DOCUMENT REFERENCE:
SQ310-003-EN

SAMKNOWS TECHNICAL WHITEPAPER
Ofcom Wi-Fi Checker App

November 2015

SAMKNOWS QUALITY CONTROLLED DOCUMENT.					
SQ	REV	LANG	STATUS	OWNER	DATED
310	3	EN	FINAL	LR	20160106
REVISION HISTORY					
DATED	REV	AUTHOR	COMMENTS		
20160106	003	LR	General Updates		
20151119	002	LR	General Updates		
20151116	001	SC	Original.		

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1 Important Notice

IMPORTANT NOTICE

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2 Overview

The Ofcom Wi-Fi Checker app, developed in partnership with SamKnows, is designed to help users better understand whether their home Wi-Fi network is the cause of poor Internet performance they may be experiencing.

The app is aimed at consumers, who may not be savvy in the technical aspects of networking, so the messaging and user interface has been designed to be user friendly and free of jargon. Users are simply informed of one of two outcomes: either their home Wi-Fi network appears to be operating well, or there may be issues with it. More technical users may wish to view some of the underlying measurement results, which are accessible via a menu button.

The app solely focuses on the performance of the in-home Wi-Fi network (i.e. the wireless link between their device and their Wi-Fi router). It does not attempt to characterise the performance of the user's Internet connection supplied by their ISP.

Underpinning the answer the app produces are a series of measurements that are conducted both to the user's home router and to the Internet. The app analyses and compares the resulting measurements to infer whether a bottleneck exists and, if so, where it lies.

The app is compatible with modern Android and iOS based smartphones and tablets. The approach does not rely on software being installed on computers or additional hardware within the user's home. The approach does assume that the user has a home Wi-Fi router. This is a reasonable assumption; such devices are supplied as standard by all major ISPs nowadays and have been for some years.

3 Measurement Methodology

At a high level, the app relies on analysis of latency, variation of latency and packet loss measures, both whilst the Wi-Fi connection is idle and under-load, to identify whether a network issue exists and where it may lie. This section outlines the methodology that underpins the steps involved in carrying out a test and how the final result is reached.

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

1) The device is connected via Wi-Fi;

2) The user's home gateway responds to ICMP echo requests (also known as pings) or TCP connections; and

3) The Internet is reachable.

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. Please see section 5 for details on these compatibility scenarios. Moreover, it is worth noting that the app uses ICMP pings as opposed to traceroute traffic.

During phase one of the test, pings are sent to the home router and to high-capacity test servers on the Internet located in London. 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 both sets of ping results (the "in-home" result set and the "internet" result set). Details of the scoring algorithm can be found in section 4. Scoring is performed out of 100; a score of 50 or greater is deemed as "pass" and lower than 50 is deemed a "fail". At this point there are three possible outcomes:

1) In-Home and Internet both achieve passing scores. This will occur when the standard deviation of round-trip-time and packet loss to both destinations is low. This suggests that the network is reliable enough to pass a low-rate volume of pings reliably, and an impairment has not been identified or the volume of test traffic being used is not high enough to trigger the fault.

2) In-Home scores well, but the Internet scores poorly. This will occur when the standard deviation and packet loss to the home router is very low, but high or erratic values are seen when testing to the Internet. This indicates the bottleneck is likely in the Internet connection.

3) In-Home and Internet both score poorly. This will occur when standard deviation and packet loss are high or erratic to both destinations. Of course,

impairments between the user's device and the home router will manifest themselves in the results to the Internet as well, as the path includes the impaired section. This indicates the home Wi-Fi is the likely cause of the impairment.

A second phase of testing is then conducted in order to ascertain how the in-home Wi-Fi connection performs under load. This phase of testing begins with the app downloading a large binary file over multiple concurrent TCP connections from the Internet. The transfer is limited to ten seconds. Simultaneously, the app also begins a new set of ping measurements to the home router. The pings to the home router are scored using the same algorithm outlined in section 4.

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.

The current version uses scores from phase two of the testing to determine the final result that is displayed to the user. As noted in section 6 results from both phases are recorded for later analysis.

4 Scoring Algorithm

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.

5 Compatibility and Platform Limitations

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

- Android: 4.03 and above
- iOS: 8.3 and above

A number of limitations and compatibility issues are worth highlighting which impact the way measurements are conducted in different environments.
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 user is informed that their home Wi-Fi network cannot be tested.

The fallback to TCP on incompatible Android devices has subtle implications for some satellite broadband connections, where "TCP optimisation" inside the modem is quite common. In these cases the modem itself will essentially hijack outbound TCP connections destined to the internet and proxy them, typically with optimised parameters to deal with the high bandwidth-delay-product present on satellite links. The side-effect of this approach is that TCP connections to internet destinations appear to have extremely low latency (essentially the home network latency, as opposed to the 600+ms latency one would expect from a satellite link). Whilst this causes potential problems for phase one of the testing (where latency to a remote server plays a role), it does not pose an issue for phase two of testing (as latency to a remote server is not used here).

6 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 SSL.

This data may be used for internal or external reporting purposes.

The data captured for each platform is as follows:

Description	JSON Element Name	Android	iOS
In-home Wi-Fi ping measurements (Phase 1, idle) - Score (0-100) - Packets sent and received RTT Min, Max, Average and Std Deviation (ms)	local	Yes	Yes
In-home Wi-Fi ping measurements (Phase 2, under load) - Score (0-100) - Packets sent and received RTT Min, Max, Average and Std Deviation (ms)	local2	Yes	Yes
Remote (Internet) ping measurements (Phase 1, idle) - Score (0-100) - Packets sent and received RTT Min, Max, Average and Std Deviation (ms)	remote	Yes	Yes
Remote (Internet) download speed measurement (Phase 2) Download speed, Mbps	download_speed_mp bs	Yes	Yes
Final phase completed in the testing (will always by "2" currently)	finish_stage	Yes	Yes
Final local Wi-Fi score (0-100)	final_local_score	Yes	Yes

Phone model	model	Yes	Yes
Phone manufacturer	manufacturer	Yes	Yes
Operating system type (Android or iOS)	os_type	Yes	Yes
Operating system version	os_version	Yes	Yes
Date/Time the tests started (Unix timestamp)	timestamp	Yes	Yes
Date/time the tests started (ISO format)	datetime	Yes	Yes
App version number	app_version_name	Yes	Yes
Survey question and response (scale of 1-5, optional)	question	Yes	Yes
The channel and signal strength (dBm) of the associated Wi-Fi access point	wifi_associated_ap	Yes, but depends on device	No
The channel and signal strength (dBm) of all visible Wi-Fi APs in the vicinity. Optional array.	wifi_adjacent_aps	Yes, but depends on device	No
The approximate geographic location of the user (up to 100m accuracy). Expressed in longitude and latitude, degrees.	location	Yes	No

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.


```
{
    "model": "Samsung SIII mini - Google Nexus S - 4.1.1
- API 16 - 480x800 240 ppi",
    "finish_stage": 2,
    "download_speed_mbps": 7.261,
    "final_local_score": 99,
    "remote": {
        "score": 77,
        "sent": 50,
        "rtt_min": 18.4,
        "rtt_max": 61.5,
        "recv": 50,
        "rtt_std": 77
```

```
    },
    "os_version": "4.1.1",
    "os_type": "android",
    "timestamp": 1447082321,
    "wifi_adjacent_aps": [],
    "manufacturer": "Genymotion",
    "wifi_associated_ap": {
        "channel": 1,
        "signal": -55
    },
    "question": {
       "question": "How satisfied are you with the
performance of your home broadband connection?",
     "result": 4
    },
    "local": {
        "score": 98,
        "sent": 50,
        "rtt_min": 1.31,
        "rtt_max": 2.66,
        "recv": 50,
        "rtt_std": 98
    },
    "datetime": "2015-11-09T15:18:41+0000",
    "app_version_name": "1.37",
    "local2": {
        "score": 99,
        "sent": 50,
        "rtt_min": 1.16,
        "rtt_max": 2.47,
        "recv": 50,
        "rtt_std": 99
    }
}
```

7 Passive Metrics

The app will attempt to collect a range of passive metrics related to the user's Wi-Fi and geographical environment where possible. 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) Approximate physical location. The Android app requests permission to obtain the users approximate physical location. In practical terms this usually means cell-tower triangulation as opposed to GPS. Additionally, the app will artificially reduce the accuracy of the location data returned from the operating system to an area approximately 100m square.

2) The associated Wi-Fi access point. The app will record the signal strength and channel of the Wi-Fi access point that the device is associated with. The MAC address and SSID are not recorded as these could be considered personally identifiable data. This functionality is only available on Android due to limitations in the iOS APIs.

3) Nearby Wi-Fi access points. The app will perform a Wi-Fi site survey to determine the presence of nearby Wi-Fi access points. This is used to determine whether there are multiple access points on the same or adjacent channels to the user's associated access point. This in turn is used to inform some of the troubleshooting messages presented to users when a problem is identified. This functionality is only available on Android due to limitations in the iOS APIs.

4) Device information. The device's manufacturer, model and operating system version is collected by the app.

8 Application permissions

Both the Android and iOS variants of the app have been built with the minimum possible set of permissions need to carry out their measurement functions. In practical terms, this limits the app to:

1) Carrying out network communications
2) Inspecting the device's current system and network state (i.e. is Wi-Fi connected, what access points are nearby)
3) Determining approximate geographic location (only on Android)

This means that the apps have no ability to access the address book, messages (emails, text messages, etc), call history, the file system or any other private content. This should provide additional reassurance to users that the application is not doing (or even capable of doing) anything nefarious. Please note that the application will not run in the background and collect data, the only circumstance in which the application will collect data is when the user chooses to run a test.

9 Traffic Volumes and CDN-fallback

SamKnows has 12Gbps of measurement server capacity available in London. Whilst this is not dedicated exclusively to the app, the headroom should be more than sufficient for ongoing testing.

However, the public announcement of the deployment of the App may lead to its usage being significantly higher during the early phases of its deployment and the precise levels are impossible to predict. For this reason, SamKnows has configured a CDN to act as an automatic fall back in case total traffic volumes to the measurement servers exceeds 12Gbps.

[DOCUMENT ENDS]