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SAMKNOWS TECHNICAL
Ofcom Mobile and Broadband Checker
White Paper

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IMPORTANT NOTICE

2 Overview

The Ofcom Mobile and Broadband Checker, developed in partnership with SamKnows, is designed to help consumers understand their fixed-line and mobile broadband performance, as well as the availability of these services in their area.

The app is aimed at consumers, particularly those unfamiliar with the technical aspects of networking. Whilst the app sometimes needs to use technical terms to refer to specific aspects of broadband performance or availability, plain English explanations of the terms in use have been provided.

One of the primary features of the app is the detailed fixed-line and mobile availability data that it provides. In particular, users of the app can search for availability data by postcode and even individual addresses.

The app also incorporates a range of network measurements, which assess the quality of the user's Internet connection as well as their in-home Wi-Fi. By default, users are presented with a summary of the services that their broadband connection would be likely able to support (such as HD video streaming) based upon analysis of the network-level measurements.

Users are also presented with a summary of how their (mobile or fixed line) connection (be it mobile or fixed-line) is performing. This analysis takes into account the services available within their area, the user's environment, and the likelihood of their connection being able to support the use of common Internet applications.

The app is the successor to the Ofcom Wi-Fi Checker app released in 2015, and will replace it in the mobile app stores.

The app is compatible with modern Android and iOS based smartphones and tablets. A web-based app is also available with reduced functionality. It is important to note that:

a) The web-based approach does not require software being installed on computers;

b) This approach does not require any hardware to be installed in the home or premises;

c) The software does not monitor the services or applications on the user's device.

3 Mobile Broadband Coverage

The app incorporates postcode-level and address-level coverage data for the UK's four biggest mobile network operators: EE, O2, Three and Vodafone. Coverage is split out by voice, 3G data and 4G data, for both indoor and outdoor locations. Users are presented coverage information in an easy-to-understand RAG (Red, Amber, Green) format.

The source data are 100m^2 blocks, with the underlying data supplied to Ofcom by the MNOs.

By default, the app will determine the user's approximate physical location (using the platform's geo-location services), map this to the nearest postcode, and then lookup mobile coverage for that postcode. The nearest 100m^2 block to the left-bottom-most address (i.e. the one with the smallest Eastings/Northings) is used in the display of the postcode-level results.

Users may manually enter an alternative postcode and optionally refine their location down to an individual address. In this instance, the coordinates of the address are used to lookup mobile coverage against the 100m^2 blocks. This is useful in locations where postcodes cover a large geographic area.

The app also provides an interactive map that overlays the Red/Amber/Green coverage status for the area over a map of their physical location. Users can again toggle between the different MNOs, radio access technologies (voice/3G/4G) and indoor/outdoor.

Mobile coverage data will be refreshed monthly from the MNOs.

4 Fixed-line Broadband Availability

The app incorporates postcode-level and address-level availability data for standard, superfast and ultrafast broadband. These terms are defined as follows:

- Standard broadband: Services below 30Mbps
- Superfast broadband: Services at 30Mbps or greater, but below 300Mbps
- Ultrafast broadband: Services at 300Mbps or greater

The results are presented in a technology and provider neutral manner. Underpinning the results is availability data provided by the UK's largest fixed-line network providers, representing ADSL, ADSL2+, VDSL/FTTC, DOCSIS Cable and FTTH access technologies.

Users are presented with an easy to understand RAG (Red/Amber/Green) status to indicate availability of Standard, Superfast and Ultrafast broadband services in their area. Moreover, the expected download and upload performance for each of these services is also visible to the user.

By default, the app will determine the user's approximate physical location (using the platform's geo-location services), map this to the nearest postcode, and then lookup fixed-line broadband availability for that postcode. Expected speeds in each broadband category are based on the highest predicted speed across premises in the postcode.

Users may refine their search by entering a different postcode or selecting an address belonging to that postcode. In the case of an address-level search, the expected speeds at that individual address are displayed to the user.

The app also provides an interactive map that overlays average speeds over a map of their physical location.

Fixed-line broadband availability data will be refreshed regularly.

5 Measurement Methodology

At a high level, the app uses a series of network-level measurements (such as download speed, upload speed, latency and packet loss) to assess the quality of the user's network connection. In turn, these results are also used to infer the likelihood of the user being able to support common Internet applications (such as HD video streaming).

This section of the document describes the underlying methodology for each of the key measurements used within the app.

Background

Upon starting a test, the app performs some preliminary checks to ensure that testing can reasonably proceed. This includes ensuring that:

1) If the user has requested to run tests over Wi-Fi, then verify that they are connected to a Wi-Fi network and this is their active network connection. If not, prompt the user to enable Wi-Fi and connect to a network.
2) If the user has requested to run tests over mobile, then verify that they are not first connected to Wi-Fi (as the device will prefer Wi-Fi networks if available).
3) The user is able to reach the Internet and communicate with the London-based measurement servers.

Assuming these checks are successful, the tests outlined in the following sections run immediately in a predetermined sequence.

At the conclusion of the tests, the user is presented with an assessment of the quality of their network connection (see the Outcomes Methodology section), and the likelihood that they will be able to support major Internet services (see the Services Scoring section).

Download and upload speed

This test measures the download and upload speed of the broadband connection in bits per second. The transfer is conducted over one or more concurrent HTTP connections (using the GET verb of download and the POST verb for uploads). In the web app, WebSockets are used instead.

In the download speed test the client will fetch a portion of a 1GB binary (nonzero, randomly generated) payload hosted on an HTTP server on the target test node. The content is discarded as soon as it is received.

In the upload test the client will generate the payload itself to send to the server.

The speed tests (both download and upload) operate for a fixed-duration of 10 seconds each. A fixed duration test caters well for all broadband access speeds, including LTE and high-speed Wi-Fi services.

The test uses three concurrent TCP connections, in order to capture the maximum capacity of the user's broadband connection. This is in keeping with Ofcom's fixed-line broadband measurement project.

Factors such as TCP slow start are accounted for through the use of a "warm-up" period. This period begins as soon as the test starts and seeks to establish that the throughput has reached stable rate before starting the real test (which will continue over the same TCP connection(s)). It is important to note that the data transferred in the warm-up period is excluded from the main test results, but it is still recorded separately as a supplementary metric.

The speed test client will record the throughput, bytes transferred and time taken at the end of the test.

Latency, packet loss and jitter (mobile apps only)

This test measures the round trip time of a series of small UDP packets between the client and a target test node. Each packet consists of an 8-byte sequence number and an 8-byte timestamp. If a packet is not received back within two seconds of sending, it is treated as lost. The test records the number of packets sent, the mean, minimum and maximum round trip time, and the total number of packets sent and received. Up to 100 packets are used in the assessment of this metric.

Latency (web app only)

In the web app, latency is measured over an established WebSockets connection. This is in lieu of the UDP-based approach, which is not possible inside a web browser using only HTML5 APIs.

A series of zero-byte WebSocket messages are transmitted to the measurement server, which immediately echoes them back to the client. The average round-trip time of these messages (as measured by the client browser) is used to provide an estimate of round-trip latency.

In-home Wi-Fi test (mobile app only, Wi-Fi only)

The in-home Wi-Fi test attempts to assess the reliability of the user's in-home Wi-Fi connection by sending a high-rate stream of pings to the user's home gateway, alongside a high-capacity throughput measurement. This test runs in parallel with the download speed test. The volume of traffic used by this test is very small and does not interfere with the assessment of the user's download speed.

The term "ping" will be used for the remainder of this section to refer to ICMP pings or TCP connection requests. ICMP is always preferred, but is sometimes not possible due to either device or router restrictions.

During the test, pings are sent to the home router whilst the download speed test is running. Pings are sent for a fixed period of 10 seconds. Pings are sent in series; the app waits for a response to the current ping (or a timeout of 500 milliseconds is reached) before sending the next one. The response time and status for each ping is recorded individually.

Once all ping results have been collected, the scoring algorithm is applied to the ping results. Details of the scoring algorithm can be found below. Scoring is performed out of 100; a score of 50 or greater is deemed as "pass" and lower than 50 is deemed a "fail".

If the home Wi-Fi network has more capacity than the Internet connection (as is desirable), then the pings to the home router should continue to show low and stable results (because the bottleneck lies in the consumer's Internet connection and there should still be plenty of spare capacity between the consumer's mobile device and the home router). Conversely, if the latency and packet loss to the home router increase significantly then we can infer the in-home Wi-Fi network is struggling under the volume of traffic and is not able to meet the demands of the consumer's Internet connection. It is important to note that the bulk TCP transfer does not need to saturate the link (the client device may not be powerful enough to do this); merely putting it under pressure will be sufficient to expose volatility in latency and packet loss.

For each set of pings collected, a score out of 100 is calculated. This score is computed as follows:

1. Discard the result of the first ping. The first ping result may include additional overhead for ARP (Address Resolution Protocol) requests.
2. Sort the results of the pings by round-trip time. Discard the worst 5%. By removing the worst 5% of results we ensure that the occasional outlier cannot significantly skew our score.
3. Compute a score for the round-trip time as follows:

   RttScore = max(0, 100 - stddev(RTTs) - (log(min(RTTs)*10))

This scoring approach heavily penalises highly variable round-trip times. This is particularly symptomatic of a troublesome Wi-Fi environment. A penalty is also applied to high baseline round-trip times. This typically has a very minimal effect on home networks though, where the baseline latency is likely to be 1-2 milliseconds.

4. Compute a score for the packet loss component as follows:

   If LossPercentage > 20% then

   LossScore = 0

   Else

   LossScore = 100 - LossPercentage

5. Compute a final score as follows:

   Score = min(RttScore, LossScore)

   If fewer than 10 successful ping samples are collected for any reason, an 'unknown' result is returned. This does not produce a 'pass' or 'fail' message to the user, but instead informs them that testing failed and they should retry later.

6 Measurement Outcomes

Fixed-line / Wi-Fi using the Mobile Apps

The following conditions are used to trigger the guidance messages displayed to users following the completion of the measurements:

	Scenario	Conditions
1	No problems identified. Speed is within highest available band	(If UFBB available and Speed > 300Mbps & all tests green; OR If SFBB available & speed > 30Mbps & all tests green; OR If only BB available & online gaming, VoIP and web browsing tests green); AND In-Home Wi-Fi passes
2	No problems identified. Speed is lower than highest available band	(If UFBB available & speed > 30Mbps & all tests Green; OR If SFBB or UFBB available & speed < 30Mbps & online gaming, VoIP and web browsing green); AND In-Home Wi-Fi passes
3	Wi-Fi may be constraining connection	In-home Wi-Fi test reports a score < 50
4	Poor broadband performance	Web browsing or online gaming or VoIP are red; AND In-Home Wi-Fi passes
5	Could not complete tests	(Could not complete the download or upload tests; OR Packet loss returning 100%);
6	Variant of scenario 1 in which the test results don't match the criteria of scenario 1 or 4.	Test results don't fall into scenarios 1 or 4; AND In-Home Wi-Fi passes

	Your connection might not be performing optimally.	
7	Variant of scenario 2 in which the test results don't match the criteria of scenario 2 or 4. Your connection might not be performing optimally.	Test results don't fall into scenarios 2 or 4; AND In-Home Wi-Fi passes
8	No problems identified. Variant on scenario 2 where location services are unavailable.	If speed online gaming, VoIP and web browsing green; AND In-Home Wi-Fi passes

Mobile broadband using the Mobile Apps

The following conditions are used to trigger the guidance messages displayed to users following the completion of the measurements:

	Scenario	Conditions
1	Connection is performing well	Web browsing test is Green; AND speed >= 2Mbps; AND latency < 100ms
2	Poor results, signal expected to be poor	Tests fail to meet the criteria in scenario 1; AND Predicted signal in the database is poor.
3	Poor results, but signal ought to be ok	Tests fail to meet the criteria in scenario 1; AND Signal in the database is good.
4	Your internet connection is not strong enough to complete the tests	Cannot execute the tests

All broadband services using the Web App

The following conditions are used to trigger the guidance messages displayed to users following the completion of the measurements:

	Scenario	Conditions
1	No problems identified. Speed is within highest available band	Speed > 300Mbps & all tests green; OR If SFBB available & speed > 30Mbps & all tests green; OR If only BB available & online gaming, VoIP and web browsing tests green
2	No problems identified. Speed is lower than highest available band	If UFBB available & speed > 30Mbps & all tests Green; OR If SFBB or UFBB available & speed < 30Mbps & online gaming, VoIP and web browsing green
3	Poor broadband performance	Web browsing or online gaming or VoIP are red.
4	Could not complete tests	- Could not complete the download or upload tests
5	Variant of scenario 1 in which the test results don't match the criteria of scenario 1 or 3.	Test results don't fall into scenarios 1 and 3.
6	Variant of scenario 2 in which the test results don't match the criteria of scenario 1 or 3.	No problems identified with Wi-Fi, & test results don't fall into scenarios 1 and 3.
7	No problems identified. Variant on scenario 2 where location services are unavailable.	If online gaming, VoIP and web browsing green

7 Scoring of Services

Using the Mobile / Wi-Fi Apps

The following conditions are used to indicate the red/amber/green status of individual services inside the mobile app. These statuses are inferred from the results of the active network performance measurements.

Service	Green	Amber	Red
Web browsing	- Tests to all websites must succeed; and - All page load times must be under 5 seconds	- One or more pages fail to load; or - One or more page load times is over 5 seconds	- All websites fail to load; or - All pages take over 10 seconds to load
HD video streaming to TV	- Download speed is over 5Mbps	- Download speed is 3.5 – 5Mbps	- Download speed is <3.5Mbps
Ultra HD video streaming to TV	- Download speed is over 30Mbps	- Download speed is 15 - 30Mbps	- Download speed is <15Mbps
Voice over IP	- Download is over 256Kbps; and - Upload is over 256Kbps; and - Latency is under 100ms; and -Packet loss is under 0.5%	- Download is 128-256Kbps; or - Upload is 128-258Kbps; or - Latency is 100 – 250ms; or - Packet loss is 0.5% - 2%	- Download is under 128k; or - Upload is under 128k; or - Latency is over 250ms; or - Packet loss is over 2%
Real Time Online gaming	- Download speed is over 512Kbps; and - Upload is over 512 Kbps; and - Latency is under 50; and - Packet loss is under 0.5%	- Download is 256 - 512Kbps; or - Upload is 256 – 512Kbps; or - Latency is 50 - 300ms; or - Packet loss is 0.5% - 2.5%	- Download is under 256Kbps; or - Upload is under 256Kbps; or - Latency is over 300ms; or - Packet loss is over 2.5%
Video Calling	- Download speed is over 1Mbps; and - Upload speed is over 1Mbps; and	- Download speed is 0.5Mbps-1Mbps; or Upload speed is 0.5 - 1Mbps; or	- Download speed is less than 0.5Mbps; or - Upload speed is

	- Latency is under 100ms; and -Packet loss is under 0.5%	- Latency is 100 – 250ms; or - Packet loss is 0.5% - 2%	less than 0.5Mbps; or - Latency is over 250ms; or - Packet loss is over 2%

Using the Web-based Checker

The following conditions are used to indicate the red/amber/green status of individual services inside the web app. These statuses are inferred from the results of the active network performance measurements. Fewer metrics are available in the web app (see the Compatibility and Platform Limitations section), thus requiring the need for a different scoring mechanism here.

Service	Green	Amber	Red
Web browsing	- Download speed is over 1Mbps; and - Latency is under 100ms	- Download speed is 256kbps-1Mbps; or - Latency is 100 – 250ms	- Download speed is under 256kbps; or - Latency is over 100ms
HD video streaming	- Download speed is over 5Mbps	- Download speed is 3.5 – 5Mbps	- Download speed is <3.5Mbps
Ultra HD video streaming	- Download speed is over 30Mbps	- Download speed is 15 - 30Mbps	- Download speed is $<_{15Mbps}$
Voice over IP	- Download is over 256Kbps; and - Upload is over 256Kbps; and - Latency is under 100ms	- Download is 128-256Kbps; or - Upload is 128-258Kbps; or - Latency is 100 – 250ms	- Download is under 128k; or - Upload is under 128k; or - Latency is over 250ms
Real Time Online gaming	- Download speed is over 256Kbps; and - Upload is over 512 Kbps; and - Latency is under 50ms	- Download is 256 - 512Kbps; or - Upload is 256 – 512Kbps; or - Latency is 50 - 300ms	- Download is under 256Kbps; or - Upload is under 256Kbps; or - Latency is over 300ms
Video Calling	- Download speed is over 1Mbps; and	- Download speed is 0.5Mbps-1Mbps; or	- Download speed is less than 0.5Mbps;

	- Upload speed is over 1Mbps; and - Latency is under 100ms	Upload speed is 0.5-1Mbps; or - Latency is 100 – 250ms	or - Upload speed is less than 0.5Mbps; or - Latency is over 250ms

8 Compatibility and Platform Limitations

Mobile apps

The mobile apps have been built to operate on Android and iOS devices with the following minimum versions:

- Android: 4.4 and above
- iOS: 9.1 and above

The in-home Wi-Fi test has a number of platform limitations that are worth drawing attention to. Some Android handsets restrict the use of ICMP pings. In such cases, the Android app will attempt to use TCP connection establishment time to TCP port 80 as a proxy for round-trip time. Similarly, some home routers may not respond to ICMP pings (this is extremely uncommon). In these cases the app will again fall back to TCP connections.

However, in some cases the home router may not have an application (i.e. a web server) listening on TCP port 80, so the connection will fail. In these cases it is most common for the router to "refuse" the connection by responding to the TCP SYN with an immediate TCP RST packet. Where this occurs we use the response time of the TCP RST packet as a proxy for round-trip time. If the router simply does not respond at all over TCP and ICMP testing is not possible then the quality of the user's in-home Wi-Fi network is ignored in the scoring assessment.

The app also makes extensive use of the user's physical location in the assessment of the measurement results. If the physical location is unavailable (perhaps due to the device not supporting it, not returning it quickly enough, or the user disallowing it), the app will fall back to scoring the performance without relation to expected performance in their area.

Web app

The web app has been designed to operate on all major, modern web browsers, including:

- Microsoft Internet Explorer 10 and above
- Microsoft Edge
- Google Chrome
- Mozilla Firefox
- Apple Safari

The web app has been built to operate in a responsive manner, meaning it should scale to display well on desktops, tablets and mobiles.

The web app utilises HTML5 WebSockets for the speed and latency testing services. It also uses the HTML5 Location API for determining the user's physical location. Both of these dependencies on HTML5 require the use of a modern web browser.

The use of HTML5 WebSockets means that there is no requirement for Flash or Java applet plugins operating in the web browser. This in turn opens up support for Apple mobile devices, which do not support either plugin.

Operating inside a web browser carries a number of limitations though. The following outlines the measurement methodology differences between the mobile apps and the web app:

- The web app measures speed over WebSockets rather than raw TCP sockets.
- The web app measures latency over WebSockets rather than a stream of UDP packets. Web browsers do not support the transmission of arbitrary UDP packets through the HTML5 APIs.
- Consequently, the web app also does not measure packet loss.
- The web app does not support the web browsing test, due to cross-domain policy limitations.

Additionally, information about the user's network environment (whether they are connected to mobile or Wi-Fi, signal strength, and the network operator in use) is also unavailable inside a web browser.

9 Data Reporting

Measurement data, the survey results, and any passively collected metrics are transmitted back to a data collection server operated by SamKnows in the UK. This captures no personally identifiable information. All communications are conducted over TLS.

This data may be used in the future by Ofcom for internal or external reporting purposes.

An example of the collected data, as transmitted by the app is JSON format, can be found below. This example is taken from an Android device.


```
{
   "device": {
      "app_version": "1.0.11 (12)",
      "manufacturer": "LGE",
      "model": "Nexus 5X",
      "os_version": "Android 6.0.1"
   },
   "location": {
      "accuracy": 13.936,
      "latitude": 51.514214,
      "longitude": -0.1468947,
      "provider": "gps"
   },
   "mobile_environment": {
      "location": "indoor",
      "operator_code": "23410",
      "operator_name": "O2 - UK",
      "signal_strength": -92
   },
   "rating": 2,
   "results": {
      "download": {
         "bytes_sec": "603574.1452774394",
         "duration": 10001603,
         "success": true,
         "target": "all-the1.samknows.com",
         "timestamp": 1481047964,
         "bytes_total": "6036712"
      },
      "latency": {
         "rtt_avg": 56546,
         "lost_packets": 0,
         "rtt_max": 872310,
         "rtt_min": 34405,
         "packets_received": 42,
         "packets_sent": 42,
         "success": true,
         "target": "all-the1.samknows.com",
         "timestamp": 1481048024
      },
      "inhome_latency": {
         "rtt_avg": 290.7441860465116,
         "duration": 10.0,
         "jitter": 71.09479195371578,
         "rtt_max": 425.0,
```

```
            "rtt_min": 163.0,
            "packets_received": 50,
            "packets_sent": 50,
            "score": 100.0,
            "success": true,
            "target": "192.168.1.36",
            "timestamp": 1481048025162
         },
         "upload": {
            "bytes_sec": "183087.92231008175",
            "duration": 14765363,
            "success": true,
            "target": "all-the1.samknows.com",
            "timestamp": 1481048019,
            "bytes_total": "2703360"
         },
         "web_browsing": [{
            "duration": 381433,
            "success": true,
            "target": "www-ofcom.samknows.com/static/mobile-test/",
            "time_to_connect": 342560,
            "time_to_first_byte": 380239,
            "time_to_page_load": 381246,
            "timestamp": 1481048025110
         }]
      },
      "test_type": "wifi",
      "wifi_environment": {
         "channel": 9,
         "signal_strength": -43
      }
}
```


An example of the results returned to the client application are as follows:


```
{
   "data": {
      "score": 1006,
      "description": "Your connection might not be performing
optimally.",
      "result_id": 8446,
      "tests": {
         "web_browsing": "PASSED",
         "hd_video": "WARNING",
         "uhd_video": "FAILED",
         "voip": "WARNING",
         "online_gaming": "WARNING",
         "video_calling": "FAILED"
      }
   },
   "code": "OK",
   "message": "Request Successful"
}
```

10 Passive Metrics

The app will attempt to collect a range of passive metrics related to the user's Wi-Fi, cellular and geographical environment where possible. This information is transmitted to backend servers for the purposes outlined below. The availability of these passive metrics is highly dependent on the user's device, operating system and version.

The passive metrics collected are as follows:

1) Precise physical location. The app requests permission to obtain the users precise physical location. In practical terms this usually GPS or Wi-Fi geolocation, rather than using network / cell tower information. Precise location information is required to assess the user's network performance relative to the expected levels for their area. Additionally, the location is used to load availability data for the user's area.

2) The associated mobile network, signal strength and radio access technology in use. This is used to determine whether the user is receiving good, poor or bad mobile coverage for their area, by correlating against the data provided by MNOs. This functionality is only available on the Android and iOS apps (although iOS does not provide signal strength), and is not present in the web app.

3) Whether the user is on mobile or Wi-Fi. This is used to determine whether to score the user's network performance against the mobile or Wi-Fi criteria outlined earlier. This functionality is only available on the Android and iOS apps (although iOS does not provide signal strength), and is not present in the web app.

4) Device information. The device's manufacturer, model and operating system version is collected by the app. This is not currently used by the backend for the scoring of the user's broadband performance.

11 Traffic Volumes

Each performance check will typically use between 10MB and 50MB, depending on the speed of the service being tested.

SamKnows has 32Gbps of measurement server capacity available in London. Whilst this is not dedicated exclusively to the Ofcom Wi-Fi Checker app, the headroom should be more than sufficient for ongoing testing.

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