Is it 5G or not? Investigating doubts about the 5G icon and network performance

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***Abstract*—Following the rollout of the first 5G networks in 2018, press reports in the US began to emerge that the 5G icon on smartphones was not depicting 5G connectivity. Such reports about 'fake' 5G icon reverberated across the industry, exposing a mismatch between the icon on the phone and the actual experience of users. Between 2018 - early 2020, 3GPP and the GSMA sought to provide industry guidance on what and when the 5G icon should be used and how 5G performance can differ from 4G. In this paper, we introduce an intuitive four stage investigation framework to explore the technical considerations that ultimately confirm the veracity of the 5G connectivity. Then, following the launch of 5G in the UK in late 2019, we set out to explore if there were similar confusion on 5G notification and performance in the country. We conducted field measurements at the five busiest train stations in the UK, during rush hour, - using a Samsung 5G S10 and a Samsung S6 Edge+ 4G device - to compare 5G notifications and perceived network performance on 4G and 5G networks. We observe confusing messages to the user - device icon says 5G but Android's TelephonyManager API says 4G; worst cases for latency and uplink/downlink speeds were minimised but best case performance was the same on 4G and 5G devices. Based on our observations, and while we expect any lingering concerns to be ironed out as 5G deployment and adoption matures, we draw lessons that should guide the industry to avoid doubts about the icon and connectivity in 6G.**

***Index Terms*—6G, 5G, 4G, fake icon, network measurements**

I. Introduction

5G network rollout and adoption is ramping up since the first network rollouts in 2018 in South Korea and USA. Since then, the number of 5G networks in the world, whether for mobile services or for fixed wireless access, and regardless of the spectrum in use, has continued to grow. By September 2020, the Global mobile Suppliers Association (GSA) reported that a total of 101 operators in 44 countries/territories have launched commercial 3GPP-compliant 5G services [1]. Expectation is high that 5G will deliver a compelling performance improvement over previous network generations. Industry body, the GSM Association (GSMA), projects that there will be 1.35 billion 5G connections by 2025 and provides a summary of the performance improvements of 5G [2]. The improved performance of 5G will come from a more advanced 5G core network (5GC), more efficient radio technologies - e.g. reliance on massive MIMO (massive input massive output) antennas -, using larger spectrum bands and from a denser network topology [3].

For the user, 5G speed/throughput of between 10 - 100 times faster than 4G and latency of up to 10 times smaller than 4G will be two key considerations [2]. Achieving this will however depend of which of the five 5G deployment options chosen by the operator (Option 2 & Option 5 for Standalone; Option 3, Option 4 & Option 7 for Non Standalone). While Standalone (SA) 5G should deliver the best performance, all early commercial 5G networks are based on Non Standalone (NSA) 5G which rely on connecting the 5G new radio (NR) to the 4G Enhanced Packet Core (EPC) [4]. Figure 1 compares Option 2 for SA and Option 3 for NSA.

Meanwhile many current 4G networks are being upgraded to LTE-Advanced Pro, leveraging MIMO antennas to boost throughput [5]. These disparate deployment scenarios mean that it is difficult to establish a comparative benchmark between 4G and 5G because the intermediate steps of LTE-Advanced Pro and 5G NSA muddle the comparison. However, several press articles and industry commentators vouch that 5G (which is NSA) achieves much faster throughput than 4G. For example, [6] claims that UK network operators were achieving real world download speeds of between 150Mbps to 1Gbps compared to 20-30Mbps for 4G.

To further complicate matters, there has been disagreements, debates and delays on when to use the 5G icon or how to describe the 5G icon [7]. These have triggered user/press concerns about 'fake' 5G icon or notifications in a way that was not seen for 1G/2G/3G, and drawn 3GPP into a rearguard action to retrospectively provide clarification [8].

In this paper, we investigate the 'if', 'why' and 'how' a 5G icon or improved performance may not mean 5G connectivity. We introduce a 4-stage investigation framework (Section II) to methodologically explore how the 5G icon and connectivity is established in an Android device. In Section III, we describe our field measurement at the five busiest train stations in the UK during rush hour to explore what the notifications and performance of 5G looks like. Our observations (Section IV) suggest an attachment to a 5G-enabled base station, but does not provide conclusive confirmation of communication via 5G in 540 minutes of measurement. In Section V, we explore the industry decisions that led to this uncertainty, and while we expect concerns about 'fake' 5G icon to disappear as 5G network rollout accelerates, we identify lessons to guide the industry to avoid a repeat of this for 6G.

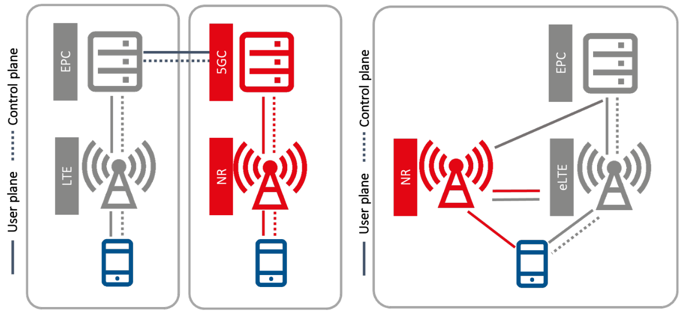


Fig. 1: 5G NSA vs SA. In (a) 5G SA (3GPP Option 2), device is connected to 5G new radio (NR) and the 5G icon is shown by default. In (b) 5G NSA (3GPP Option 3), device is connected to both the 4G & 5G via Dual Connectivity & 5G icon decision is determined by GSMA's recommendations [8]

II. Confirming 5G status: 4-stage framework

A. Network

A 5G network has to be available and the users notified of its availability. 5G 'availability' covers the actual deployment of a 5G NR (New Radio) radio, in the appropriate frequency bands that will be supported by devices in a market. It also includes the interrelationship of the 5G NR with the LTE radio, the 4G EPC and the 5G core network (5GC), if available. For 5G SA, this decision is straightforward as the 5G NR, running on a 5G base station (gNb), is connected to a 5GC. However, for 5G NSA, the decision is based on 'dual connectivity' (DC), a mechanism introduced in 3GPP release 12 to permit connectivity to both a macro LTE base station and a small cell [9]. In 5G NSA option 3, using DC means that a device can connect simultaneously to both LTE and 5G NR; LTE manages the control plane while the NR manages the data plane.

'Notification of availability' of 5G is set by the *upperLayerIndication* bit, as contained in 3GPP TS 36.331 specifications on Radio Resource Control (RRC) [10] and clarified in the discussion paper R2-1801529 [11]. Under the guidance, each mobile network operator - i.e. Public Land Mobile Network (PLMN) - adds a 1 bit NR indicator to the System Information Block type 2 (SIB2) to indicate that a 5G cell is co-located and that a user has entered a coverage area that offers 5G capabilities. The *upperLayerIndication* is set as *true* when 5G co-location is available or, otherwise, is omitted.

B. User equipment (UE)

A UE will support 5G if it has the appropriate 5G chipset (e.g. Exynos 9820 Octa and Qualcomm Snapdragon X55 5G) and supports any one of the C/mmWave 5G NR frequency bands. The network uses the 'UE capability enquiry and information' mechanism to determine if UE can support 5G [10]. This is done during the LTE/5G attach procedure when the network sends an RRC 'UE Capability Enquiry' message to the UE and receives the 'UE Capability Information' from the UE detailing all the information that the UE is capable of.

Once established, the UE can then decide on the 5G icon based on the *upperLayerIndication* status. However, while the network informs its 5G status via the *upperLayerIndication* bit, the UE relies on a not-so-definite decision framework for its decision. This is because 3GPP has left it to individual operators to decide how to implement *upperLayerIndication*. After several iterations, and after early 5G devices have shipped causing confusion about the 5G icon for users, in a Liaison Statement (LS) to 3GPP in January 2020, the GSMA's 5G Status Indicator (5GSI) taskforce proposed that when a UE is connected in an active mode to a 5G NR, the 5G icon should be shown [8]. Conversely, when the UE is in idle mode, it will only show a 5G icon if it is in an LTE cell that is capable of 5G NSA and has been notified that it is in an area where 5G is available. Figure 2 summarises the GSMA 5GSI guidance.

C. Operating System (OS)

The OS provides a linkage between the low level hardware functions in a UE and the higher lever application stacks. We focus on the Android OS, the predominant mobile device OS/platform in the world (>70% market share) and use its 5-layer architecture to understand how the OS will interpret 5G availability - Figure 3.

A UE with the requisite 5G chipset will have vendor-specific modem drivers managed by the Linux kernel. In the hardware abstraction layer, Android runs a Radio Interface Layer (RIL) daemon to provide an interface with these device drivers [12]. Within the application framework, Android provides a TelephonyManager package or sets of classes which exposes APIs that an app can use to interact with the UE hardware and system information [13]. While there are several parameters that report on 5G connectivity in the TelephonyManager package, the 'Network_Type_NR', added in Android 10 - API Level 29, returns a numerical value of 20 to indicate that the UE is connected to a 5G New Radio.

In practice, while the UE's system information log will report 5G connectivity based on *upperLayerIndication*, the RIL reports 5G based on the connectivity established in the modem. Accordingly, Android OS reports a 'Network_Type_NR' = 20 only when the RIL reports connection to a 5G NR.

D. Applications

While there maybe temporal, situational and contextual variations in network quality and performance [14], the default capability of the underlying network connection will impact application behaviour and performance. Thus, we expect that, for applications that require connectivity, performance will progressively improve from 3G to 4G to 5G. We focus on the two performance measures that are predominantly used in the literature to describe network quality: latency/delay and speed/throughput. Applications connected to 5G ought to perform better than those connected to the best performing 4G and 3G networks, achieving latencies of <10ms and speeds in excess of 100Mbps [2]. However, and as shown by [15] in their first look at 5G performance in the field, 5G NSA offers only a marginally better latency than 4G.

	Use 5G icon	Do not use 5G icon
Idle	The UE shall be able to display a 5G icon when it is in idle mode in an LTE cell capable of NSA and is notified that it is in an area where 5G is available.	The UE shall not display a 5G icon when all the following conditions are met: a) The UE is camped on a base-station capable of NSA; and b) The UE has been provided with a list of NR frequency band(s) deployed in the area; and c) The UE supports none of the NR frequency bands that are deployed in the area or cannot use NR for any other reason known to the UE.
Active	The UE shall display a 5G icon when the UE is in active mode and is using NR. Regarding the length of time the 5G icon is displayed, operators should seek to strike a balance between a frequently-changing icon and miscommunicating the connectivity status.	

Fig. 2: Summary of GSMA recommendation to 3GPP on when to show a 5G icon [8]. The guidance recommends how the User Equipment (UE) will make a decision to show a 5G icon based on whether it is in idle mode or active mode.

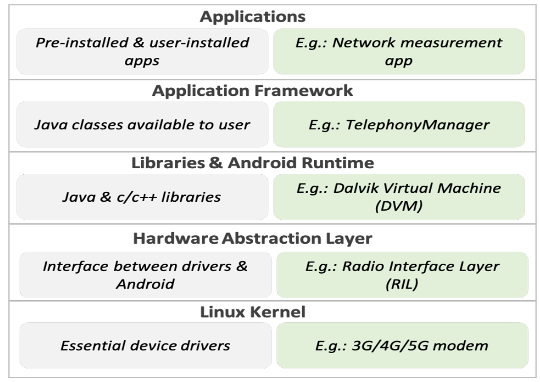


Fig. 3: Android Architecture Stack. Android provides a TelephonyManager API package which reports a value of 20 for 'Network_Type' when the OS is connected to a 5G radio.

III. Field Study

A. Locations

The measurement was conducted at the five busiest train stations in the UK. The stations were selected because we expected them to be among the first locations to have 5G due to high footfall, especially during rush hour. Coincidentally, the five busiest stations in the UK, according to the UK's Office of Rail and Road (ORR), were all in London. Using the ORR's data for 2017/18, these were Waterloo, Victoria, Liverpool Street, London Bridge and Euston. However, we opted to measure at Kings Cross/St Pancras instead of Euston as St Pancras (no 9) and Kings Cross (no 10) are co-located, with a combined traffic that puts them in no 3. Finally, we also did measurement in Stevenage Hertfordshire, 30 miles from London, where 5G was not available.

B. Date and Time

Our measurements were conducted in the week starting Monday, 20th January 2020. On each of the five working days, between 17:30 - 19:00pm, we sat at the train concourse of one of the stations and observed network performance as it would apply to the average commuter. In total, we had 450 minutes (7.5 hours) of measurement data. The choice of 17:30 - 19:00pm was to ensure that we are capturing the peak travel time of the day when commuters were on their way home and, we assume, are enjoying infotainment activities on their phones instead of work related activities. Then on 27th January, we took the measurements at Stevenage during the same time and for the same duration. In total, we conducted the field observations for 540 minutes (i.e. 9 hours).

C. Equipment

Our 5G measurement device was a Samsung S10 5G, version SM-G977B that was released in April 2019. Its CPU is the Octa-core (2x2.73 GHz Mongoose M4 & 2x2.31 GHz Cortex-A75 & 4x1.95 GHz Cortex-A55), running on the Exynos 9820 (8nm) chipset. The device runs Android version 9.0, supports Android SDK version of up to API level 28 and has a 5G-enabled SIM card. Our 4G measurement device was a Samsung Galaxy S6 Edge+, version G928F that was released in August 2015. Its CPU is the Octa-core (4x2.1 GHz Cortex-A57 & 4x1.5 GHz Cortex-A53), running on the Exynos 7420 Octa (14nm) chipset. The device runs Android version 7.0 and supports Android SDK version of up to API level 24. Both 5G and 4G devices have SIM cards from the same network operator. However, we are intentionally keeping the identity of the network operator a secret so as not to detract from the core focus of this paper.

D. Measurement app

We used an adaptation of the Multiping-for-Android app [16] for our measurement. The original app enables us to capture Round Trip Times (RTT), in milliseconds, for a selection of websites. Our adaptation enables to automatically conduct the RTT measurements every 5 minutes for our selection of 14 UK-focused websites. The websites are selected based on their Alexa ranking (e.g. Google.com) or their relative importance to the digital society (e.g. gov.uk). Using the Android TelephonyManager class, we measure uplink and downlink speeds in kbps, base station ID and network type. We also adapted the app to stream a 30 seconds YouTube video every 5 minutes and captured the playback time duration.

IV. Observations

A. UE's 5G icon indicator

The first observation is that the 5G icon was on for most or all of the time during the 450 minute measurements in London. We did not visually observe any moment when the 5G icon, on the 5G UE, was off. This suggests that at the minimum, all the 4G base stations at the train stations have been upgraded to support 5G NSA and that the network operator has opted to set the *upperLayerIndication* bit to true.

B. Android's Network Type indicator

Out of the 2,224 readings on the 5G device, 100% of them reported an Android network connection to only LTE. That is,

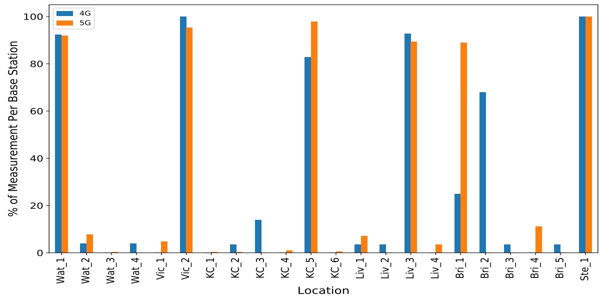


Fig. 4: Base stations connected to per location, based on Android's TelephonyManager API. Wat = LN Waterloo; Vic = London Victoria; KC = London Kings Cross; Liv = London Liverpool Street; Bri = London Bridge; Ste = Stevenage

the 'Network_Type' api returned code 13 - for LTE - for all the readings. Our readings include 1,804 readings in London locations where there was a 5G icon on the device and 420 readings in Stevenage where there was no 5G icon. While we expected to see some active 5G network connection in the 5G measurement data, i.e Network Type = 20, we only saw 'Network Type = 13 = LTE'. This was contradictory to the device 5G icon and raised more questions about the authenticity of the 5G connection. We later confirmed that all 5G phones released before October 2019 cannot be upgraded to Android 10, making them unable to show the 5G network type, due to Android API support.

C. Base station analysis

Figure 4 shows the diversity in the base station IDs that both the 4G and 5G devices connected to based on the Android TelephonyManager's cellID API. Although the devices were always in a fixed, stationary position during the measurements, we observe connection to multiple base station IDs. In total, both devices connected to a total of 15 base stations in the six locations and these were mostly shared by both the 4G and 5G devices. However, while the 5G device always connected to at least one unique ID per London location, the share of measurements from those unique base stations was minimal and so we cannot establish a meaningful correlation.

D. Latency

We measure latency as the round trip time (RTT) delay recorded in accessing a website from our app. As some websites block ICMP ping by default, we send a 56 byte packet to both the TCP port 80 and TCP echo port 7 to assure a response from the remote server. We take the lesser of the two values as the lowest RTT measure.

Given that much of the expectation on 5G is that it will deliver significantly lower latency, our observation was that there were no demonstrably clear performance advantage with the 5G device on lower latencies. For example, we note that 28% of all RTT measurements on the 5G device were <50ms compared to 27% on the 4G device, a non-convincing comparison between an April 2019 5G device vs an August 2015 4G device. This also supports the findings of [15] that latency improvement in 5G NSA was insignificant.

However, as latency became longer, the 5G device begins to noticeably outperform the 4G device and this is reflected in Figure 5 . For example, 47% of measurements on the 5G device had latency <100ms compared to 38% on the 4G device. At 500ms, this was 62% vs 43%; at 1000ms, 68% vs 47%; at 2000ms, 77% vs 53%; and at 3000ms, 84% vs 60%. This divergence is reflected in the overall median of 131ms on the 5G device vs 1275ms on the 4G device (877% improvement), raising the question if this was based on improved connectivity or improved device capability. On the assumption that the 5G device was communicating via 5G, this suggests that the main benefit of 5G is to minimise very poor performance rather than to maximise very good performance.

E. Downlink and Uplink speeds

To measure downlink and uplink speeds, we relied on the Android ConnectivityManager API. The *getLinkDownstreamBandwidthKbps()* and *getLinkUpstreamBandwidthKbps()* methods return the speed of the connection in kbps. In Figures 6 and 7, we convert these kilobits speeds to Megabytes per second (Mbps).

Similar to latency, we observe that both the downlink and uplink speeds recorded on either the 5G or 4G device were comparable at lower Mbps levels until after the 70% percentile value. For example, the median (50% percentile value) uplink speed on the 5G device was 3.18 Mbps vs 3.23 Mbps on the 4G device (2% worse performance on the 5G device). The 75% percentile values were 3.5 Mbps on both the 5G and 4G devices. For downlink, the median was 6.4 Mbps on 5G device vs 7.3 Mbps on 4G device (12% worse performance on the 5G device) whereas the 75% percentile values were 12.9 Mbps vs 10.5 Mbps. 5G device outperformed 4G in Stevenage where there is no 5G and both devices were connected to same base station, suggesting a strong role for device improvements.

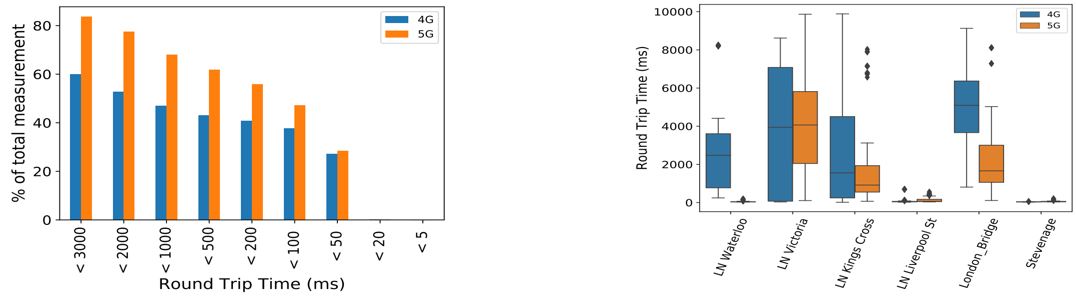
F. Video Playback analysis

While latency and throughput/speed can provide theoretical insights on the quality of the connection, we went further to download and playback a 30 seconds Youtube video, every five minutes, to evaluate the impact of connection quality on actual application performance. Figure 8 summarises the playback time of the videos on the 5G vs 4G devices, showing clearly that the Youtube application playback was worse off on the 5G device - a 19% inferior performance in playback time.

V. Key lessons

A. On 5G performance

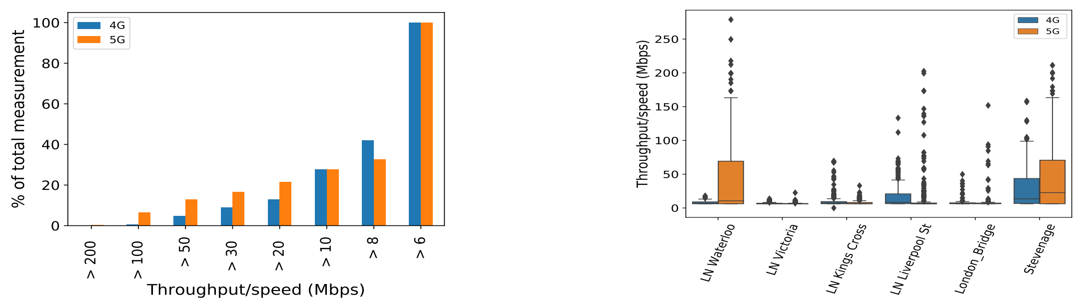
1) Device vs network performance: From our observations, we do not have a clear evidence to conclude that the 5G device outperformed the 4G device. Any out-performance could have come from being connected to a 5G network or the superior capabilities of a much newer device. With the 5G icon, plus latency and speed/throughput measurements and without delving deeper into what was actually going on, a



(a) RTT performances by device

(b) RTT performance by locations

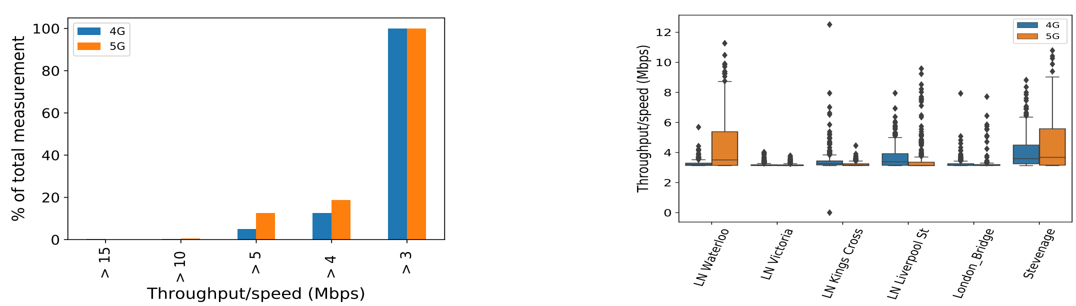
Fig. 5: Round Trip Times (RTT) measurements analysis. (a) shows that performance is similar for RTT <50ms. However, overall 5G device median = 131ms; overall 4G device median = 1275ms (b) shows that RTT varies significantly across locations



(a) Downlink speed performances by device

(b) Downlink speed performance by locations

Fig. 6: Downlink speed measurements (a) shows more 4G device measurements achieved speeds >10Mbps although 5G device had more individual high speeds. This is reflected in overall 5G device median = 6.4Mbps vs 7.3Mbps on the 4G device (b) shows faster speeds on the 5G device in Stevenage where there was no 5G availability and both devices were connected to only 1 base station. Does this suggest that device improvements are driving better performances instead of network type?



(a) Uplink speed performances by device

(b) Uplink speed performance by locations

Fig. 7: Uplink speed analysis. Both (a) & (b) show better performance on 5G device. 5G & 4G device median = 3.2Mbps

typical user could conclude that there was 5G connectivity. However, a deeper level analysis shows that the 5G device did not show superior performance across all indicators.

2) 5G will get better with time: 5G will eventually deliver significantly superior latency and speed performances than 4G. But in the early days of a new network generation, it may take some time to fully tune the network for optimal performance or it may even be that a new network configuration is needed to realise the promised benefit - cf: 3G UMTS vs 3G HSDPA.

3) Consistency vs Speed: If 5G is helping to minimise very poor performance rather than to maximise very good performance (as observed for latency plus downlink speeds), it supports the call to focus 5G on ensuring a ‘consistent’ experience rather than a ‘speedier’ experience [17].

B. On 5G icon/notification

1) Consequences of haste in standardisation: We note that the remote trigger for the confusion on the 5G icon/notification was the decision in February 2017 to accelerate the standardisation of 5G NR and create the 5G NSA option [18]. This acceleration meant that 5G first arrived in late 2018 instead of early 2020. However, it left little time to resolve the 5G

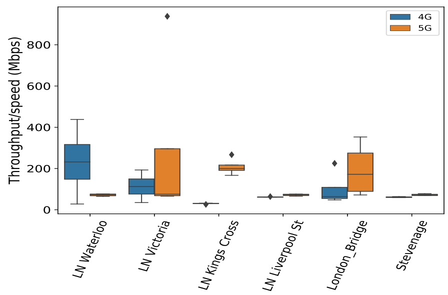


Fig. 8: Video playback time per location

icon question or for some product developers to adjust their schedules to accommodate 5G. For example, iPhones did not support 5G until the release of iPhone 12 in October 2020. Likewise, Android 10, scheduled for release in October 2019, would have been timely for 5G device rollout in early 2020 but not for devices rolled out earlier.

2) Commercial vs technical decision: As noted by [7], part of the reasons for the delay in resolving the 5G icon status was over disagreements on what the icon should signify (e.g. showing 5G, 5G+ etc) and how many bits to use to reflect this. This commercially-triggered disagreement impacted what ought to have been a purely technical standardisation decision.

3) Implications of decoupling RAN and core deployment: The route to deliver NSA was the decision at 3GPP to break up, for the first time, the RAN and core network deployment. This resulted in the reality of the new 5G NR to be connected to the legacy 4G EPC, allowing early deployment of 5G to commence [4]. However, it meant that operators are now faced with five non-mutually exclusive deployment scenarios to choose from and some uncertainty over when an actual 5G connection exists or when/how to use the 5G icon.

4) Plan ahead and better for 6G: The biggest lesson from our analysis is to provide guidance to (hopefully) prevent any similar confusion as 6G networks begin to debut. We do note that this icon confusion did not exist for 2G and 3G, but has now happened for 4G [19] and 5G. Whether the confusion emanates from lack of clarity or consensus on how to act, or it is a deliberate attempt to misrepresent the connection status, the industry should be working towards a 6G future where such confusion is avoided, perhaps by going back to a pure/traditional full system deployment instead of the 5G approach of decoupling the RAN and core deployment.

VI. Conclusion

Our work explores the ‘if’, ‘why’ and ‘how’ a 5G icon or improved performance on a 5G device may not mean 5G connectivity. This realisation has led to accusations of ‘fake’ 5G and concerns that users may be left disillusioned about 5G. We introduce a 4-stage investigative framework to explore the technical considerations that determine if 5G connection is actual. We then embark on a field study, running the same app on a 4 year old Samsung device and a 6 month old 5G Samsung device. We do this at the five busiest train stations in the UK and at a suburban location in Stevenage. Based on our observations, we highlight that the icon, notifications and performance on the 5G device is not conclusively convincing about 5G connectivity. While we expect these incidences to resolve eventually, our paper provides guidance for the industry to avoid such confusion during 6G development.

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