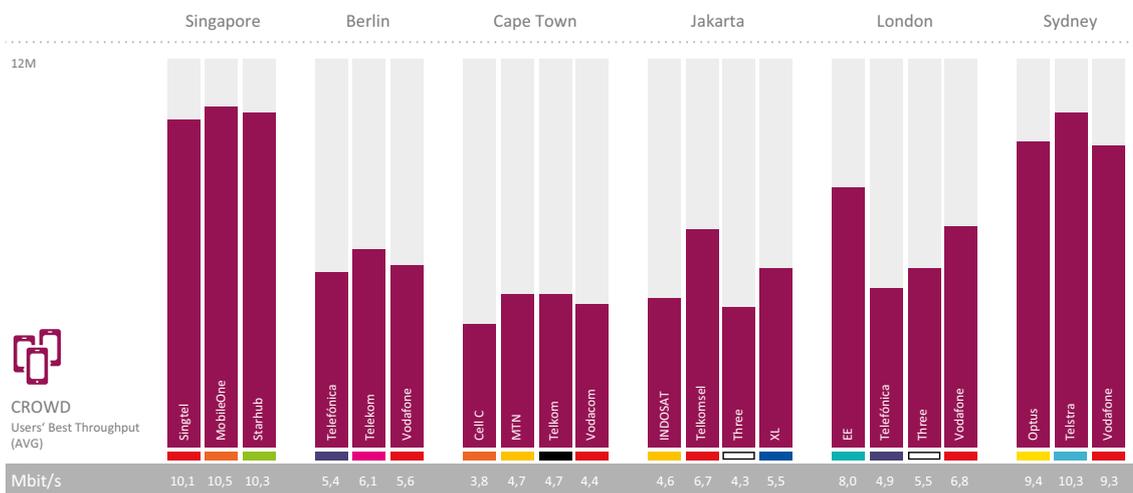
In London, only EE achieves similar results, while the other British operators as well as the mobile networks in Berlin, Cape Town and Jakarta overall deliver slower data rates. When looking at the P90 value (the threshold below which 90 per cent of the gathered values are ranging – see also the description of our methodology on pages 10 and 11), Sydney even shows slightly better overall results than Singapore.

However, when evaluating the actual values, it must be taken into account that areas such as Singapore are densely covered with buildings, whereas cities like Berlin or London contain a higher share of open spaces such as parks or fringe areas, which are provided with less mobile coverage and also comprise of less mobile users.

Furthermore, in order to ensure statistical relevance, we had to exclude Jakarta's smallest operator Smartfren from this comparison.

The analysis at hand concentrates on data throughputs. But an additional look at the Areas and Quality of Coverage with 4G services, 3G/2G data services as well as voice services in the considered cities also shows favourable results for Singapore and Sydney – however, some competitors such as London or Jakarta come close in one or the other of the analysed metrics. Deeper insights can be made available to interested parties on request.

	Singapore			Berlin			Cape Town				Jakarta				London				Sydney		
	Singtel	MobileOne	Starhub	Telefónica	Telekom	Vodafone	Cell C	MTN	Telkom	Vodacom	INDOSAT	Telkomsel	Three	XL	EE	Telefónica	Three	Vodafone	Optus	Telstra	Vodafone
Mbit/s	10,1	10,5	10,3	5,4	6,1	5,6	3,8	4,7	4,7	4,4	4,6	6,7	4,3	5,5	8,0	4,9	5,5	6,8	9,4	10,3	9,3

CROWD
Users' Best Throughput (AVG)

Shown values are rounded.

METHODOLOGY

*The methodology of the P3 connect Mobile Review is the result
of more than 15 years of testing mobile networks. Today, network tests
are conducted in more than 80 countries. They were carefully designed
to evaluate and objectively compare the performance and service quality
of mobile networks from the users' perspective.*

Boxes were mounted into the rear and side windows of each measurement car supporting the smartphones used for the drivetests.

The P3 connect Mobile Review for Singapore includes the results of an extensive data drivetest as well as a sophisticated crowdsourcing approach.

DRIVETESTS
The drivetest was conducted on 12 measurement days from May 2nd to May 16th, 2018. All samples were collected between 8am and 10pm. Two drivetest cars drove a total of 2,100 kilometres, covering 99.5 per cent of Singapore's total population.

Each of P3's drivetest cars was equipped with arrays of Samsung Galaxy S8 Smartphones. These „Cat 9" phones are capable of supporting 300 Mbit/s download and 50 Mbit/s upload speeds. All data measurements were done in 4G preferred mode. Each car carried one smartphone per operator.

DATA TESTING
For the web tests, the test smartphones accessed web pages according to the widely recognised

All test phones used in the drivetests were operated and supervised by P3's unique control system.

Alexa ranking. In addition, the static Kepler test web page as specified by ETSI (European Telecommunications Standards Institute) was used.

In order to test the data service performance, files of 3 MB and 1 MB for download and upload were transferred from or to a test server located on the Internet. In addition, the peak data performance was tested in uplink and downlink directions by assessing the amount of data that was transferred within a seven seconds time period.

Another discipline was the playback of YouTube videos. It took into account that YouTube dynamically adapts the video resolution to the available bandwidth. So, in addition to success ratios, start times and playouts without interruptions, YouTube measurements also determined average video resolution. All tests were conducted with the best performing mobile plan available from each operator.

RANKING AND GRADING
As this Mobile Review is intended just as an indication of network performance and quality, we abstained from ranking or grading the operators considered based on the number of total achieved points. However, the published percentages give a good indication of their achievements.

CROWDSOURCING
As an addition to the drivetests, P3 conducted thorough crowd-based analyses of the Singapore networks. These analyses are

based on crowd data that had been gathered in two periods of three months each. P3 decided to follow this approach because our crowdsourcing metrics are based on three-month periods. As the drivetests were conducted in May 2018, we wanted to factor in crowdsourcing data from this period as well — thus, we have included the months from April to June 2018. On the other hand, we wanted to present as current data as possible, which is why we also included the period from July to September 2018. The consideration of two crowdsourcing periods of a duration of three months each allows us to also have a look at trends and developments between the two compared periods.

For the collection of crowd data, P3 has integrated a background diagnosis processes into 800+ diverse Android apps. If one of these applications is installed on the end-user's phone, data collection takes place 24/7, 365 days a year on this device. Reports are generated for every 15 minutes and daily sent to P3's cloud servers. Such reports generate just a small number of bytes per message and do not include any personal user data. Interested parties can deliberately take part in the data gathering with the specific "U get" app (see box on next page). ▶

Other crowdsourcing solutions have a very technical user base. Thus, their results are typically skewed towards high-end, heavy data users. With the integration into more than 800 diverse apps covering different market segments, P3 has generated data which is a fair and equal representation as opposed to that of classical speed test apps. The unique crowdsourcing technology allows P3 to collect data about real-world customer experience in a truly passive way – wherever and whenever customers use their smartphones.

P3's crowdsourcing data set is the most realistic, since it is the most diverse that is currently available in the market in terms of locations, geography, times, devices, subscriptions, networks, technologies and smartphone usage patterns. P3 applies advanced big data analytics to distill the essence of information from the bulk data. By analysing data according to predefined metrics, P3 can provide information for the optimisation of networks and also show whether networks live up to the expectations of their customers.

RATING OF NETWORK COVERAGE
For the assessment of network coverage, P3 lays a grid of 2 by 2 kilometers over the whole test area. The so-called evaluation areas generated this way are then sub-divided into 16 smaller tiles. In order to ensure statistically

relevant statements, P3 requires a certain number of users and measurement values per operator for each tile and each evaluation area. If these thresholds are not met by one of the considered operators, this part of the map is not considered in the assessment to ensure fair terms.

Even more relevant results are accomplished by not only determining the mere network coverage but also considering its quality. The parameter Quality of Coverage reveals whether voice and data services actually work in the respective evaluation area. P3 does this because not in each area that allegedly provides network reception, the mobile services can actually be used. For this reason, the percentage for Quality of Coverage is always a little lower than the corresponding coverage value. We specify these values each for the coverage of voice services (2G, 3G and 4G combined), Data (3G and 4G combined) and 4G only.

ASSESSMENT OF DATA THROUGHPUTS
Additionally, P3 investigates the data rates that were actually available to each user. For this purpose, we have determined the best obtained data rate for each user during the evaluation period and then calculated the average of these values. In addition, we have determined the so-called P90 values for the top throughput of each evaluation area as well as of each user's best throughput. P90 values specify the threshold in a statistical distribution, below which 90 per cent of the gathered values are ranging – or above

which 10 per cent of the values are situated. These values depict how fast the network is under favourable conditions.

DATA SERVICE AVAILABILITY
Another performance indicator considered in the crowd results is the Data Service Availability. This parameter indicates the availability of a network and the number of outages or service degradations respectively.

In order to differentiate network glitches from normal variations in network coverage, we apply a precise definition of service degradation: A degradation is an event where data connectivity is impacted by a number of cases which significantly exceeds the expectation level. To judge whether an hour of interest is an hour with degraded service, the algorithm looks at a sliding window of 168 hours before the hour of interest. This ensures that we only consider actual network service degradations differentiating them from a simple loss of network coverage of the respective smartphone due to prolonged indoor stays or similar reasons.

In order to ensure the statistical relevance of this approach, a valid assessment month must fulfil clearly designated prerequisites: A valid assessment hour consists of a predefined number of samples per hour and per operator. The exact number depends on factors like market size and number of operators. A valid assessment month must include at least 90 per cent of valid assessment hours (again per month and per operator).