Measurement Methodology

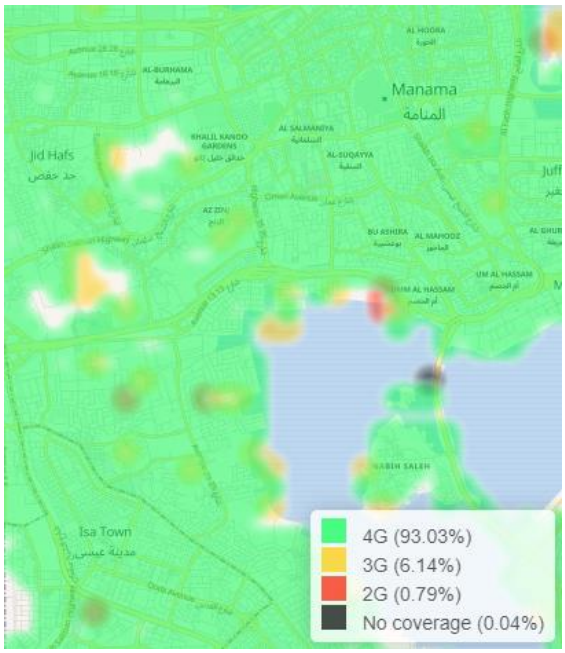
Mobile Coverage Maps

Mobile coverage maps show how the mobile access technologies 2G,3G and 4G are available for mobile handset connections. Our coverage maps offer the ability to zoom in and out to display specific parts of the city or to view the whole country with less detail. The coverage map consists of rectangular blocks which are coloured based on access technology. On highest zoom levels users can see detailed coverage maps with each block representing 100 x 100 meters area. On lower zoom levels the blocks may represent a larger geographic area which is dependent on the number of blocks and zoom level.

Coverage maps by default show all access technologies (2G/3G/4G) by colour. Green block defines that in that particular area covered by the block, 4G is the best available technology used by mobile devices in our crowdsourced data. The availability of that particular technology is defined by the presence of a successful connection of a mobile device to the particular access technology in a given block.

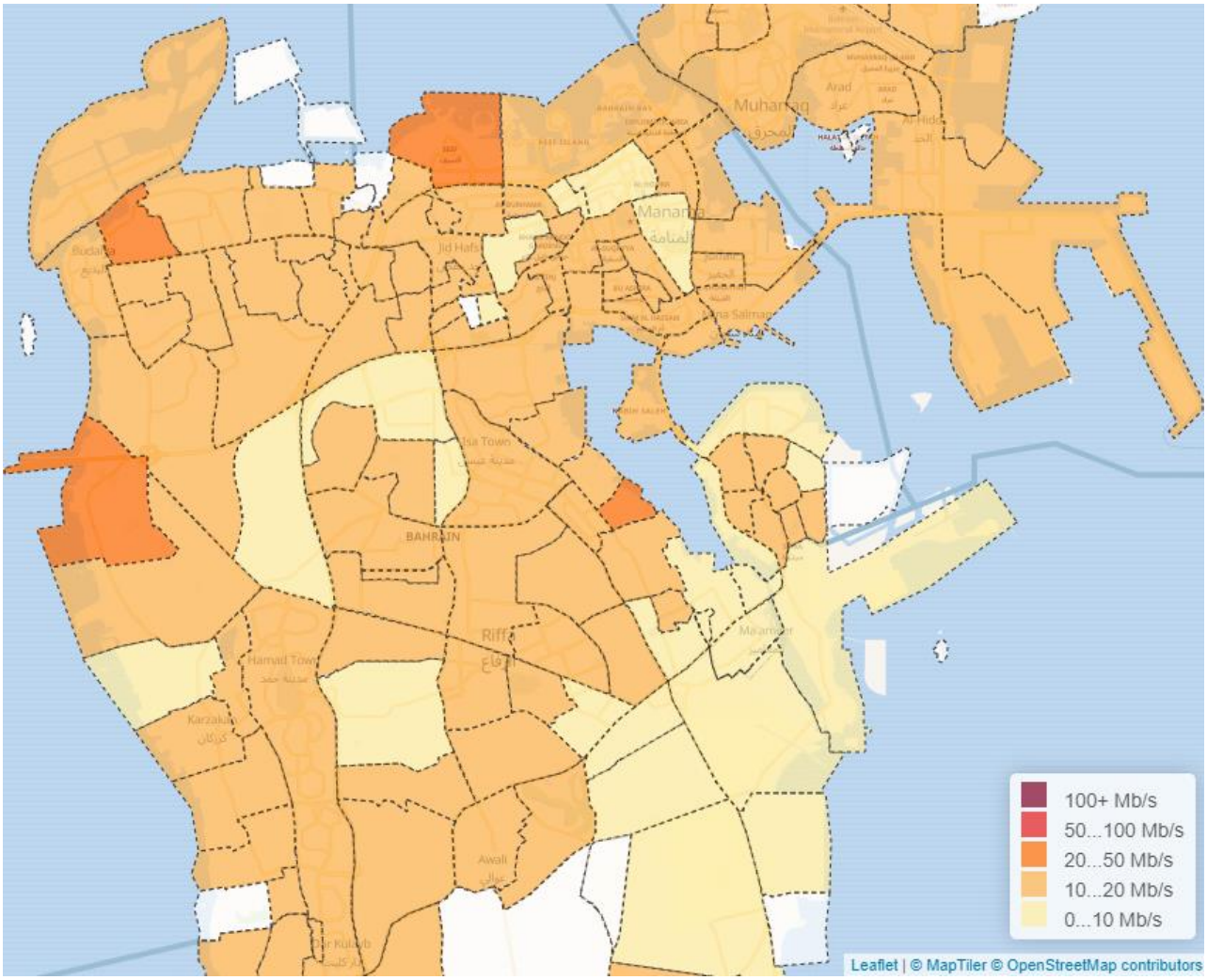
It is also possible to limit the map to one specific access technology.

The areas where there is no coverage are coloured in black. Similarly, if all the mobile devices in a given geographic block do not have any coverage, then that specific block is defined as no coverage. The areas that have no colour (transparent blocks that only show map layer) are the areas that do not have any data samples collected and should be excluded from analysis.



Internet Speed Maps

Traditional visualizations using heatmaps do not represent a true picture of performance in a given area and rather confuse end-users. Single colour-coded dots on the map are influenced too much by an individual user's connection parameters and cannot be individually analysed: they need to be aggregated within a sufficiently large area to give true meaning. SpeedChecker believes internet speed measurements displayed using choropleth maps that show average internet speeds per district (in a given country) not only show accurate information but are also easy to understand by the end users.



How the internet speed is measured and collected

The data for our internet speed maps is collected from end user devices such as Android and iOS phones. All measurements must be collected using a comparable measurement methodology that is described in this document below. Each end user device has a monthly quota on the amount of

transferred data that the active measurements can consume. Monthly quota is communicated to the user during the installation of the app that performs the measurements.

All measurements must contain accurate location information using GPS or wi-fi geolocation method. Measurements are considered only from the apps that have been approved by SpeedChecker. Submitted measurements are checked if they are within expected ranges and additional security precautions are implemented to ensure measurement data is not being manipulated.

Furthermore, measurements from the same device within a defined area (e.g. district) and reporting frequency (e.g. month) are aggregated together to form one average value. This increases the accuracy of the final values by treating data from a large pool of devices in a uniform way without attributing too much weight to devices that are more active than others.

Map accuracy and confidence levels

By default, for our district maps, which are coloured based on the average internet speed, we need to set some thresholds that prevent displaying low accuracy data. It is difficult to read a map with variable confidence levels and therefore by default we set a target of each data point being calculated from at least 10 different user devices. If a particular district does not reach that criteria, we do not colour the district based on speed and leave the district layer transparent.

Fixed broadband speed measurements

When testing fixed broadband speeds using a crowdsourced approach it is important to consider the impact of wi-fi network that end user device is connected to. SpeedChecker own research indicates at least 16% of broadband connections world-wide are accessed using inadequate wi-fi connection which slows the access (https://blog.speedchecker.com/2019/06/20/speedchecker-cpe-wi-fi-performance-ranking/) . The impact of slow wi-fi connections has a direct impact on internet throughput measurements and brings the average internet speeds down. SpeedChecker fixed broadband measurements through wi-fi connections leverage our specially designed wi-fi test which correctly identifies slow wi-fi and subsequently eliminates those measurements from further analysis.

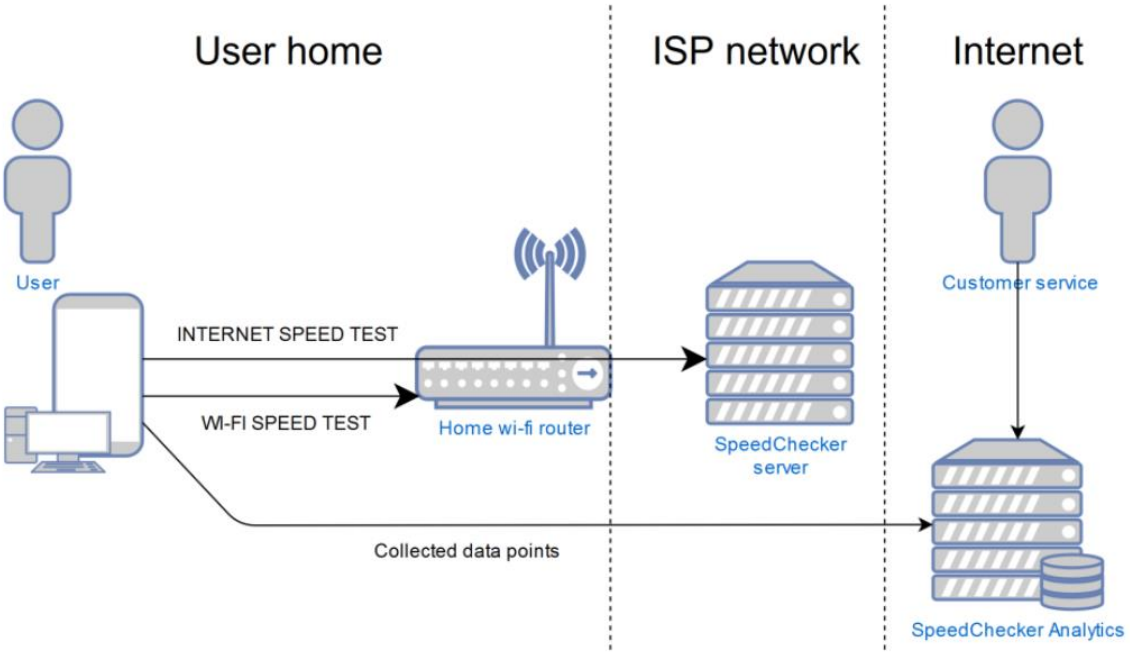


Diagram: Architecture of the measurement setup for wi-fi vs internet speed test.

Usage Trends Map

Overview

The Usage Trend Map is a choropleth map that indicates the user density in a given district in Bahrain. Each district is shaded according to which percentile of the sorted results of user density they are in. Changing the month, ISP or Access Type will show how usage in each district changes.

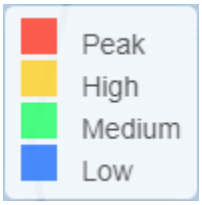
The Method

For each district we record:

- The number of unique users during the specified time
- The area of the district's border
- The user density for each district: users / border area

The calculation takes into account the geographical area of each district by dividing the number of unique users by the area of the district. The same number of users in a smaller district will appear higher in the sorted list than the same number in a larger district.

The results are then sorted in descending order of user density and then each district is coloured according to the which percentile it fits into. The highest density is 'Peak' and coloured red; the lowest density is 'Low' and coloured blue.



The Percentiles

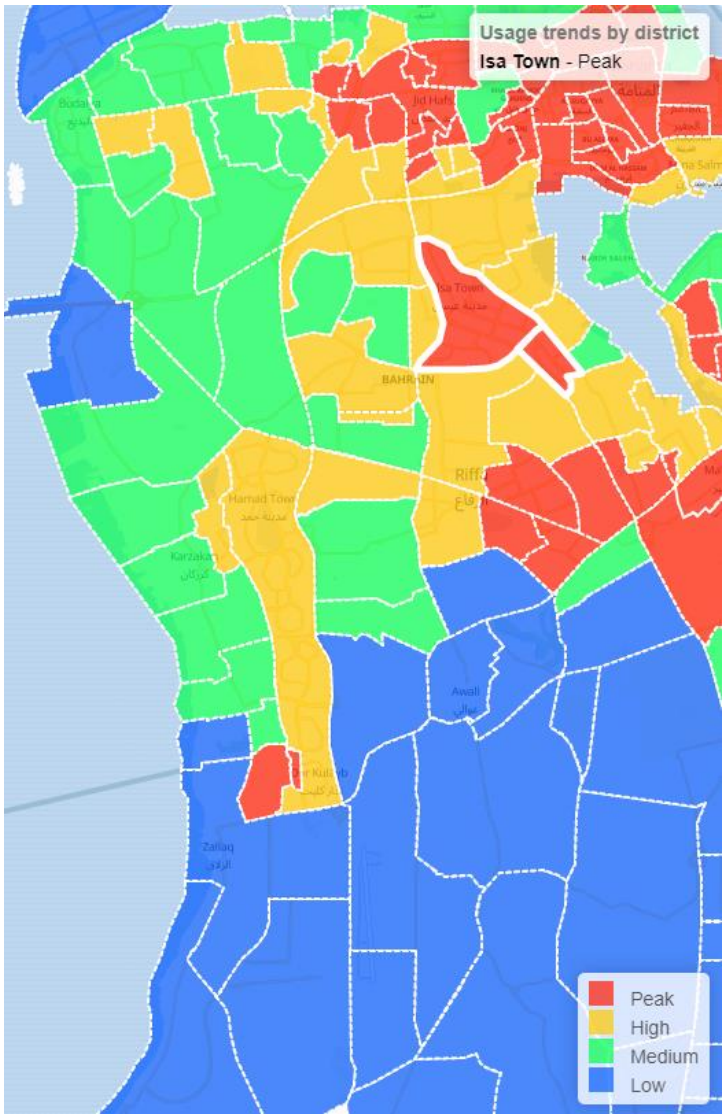
We chose four equally spaced percentiles to show the usage in each district. If a district is in the top 25% of results when sorted by user density it will be in the 75-100% percentile and the district is 'Peak' and coloured Red. Likewise, if it is in the bottom 25% it will be 'Low' and blue.

If there are insufficient results the district remains white.

COLOUR	*PERCENTILE*
Peak	75 - 100%
High	50 - 75%
Medium	25 - 50%
Low	0 - 25%

The Map

The name of the district will appear in the top right column when the mouse hovers over it.



Speed Test Measurement

The speed test algorithm has been developed and improved over time so that it provides accurate and consistent results across all devices, platforms and operating systems. It is important to state that although the measurement algorithm has different implementations on each platform but the results are comparable.

On the Android platform we have foreground and background speed tests which differs in the duration of the test. Foreground tests take 8 seconds on each download and upload phase. Background takes only 2 seconds on each download and upload phase. The reason being as foreground is executed by the user the expectations on accuracy are higher. Background test is not analysed individually but only in aggregate across multiple results and therefore accuracy is acceptable with shorter duration and lower bandwidth consumption.

Data consumption

HTML5 / iOS / Android foreground

3G – up to 8 MB

LTE – up to 25 MB

Fast W-IFI - Up to 50 MB

Android background

3G – up to 2 MB

LTE – up to 6.25 MB

Fast WI-FI - Up to 12.5 MB

Data consumption depends heavily on the available bandwidth on a particular access technology. Typical LTE/3G or fixed broadband speeds vary a lot between different countries. Our table assumes the following average speeds, 3G – 8Mb/s, 4G – 25 Mb/s, fixed broadband via wi-fi 50 Mb/s.

Server selection

Each MNO in Bahrain has setup a dedicated measurement server with sufficient capacity to handle the testing traffic for this project. The location of each server is on-net. For other operators TRA has setup a measurement server in AWS Bahrain datacenter. Users will be routed to the measurement server of their ISP and if that server is not setup or not accessible, the testing will be performed against the AWS server.

Latency measurement

The test uses ICMP and sends 3 packets to the measurement server. The result is calculated as an average of those 3 measurements.

Download and Upload speed measurement

Speed test measurement embedded in our SDK can be running on Android 7 and above and iOS 9.3 and above.

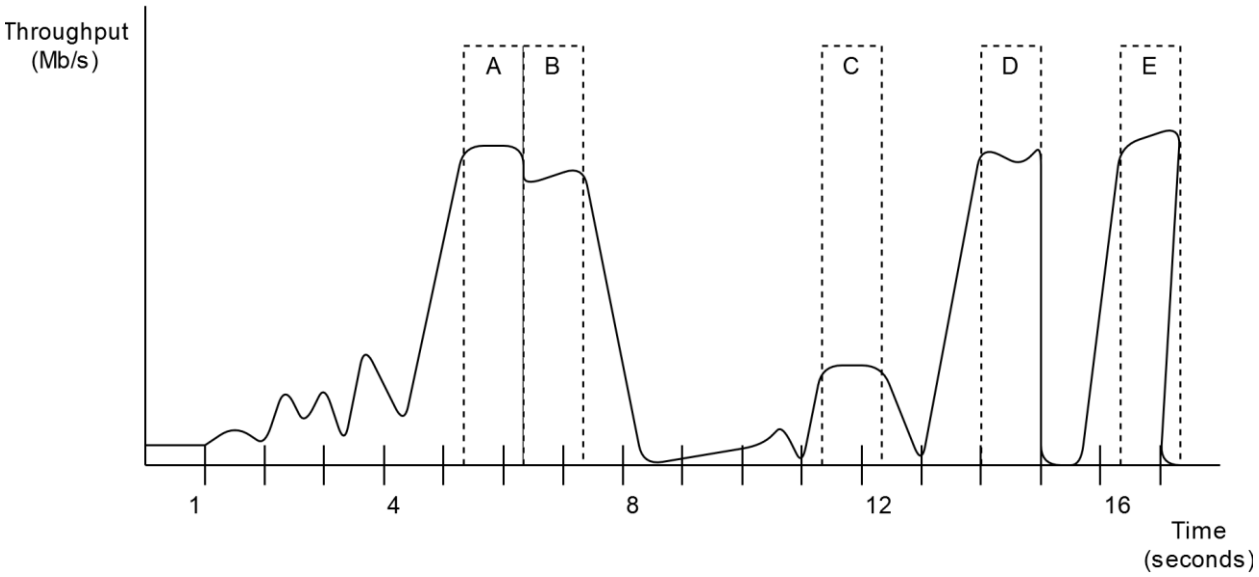
The process involves:

- Choosing between 3 or 4 threads depending on network connection capabilities
- Using HTTP requests to download/upload files between the server and client device. The selected files are large enough to fully saturate the connection for the whole duration of the test.
- Constantly monitoring the performance and speed profile of HTTP threads during testing to ensure accurate feedback to the end user's screen
- Results are sampled with 100ms frequency, after the test completion average speed is calculated from the samples as well as from the raw measurements. The higher value of both average calculations is reported as a final result.
- This process is repeated for the Upload test

Passive throughput measurements

Speedchecker SDK also contains passive measurement module which monitors device network utilization. The module is not active 24/7 due to battery optimization mechanisms but on average we see we can collect passive measurements about 15% of the time. During the time that passive measurement module is monitoring the device network utilization we are waiting for the spikes in network utilization since using those spikes in traffic we can determine maximum available capacity at that given moment. Most of the time user devices are not reaching the capacity therefore the collected passive throughput measurements are discarded. The collected traffic is not application specific. We monitor all network traffic on the device regardless of the application used and we can calculate only the total network traffic (it is not possible to attribute certain throughput to a particular mobile app).

Using the diagram below we illustrate how we determine when the mobile device reaches a peak network utilization.



Under normal traffic conditions when the peak is not reached the total network utilization varies frequently or is near zero. If the peak is reached, the variance in collected throughput samples is much smaller. We take advantage of that phenomenon so that if the average measured throughput stays within 10% range during 1 second, we classify it as a potentially valid sample of the peak capacity measurement. In the diagram above that is measurements A,B,C,D,E. You will also notice that we exclude periods of time where throughput is near zero.

The next step is to calculate average of all the valid samples (A,B,C,D,E). The occasional low throughput measurement can appear in the result (Sample C) but its influence on the result will be minimal since these are rare samples in the overall volume of the collected samples.

Data Collection Sources

SpeedChecker collects measurements from apps operated by SpeedChecker such as our Android and iOS apps

All our data collections including our data partnerships follow strict privacy guidelines of GDPR and require user consent for sharing data location.

We collect location information that is provided or generated in any of the following ways:

- GPS coordinates
- Using the MAC address of wireless routers (an alphanumeric code that is unique to that hardware device)

This location data is collected anonymously in a form that does not personally identify the user. We do not send or store any user/device IDs that could allow tracking of location over a period of time. The location data along with network measurements is used to compile aggregate information about network statistics and bandwidth usage in particular areas but does not allow 3rd parties to track user's location or movement over period of time.

One exception is Report Issue functionality which ties user location and connection data with the user's phone number. This is to ensure that user complaints can be verified for accuracy.