

Mobile cloud gaming in central London:

the real-world gaming experience in the London Central Activities Zone (CAZ), plus a look at 5G gaming across the whole of greater London.





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The cloud gaming landscape is booming

With the arrival of 5G, more and more gamers are putting away their consoles and replacing them with cloud-based games that can be enjoyed anywhere and everywhere they go—and on any connected device they choose.

This report shows which operators in central London—as defined by the London Central Activities Zone or CAZ—can deliver a smooth mobile cloud gaming experience on 5G compared to 4G LTE for both casual games in standard definition and multiplayer online games in high definition. We've also taken a high-level look at what gamers can expect on 5G across the whole of London and how performance could differ from what we found in central London. **It's important to note that the results in this report are specific to gaming in central London (the London CAZ) and across greater London as a whole; the gaming experience in other cities could be different.** Read on to see what to expect in terms of the real-world mobile cloud gaming experience in central London.

Why did we choose central London for this report? Central London is an area where seamless and fast connectivity is critical for consumers, businesses, and government agencies alike, and it's also known for its world-class digital connectivity. Perhaps even more importantly, the impressive 5G results we recorded in central London will likely extend across the rest of the city and beyond in the near future. What better place to look closely at how 5G might help transform the gaming experience?

Central London: The London Central Activities Zone (CAZ)

While London is the UK’s most populated city, there is one particular area within the UK’s capital that is arguably the heart of the city: central London (the **Central Activities Zone or CAZ**). Central London is one of the world’s most attractive and competitive business centres. The seat of national government is in central London, and the area is world renowned for its technology, culture, and heritage. In short, central London is a critical part of the city and the UK in general, and fast connectivity is crucial for all who work or reside in the area.

The good news for gamers in central London is that the 5G results we recorded in the area were generally better than those across the whole of greater London (and other UK cities), suggesting that the operators have prioritised their 5G networks for optimal performance in central London. Given the importance of the area for both organisations and end users, such a prioritisation isn’t surprising and is excellent news for gamers in the area.

Quick takeaway: EE delivered the best combination of broad 5G availability and fast speeds in central London, but both Three and Vodafone showed strong results on 5G that should be welcome news for gamers in the area and could be a harbinger of good things to come going forward.

*Note that for the purposes of this report, central London and the London Central Activities Zone (CAZ) are used interchangeably.



Sources
<https://www.london.gov.uk/what-we-do/planning/implementing-london-plan/planning-guidance/central-activities-zone>
https://www.london.gov.uk/sites/default/files/caz_spg_final_v4.pdf
https://www.london.gov.uk/sites/default/files/intend_to_publish_-_clean.pdf

IHS Markit expects the cloud gaming content and services markets to grow from **387 million in 2018 to \$2.5 billion in 2023**, with 5G driving much of that growth.

While cloud gaming has long been a part of the digital services landscape, its full potential on mobiles and other connected devices hasn't been fully realised because cloud gaming requires consistent connectivity, fast speeds, and low latency that 4G LTE networks often can't support.

5G, however, could quite literally change the game when it comes to streaming games from the cloud: latency-based delays could become a thing of the past, and the experience of streaming precision-based, graphics-heavy multiplayer online games like Call of Duty could eventually be as smooth on a smartphone as it is on a console at home.

To show you what to expect in terms of the quality of the mobile cloud gaming experience, we looked at multiple elements of gaming, including Google Stadia's **recommended speeds** for good cloud gaming, as well as Microsoft's **latency recommendation** for optimal gaming on Xbox Game Pass. We used those speed and latency recommendations as proxies for smooth cloud gaming on any gaming platform, and we've also looked at other key gaming metrics such as packet loss and jitter.

In this report, we discuss the gaming experience in the context of three major cloud gaming platforms, but our findings and results should be considered proxies that apply to other platforms as well. However, it's important to note that the gaming experience could differ across platforms, and the results in this report aren't specific to a specific platform.

Google
Stadia

Microsoft
xCloud

Steam
Remote
Play

Using Google's speed recommendations and Microsoft's latency recommendation as benchmarks for smooth cloud gaming on any platform, we took results from our most recent mobile performance testing in central London in the first half of 2020 to show which operator networks are capable of delivering a good mobile cloud gaming experience on both 4G LTE and 5G. **It's important to note that we did not test gameplay in central London or across the greater London market as a whole; the findings in this study are based on mobile operator speeds, latency, packet loss, and other gaming-related results we recorded during testing in central London and the entire city of London.**

We looked at gaming across two broad categories at two different resolutions:



Casual games in standard definition (720p)
These include single player casual games such as Candy Crush or Tetris in SD.



Multiplayer online games in high definition (1080p)
These include games that must be played online, are designed to be multiplayer experiences, and require quick reactions and perfect accuracy—games such as Call of Duty or Final Kick 2020 in HD.

What is cloud gaming?

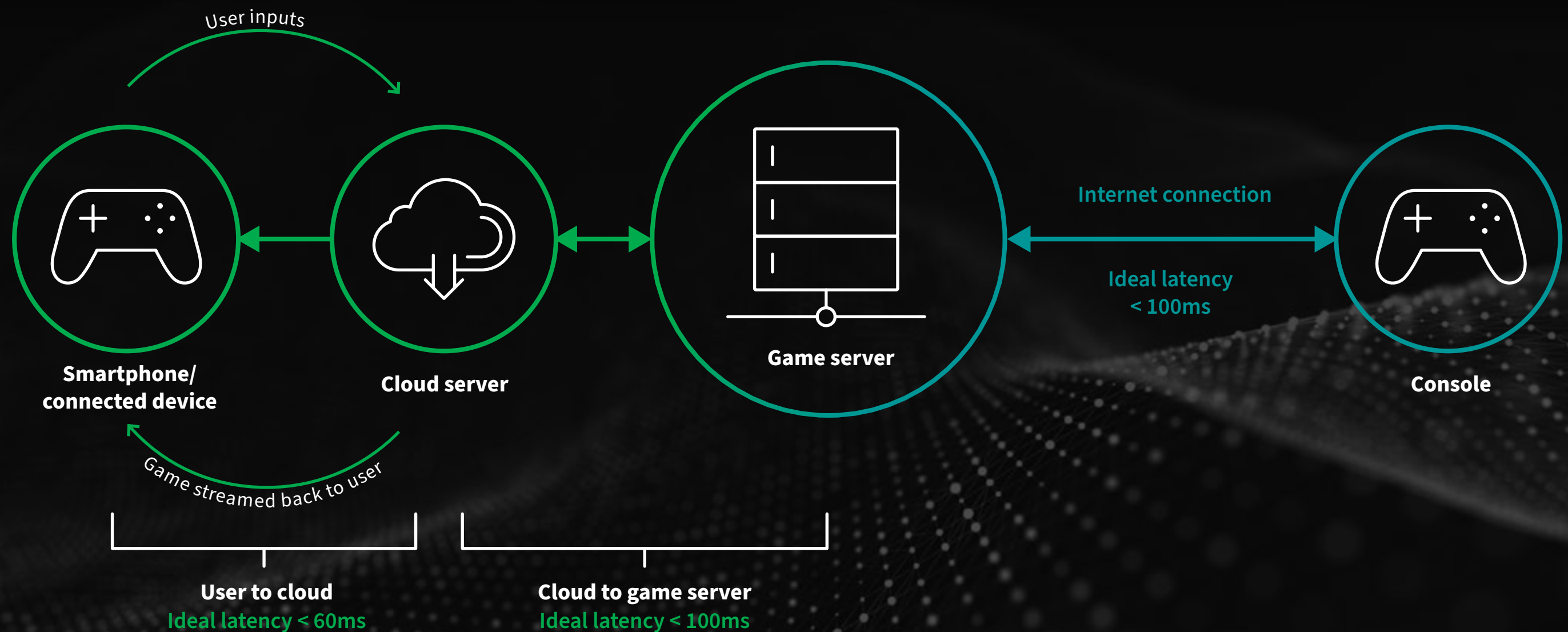
Cloud gaming allows users to play games hosted on the cloud, rather than on a console or gaming PC, and all the processing, graphics, and video rendering that historically took place on consoles now takes place on the cloud.

In effect, gamers send commands from a mobile device to platforms like Stadia or Xbox Game Pass or Steam's Remote Play by pressing a button or entering a series of keyboard commands. The cloud server receives and executes those commands and then streams the results back to the gamer. If your speed, latency, and other gaming-relevant results are strong enough, gameplay happens in effectively real time and without any delays or problems.

Gaming consoles like PlayStation, Xbox, and others were designed to process massive amounts of data on the console itself, but mobile devices simply don't have that kind of processing power. Processing on the cloud, however, can solve that problem, allowing for smooth gaming on mobile devices without the glitches and delays that can occur when processing takes place at the device level.

According to gaming analytics firm **Newzoo**, the worldwide cloud gaming market will grow to **124.7 million users by 2022**, and research firm **Niko Partners** expects the number of cloud gamers in **Asia alone to grow from 3 million in 2019 to 60 million by 2023**.

Snapshot of cloud gaming vs. console gaming





Cloud gaming has multiple benefits for gamers. It's much cheaper since there's no need to buy consoles or gaming PC's, and if a user's mobile or other connected device breaks or freezes temporarily while cloud gaming, the game can be picked up at the same exact spot later. The biggest benefit for cloud gamers, though, is that they can play any game they want, anywhere they go, and on any device they choose.

Gaming companies can also benefit from cloud gaming. Without physical copies of games, piracy becomes much more difficult (if not impossible), and gaming companies need only pay for bandwidth that gamers use while playing, which is far less expensive than manufacturing physical copies of games. Further, cloud gaming is a perfect medium for cross-promotional opportunities. Consider Fortnite, for example: it's free to play, but in-game upgrades have led to millions in sales.

While the benefits are almost countless, cloud gaming isn't quite perfect yet. In order for cloud gaming to reach a point where it's capable of truly replacing the gaming experience found on PC's or consoles, connectivity must be consistent and nearly flawless, with fast speeds and ultra-low latency, particularly for fast-paced, multiplayer online games that require precision and quick reactions.

Imagine this, for example: with consistently fast speeds, low enough latency, and outstanding packet loss and jitter results, an Esports competitor could play a high-stakes Final Kick 2020 tournament from a park bench with zero-lag gameplay, real-time responses, and perfect chat features, all while switching from a smartphone to a tablet and back without missing a beat. We're not at that point quite yet, but that's where the future of 5G and cloud gaming is headed.

Mobile gaming: the most popular lifestyle activity for always-on mobile users

In early 2020, we conducted a **comprehensive study of always-on mobile users**, and while faster data speeds topped the list of what users want and expect, our study also showed that mobile gaming is the single most popular mobile lifestyle activity, with 64% of respondents stating they use their smartphone for mobile gaming on a daily basis.

5G, edge computing, and lower latency

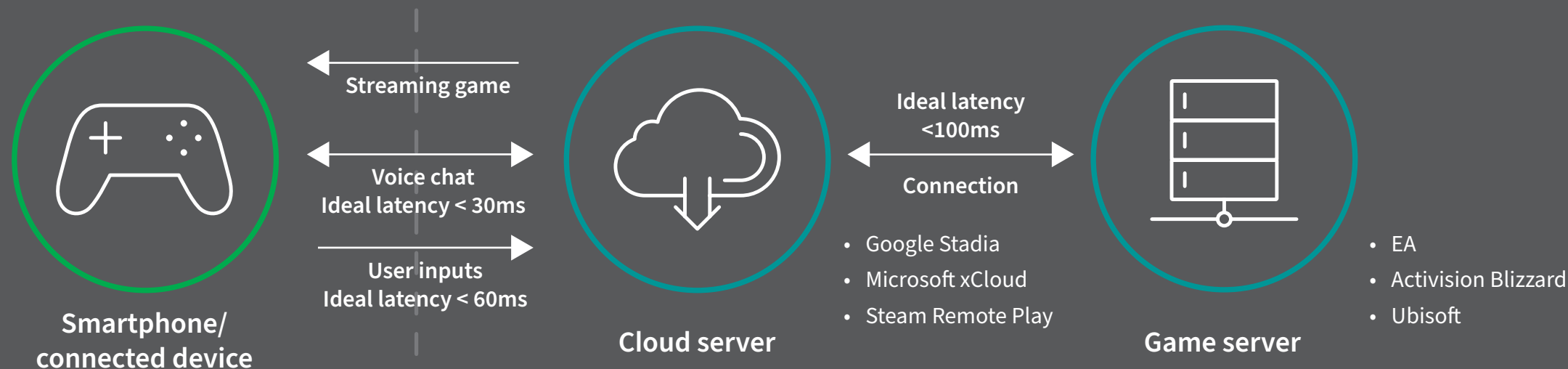
While latency is an inherent challenge for cloud gaming, good news is on the horizon in the form of 5G and edge computing, both of which will allow game providers to mitigate the effects of latency on gameplay.

5G will provide greater capacity that will allow cloud gaming providers to support countless games at the same time (and more and more users), and it will also improve the gaming experience in areas of heavy congestion. Perhaps more importantly, 5G will also (eventually) provide much lower latency and faster speeds than 4G LTE networks can offer.

Edge computing, meanwhile, is perhaps the best tool game providers and mobile operators have for improving latency. It essentially moves processing, video rendering, and video encoding physically closer to the user, which in turn reduces lag. Game streaming services typically have centralised cloud servers in different locations, and the farther away the user is from that server, the more lag they're likely to experience. That's a particularly big issue for multiplayer online games or Esports competitions where every frame is critical and even the smallest delay could mean the end of the game. However, edge computing could help level the latency playing field and remove advantages gamers currently have if they are closer to the cloud server than their geographically disadvantaged counterparts.

It's also important to understand that most latency metrics, including ours for central London below and those recommended by game providers like Microsoft, only factor in the round-trip time it takes for user inputs to reach the cloud server and return to the user. But there's also lag that happens between the cloud server and the actual game server (for example, EA's servers). While that "second layer" of latency is out of the control of both mobile operators and cloud providers, it's always there. That said, if latency is reduced on the operator side by 5G or edge computing, then overall lag will be reduced, even though cloud-to-game server latency exists. Ideal lag between the cloud server and game server is less than 100ms.

Cloud gaming network architecture



5G Benefits

- Lower latency for inputs
- Higher speeds for better graphics

Compensating for latency: user-adjusted latency and game-adjusted latency

Gamers and game developers alike employ innovative ways that don't rely on edge computing or the promises of 5G to mitigate the impact of latency.

Compensated latency is effectively a shortcut used by both gamers and game providers to reduce lag, and oftentimes, compensated latency is a subconscious act on the part of a gamer.

While compensated latency isn't measurable, it can make games move a bit quicker and play a little smoother. For example, say a character in Super Mario Brothers has to run around a wall to reach the next level, but because of minor lag that always happens in the same place, a user recognises that she must hit a button to make Mario jump a split-second earlier than what the screen would indicate. That almost imperceptible shortcut is a learned behaviour that happens over time and can reduce lag.

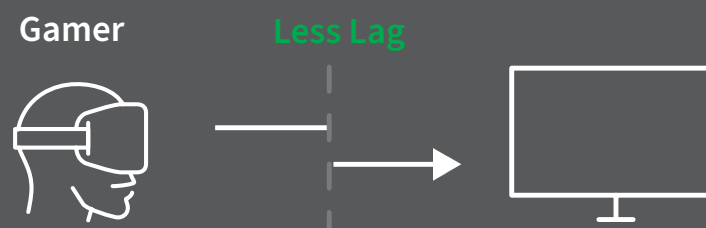
Game-adjusted latency is also common, though it's unpredictable in that gamers don't know which games have been adjusted to compensate for lag. In effect, game-adjusted latency happens when game developers learn that higher-than-normal latency occurs at certain points in a game and then create ways to lessen that lag. For example, if gaming developers notice high latency at a stage in a first-person-shooter (FPS) game in which the player must hit a target in order to advance, the developers might increase the size of the target by a pixel or two so that gamers are more likely to hit the mark and move to the next phase of the game.

Compensated latency

Ideal latency

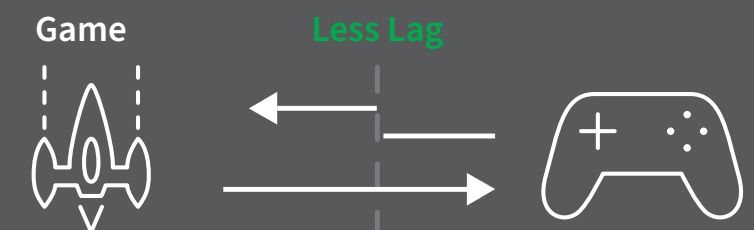


User-adjusted latency



Gamer adjusts behaviour.

Game-adjusted latency



Game developers modify certain points in a game.

Benchmarking what matters most to gamers

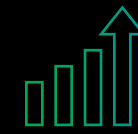
To provide a holistic view of each network's ability to reach or surpass the speed recommendations of Google Stadia and the latency recommendation of Microsoft Xbox Game Pass, we've included visuals below showing each operator's 5G availability, 4G LTE and 5G speeds, and 4G LTE and 5G latency results along with other key metrics and insights for the end-user gaming experience. Taken together, this complementary information provides a full picture of the current end-user gaming experience in central London on both 4G LTE and 5G.

To determine which operators should be able to offer a good gaming experience on any cloud-gaming platform, we looked at whether each operator reached or surpassed Google Stadia's recommended speed results for casual games in SD and online games in HD on both 4G LTE and 5G, and we compared each operator's latency to the Microsoft Xbox Game Pass recommend latency benchmark of 60ms or lower for optimal cloud gaming.



5G median download speeds

End-users won't always access a 5G network as they move through a city, so we've removed all non-5G (4G LTE) test results to show what to expect when 5G is available. Our 5G median download speeds offer a look at "everyday" 5G speeds and show how those speeds can impact cloud gaming when gamers connect to 5G. **Google Stadia recommends median download speeds of at least 10.0 Mbps for casual games in standard definition and median download speeds of 35.0 Mbps or faster for online games in high definition. In this report, we've used those benchmarks as proxies for good gaming on any cloud-gaming platform.**



4G LTE median download speeds

Since an end-user won't access 5G all the time (or hasn't upgraded to 5G yet), we also looked at speed results on 4G LTE. Comparing 4G LTE to 5G speeds helps give a more nuanced view of what gamers can expect on different technologies. Median download speeds on 4G LTE offer a look at typical 4G LTE speed performance and show how speeds affect the everyday gaming experience for users on 4G LTE. They also provide a look at how the gaming experience can differ for users on 5G compared to those on 4G LTE.



4G LTE and 5G latency

Latency is critical for gamers—even more so than speed—and the lower the latency, the better. After all, when you press the "fire" button, you need to know you'll hit your mark immediately or it's game over. High latency can disrupt (or even stop) a game in mid-stream, while low latency can provide smooth, buffer-free gaming. We measured latency on both 4G LTE and 5G to offer a look at the end-user latency experience on 4G LTE compared to that on purely 5G. The latency results in this report are based on our secure web and app testing, which characterises use cases that require continuous data usage on a secure connection, which is the most common mobile cloud gaming experience. **Microsoft Xbox Game Pass recommends latency below 60ms for optimal cloud gaming, and we've used that benchmark as a proxy for good cloud gaming on any cloud-gaming platform, both casual games in SD and online games in HD.**



4G LTE and 5G jitter

While latency is arguably the single most important factor for mobile cloud gaming, jitter can also cause problems for gamers if it's too high. Jitter, which we measure during our UDP tests, effectively means that latency is inconsistent rather than stable. The effects of jitter are similar to those of latency: high jitter can lead to choppy or laggy gameplay and/or distorted audio and chat functionality, while low jitter can keep games running smoothly (as long as latency is also low). In short, the lower the jitter, the better. We looked at jitter on both 4G LTE and 5G to provide a closer look at how 5G can impact jitter and the real-world gaming experience. **For smooth mobile cloud gaming, we recommend jitter below approximately 30ms for casual games in SD and below roughly 10ms for multiplayer online games in HD.** We've included those recommendations in the operator sections below.



4G LTE and 5G packet loss

Like jitter, we measure packet loss during our UDP tests. Packet loss can lead to an extremely frustrating gaming experience since, in effect, packet loss means that pieces, or packets, of game data are lost in transit to and from the user and cloud server. Packets can also arrive out of order, which could theoretically lead to a game that's unintelligible. We measured packet loss on both 4G LTE and 5G to show how packet loss affects the gaming experience across different network technologies. **We recommend packet loss of below about 3% for smooth casual gaming in SD, while packet loss for multiplayer online games in HD should be around 1% or lower.** In the operator sections below, we've included our recommended packet loss metrics for seamless gaming.

The types of games we looked at

We focused on mobile cloud games of two broad types and at two specific resolutions in this report: **casual games in standard definition (720p)** and **online games in high definition (1080p)**.

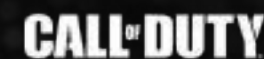
Casual games in SD (720p)

We consider SD an optimal resolution for casual, single-player games like Words with Friends or Tetris. While some casual games are certainly best played in HD and do require low latency for an optimal experience, generally speaking, casual games are usually not as fast paced or precise as multiplayer online games like Call of Duty or Final Kick 2020. In short, latency is less important for casual games where instant reactions and absolute precision aren't necessary for a good gaming experience. On the other hand, latency is critical for multiplayer online games. Examples of casual games in SD for this report include:



Online games in HD (1080p)

The online games discussed in this report are assumed to be played in HD, are usually intended to be multiplayer games, and must be played online (that is, you can't just download Call of Duty to your smartphone and play by yourself). In these multiplayer online games, fast reactions and pinpoint accuracy are required, and every frame can make the difference in the outcome. These multiplayer online games typically require perfect chat functionality, exceptional audio and video quality, real-time inputs, and minimal (or zero) delays or lag during gameplay. The online games discussed in this report include games like:



How we evaluated the quality of each operator's mobile cloud gaming experience

Google Stadia recommends median download speeds of at least 10.0 Mbps for online games in SD and speeds of 35.0 Mbps or better for online games in HD. In terms of latency, Microsoft Xbox Game Pass recommends latency below 60ms for an optimal gaming experience. We used those speed and latency benchmarks as proxies for good cloud gaming on any platform.

With those speed and latency recommendations as a baseline, we looked at results from the four major mobile operators in central London during our testing in 1H 2020 to determine which networks could provide a good mobile cloud gaming experience for casual games in SD and online games in HD. Put simply, we compared each operator's speed results on 4G LTE and 5G to the speed recommendations of Google Stadia, and we compared each network's latency results to the latency recommendation of Microsoft Xbox Game Pass.

Recommended speed and latency for casual games in SD and multiplayer online games in HD

Recommended speed and latency	Casual games in standard definition (720p)	Online games in high definition (1080p)
Recommended median download speed	10+ Mbps	35+ Mbps
Recommended latency	<60ms	<60ms

In addition, even though the providers didn't make recommendations for jitter or packet loss, we factored both metrics into our results because jitter and packet loss are key elements of the real-world gaming experience.

The results: a high-level look at the cloud gaming experience in central London

High-level key findings:

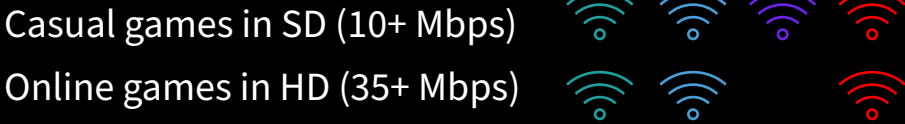
Our operator-by-operator section beginning on page 15 includes insights on the gaming experience for each network in central London on both 4G LTE and 5G, but in a nutshell, some of the high-level findings from our study include:

- **EE offered by far the most 5G in central London, though 5G availability was generally broad:** EE's 5G availability of 77.5% was incredibly widespread, though both Three (20.0%) and Vodafone (39.6%) had much greater 5G availability in central London compared to that in greater London as a whole (5.2% for both networks). We weren't able to collect enough test samples to accurately characterise O2's 5G results in central London.
- **Impressive 5G speeds in central London:** EE and Vodafone were particularly fast in central London, with EE clocking an excellent 5G median download speed of 135.2 Mbps and Vodafone delivering the fastest 5G median download speed in central London at 178.1 Mbps. Three, meanwhile, also impressed with a 5G median download speed of 79.1 Mbps.
- **Latency was generally low in central London, with Three leading the way:** While latency was generally low for all operators in central London on both 4G LTE and 5G, Three registered the lowest 5G latency among all operators at 17.0ms. EE, O2, and Vodafone also offered generally low latency, with all three operators delivering latency well below Microsoft's recommended 60ms for optimal cloud gaming.

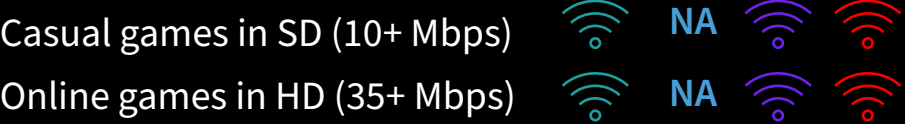
Which operators met the game providers' recommended speed and latency results in central London?

Met median download speed recommendations in central London

4G LTE

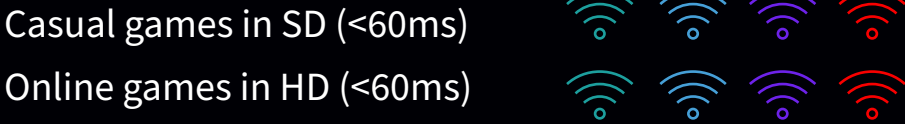


5G

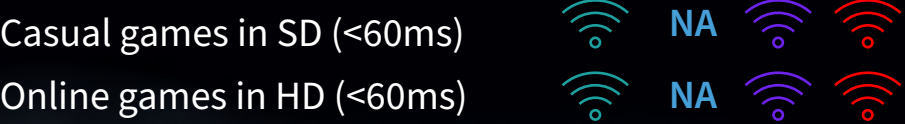


Met latency recommendation in central London

4G LTE



5G



● EE ● O2 ● Three ● Vodafone

*We didn't collect enough 5G test samples to accurately characterise O2's 5G speeds or latency in central London.

An operator-by-operator look
at the real-world gaming
experience in central London





EE’s 5G should allow for generally smooth gaming in central London, though minor issues are possible for precision-based online games in HD.

The primary differentiator between EE’s 5G network and those of Three and Vodafone in central London was EE’s 5G availability of 77.5%. Not only was it easily the highest among all networks, EE’s 5G availability approached a point of ubiquity and was well over twice as high as EE’s 5G availability across London as a whole (28.8%). In short, EE’s 5G customers should be able to access 5G the vast majority of the time while in central London. What’s more, EE’s median download speeds in central London on both 4G LTE and 5G easily surpassed Google’s speed recommendations for any type of game.

EE’s latency results on both 4G LTE and 5G were also strong and came in well below Microsoft’s recommended 60ms for optimal cloud gaming. Further, EE’s jitter results on 4G LTE and 5G were outstanding and easily met our recommended targets of 30ms for casual games in SD and 10ms for online games in HD.

EE’s packet loss was the one metric that showed room for improvement. While EE’s packet loss of 2.6% on 5G in central London marked an improvement from its 3.7% in London as a whole and met our recommended 3% for casual games in SD, it was higher than our 1% target for online games in HD. However, with packet loss below 3%, gamers should still experience generally good gameplay, though minor issues are conceivable for some online games in HD.

The bottom line is that EE gamers in central London, whether on 5G or 4G LTE, should be able to enjoy most games without much trouble. Fans of casual games in SD should find a smooth experience, while those who enjoy precision-based online games in HD like Final Kick 2020 should also see generally good gaming, though possibly with some minor issues. It’s worth noting that EE’s packet loss and latency results were relatively similar on both 4G LTE and 5G in central London, but we do expect the operator’s results on 5G to improve across the board as its network continues to mature.

YES

NO

EE 5G availability 77.5%

EE speeds	4G LTE median download speed	5G median download speed
Median download speed	108.3 Mbps	135.2 Mbps
Met recommended speed for casual games in SD (10+ Mbps)?	<div><div></div><div></div><div></div></div>	<div><div></div><div></div><div></div></div>
Met recommended speed for online games in HD (35+ Mbps)?	<div><div></div><div></div><div></div></div>	<div><div></div><div></div><div></div></div>

EE latency	4G LTE latency	5G latency
EE latency	43.3ms	45.0ms
Met recommended latency for casual games in SD and online games in HD (<60ms)?	<div><div></div><div></div><div></div></div>	<div><div></div><div></div><div></div></div>

EE packet loss and jitter	4G LTE packet loss	5G packet loss	4G LTE jitter	5G jitter
EE packet loss and jitter	2.8%	2.6%	2.2ms	2.5ms
Met recommended packet loss (3%) and jitter (<30ms) for casual games in SD?	<div><div></div><div></div><div></div></div>	<div><div></div><div></div><div></div></div>	<div><div></div><div></div><div></div></div>	<div><div></div><div></div><div></div></div>
Met recommended packet loss (<1%) and jitter (<10ms) for online games in HD?	<div><div></div><div></div><div></div></div>	<div><div></div><div></div><div></div></div>	<div><div></div><div></div><div></div></div>	<div><div></div><div></div><div></div></div>

Note: Packet loss and jitter recommendations are from RootMetrics (not the game providers).

O2

O2’s 4G LTE speeds and latency were good enough for any type of game, but the operator’s packet loss shows room for improvement.

While we weren’t able to collect enough test samples to accurately characterise O2’s 5G results in central London, the operator’s median download speed of 43.3 Mbps on 4G LTE met Google’s recommendations for both casual games in SD and multiplayer online games in HD. O2’s latency of 39.0ms on 4G LTE also met Microsoft’s latency recommendation of 60ms or better. Meanwhile, O2’s jitter of 5.0ms was the highest among all operators in central London on either 4G LTE or 5G but still fell below our recommended jitter goal for any type of game.

While O2’s speed, latency, and jitter results on 4G LTE were good news for gamers, the operator’s packet loss of 10% will likely cause issues. When packet loss is above approximately 3%, gamers can experience distorted video, poor audio, and other issues, and O2’s packet loss of 10.0% was the highest among all operators and over 3 times higher than our recommended packet loss of 3% for casual games in SD and 10 times higher than the 1% packet loss we recommend for multiplayer online games in HD.

The bottom line is that gamers on O2’s 4G LTE network will likely be able to enjoy some casual games with relative ease, but the less a game relies on precision and accuracy, the better the experience is likely to be. It’s worth noting that while O2 didn’t have a 5G presence in central London at the time of our testing, we do expect the operator’s 5G to expand going forward.

YES

NO

O2 5G availability 0%

O2 speeds	4G LTE median download speed	5G median download speed
Median download speed	43.3 Mbps	-
Met recommended speed for casual games in SD (10+ Mbps)?	<div></div>	-
Met recommended speed for online games in HD (35+ Mbps)?	<div></div>	-

*We didn't collect enough 5G test samples to accurately characterise O2's 5G speeds or latency in central London.

O2 latency	4G LTE latency	5G latency
O2 latency	39.0ms	-
Met recommended latency for casual games in SD and online games in HD (<60ms)?	<div></div>	-

*We didn't collect enough 5G test samples to accurately characterise O2's 5G speeds or latency in central London.

O2 packet loss and jitter	4G LTE packet loss	5G packet loss	4G LTE jitter	5G jitter
O2 packet loss and jitter	10.0%	-	5.0ms	-
Met recommended packet loss (3%) and jitter (<30ms) for casual games in SD?	<div></div>	-	<div></div>	-
Met recommended packet loss (<1%) and jitter (<10ms) for online games in HD?	<div></div>	-	<div></div>	-

*We didn't collect enough 5G test samples to accurately characterise O2's 5G speeds or latency in central London.

Note: Packet loss and jitter recommendations are from RootMetrics (not the game providers).

Three

Three delivers strong gaming results on 5G in central London, with its 5G showing much better performance compared to 4G LTE.

Three’s 5G availability of 20.0% was the lowest among all operators in central London, but it was almost four times higher than its 5G availability across the greater London metropolitan market (5.2%). Three’s 5G median download speed of 79.1 Mbps was easily fast enough for any type of game, and in fact, Three’s 5G could make a big difference for gamers in central London: Three’s median download speed of 14.8 Mbps on 4G LTE was markedly slower than its speed on 5G and didn’t meet Google’s speed recommendation of at least 35 Mbps for online games in HD. In what could be particularly good news for gamers, Three registered the lowest 5G latency in central London at 17.0ms, which was over twice as low as its latency of 34.0ms on 4G LTE (though 34.0ms is still low).

Three’s packet loss and jitter results in central London also showed notable improvements on 5G compared to 4G LTE. Three’s packet loss of 1.6% on 5G was much better than its potentially troublesome 8.9% on 4G LTE, and the operator’s jitter of 2.4ms on 5G was excellent and lower than its already-low 3.3ms on 4G LTE. Keep in mind that even though Three’s 5G packet loss was a bit higher than our recommended target of 1.0% for online games in HD, it was still low enough to provide generally smooth gaming.

The bottom line is that while Three’s 5G availability in central London was lower than what we recorded for either EE or Vodafone, the operator’s 5G results were strong across the board. For gamers on Three’s network, 5G could be a big benefit, as the operator’s results on 5G in central London were much better than those on 4G LTE and should lead to a smooth gaming experience for fans of all types of games, from casual games like Candy Crush to multiplayer online games like Final kick 2020 or Fortnite.

Three 5G availability 20.0%				
<div>YES NO</div>				
Three speeds	4G LTE median download speed		5G median download speed	
Median download speed	14.8 Mbps		79.1 Mbps	
Met recommended speed for casual games in SD (10+ Mbps)?	<div>YES NO</div>		<div>YES NO</div>	
Met recommended speed for online games in HD (35+ Mbps)?	<div>YES NO</div>		<div>YES NO</div>	
Three latency	4G LTE latency (ms)		5G latency (ms)	
Three latency	36.0ms		17.0ms	
Met recommended latency for casual games in SD and online games in HD (<60ms)?	<div>YES NO</div>		<div>YES NO</div>	
Three packet loss and jitter	4G LTE packet loss	5G packet loss	4G LTE jitter	5G jitter
Three packet loss and jitter	8.9%	1.6%	3.3ms	2.4ms
Met recommended packet loss (3%) and jitter (<30ms) for casual games in SD?	<div>YES NO</div>	<div>YES NO</div>	<div>YES NO</div>	<div>YES NO</div>
Met recommended packet loss (<1%) and jitter (<10ms) for online games in HD?	<div>YES NO</div>	<div>YES NO</div>	<div>YES NO</div>	<div>YES NO</div>
Note: Packet loss and jitter recommendations are from RootMetrics (not the game providers).				

Vodafone

Vodafone 5G users in central London should find a good gaming experience in general, with the operator’s relatively widespread 5G providing faster speeds and perfect packet loss.

Vodafone users in central London should find a much better gaming experience on 5G compared to that on 4G LTE. Indeed, Vodafone’s 5G performance in central London, especially when looking at speed, was outstanding. The operator registered generally broad 5G availability of nearly 40%, the fastest 5G median download speed in central London at 178.9 Mbps, low latency, and excellent packet loss and jitter results. In addition to registering the fastest 5G median download speed among all operators, Vodafone also stood out for its perfect 5G packet loss of 0.0% in central London, which marked a dramatic improvement from its packet loss of 6.0% on 4G LTE.

Vodafone’s median download speed on 4G LTE also impressed, clocking in at an excellent 90.7 Mbps, which was fast by any standard and even faster than Three’s speed on 5G. Likewise, Vodafone recorded low latency on 4G LTE, with its latency of 32.5ms on 4G LTE actually a bit lower than its latency of 34.0ms on 5G. While Vodafone’s 4G LTE speed, latency, and jitter results were strong in central London, the operator’s 4G LTE packet loss of 6.0% had room for improvement and could cause issues for gamers who don’t have access to 5G.

The bottom line is that with strong 5G results across the board, Vodafone gamers on 5G in central London should find a generally good gaming experience for nearly any type of game. It’s worth noting, though, that Vodafone couldn’t match the widespread availability we recorded on EE’s network, with EE nearly doubling the rate of Vodafone’s 5G availability in central London (77.5% for EE vs. 39.6% for Vodafone). if Vodafone’s availability continues to increase, however, the race for 5G performance in central London could become very interesting indeed.

<div><div></div> YES <div></div> NO</div>		Vodafone 5G availability 39.6%		
Vodafone speeds		4G LTE median download speed	5G median download speed	
Median download speed		90.7 Mbps	178.9 Mbps	
Met recommended speed for casual games in SD (10+ Mbps)?		<div></div>	<div></div>	
Met recommended speed for online games in HD (35+ Mbps)?		<div></div>	<div></div>	

Vodafone latency	4G LTE latency	5G latency	
Vodafone latency	32.5ms	34.0ms	
Met recommended latency for casual games in SD and online games in HD (<60ms)?	<div></div>	<div></div>	

Vodafone packet loss and jitter	4G LTE packet loss	5G packet loss	4G LTE jitter	5G jitter
Vodafone packet loss and jitter	6.0%	0.0%	2.1ms	1.1ms
Met recommended packet loss (3%) and jitter (<30ms) for casual games in SD?	<div></div>	<div></div>	<div></div>	<div></div>
Met recommended packet loss (<1%) and jitter (<10ms) for online games in HD?	<div></div>	<div></div>	<div></div>	<div></div>

Note: Packet loss and jitter recommendations are from RootMetrics (not the game providers).

What happens to gameplay when speeds slow down?

Whether you're using your smartphone to play a relatively simple casual cloud game like Tetris or a more complicated game like Final Kick 2020, any interruption can be frustrating and could mean the difference between winning and losing.

While this report has focused on median download speeds to show the most typical speed experience for mobile cloud gaming, avid gamers might also want to understand what can happen to the gaming experience if their speeds lag.

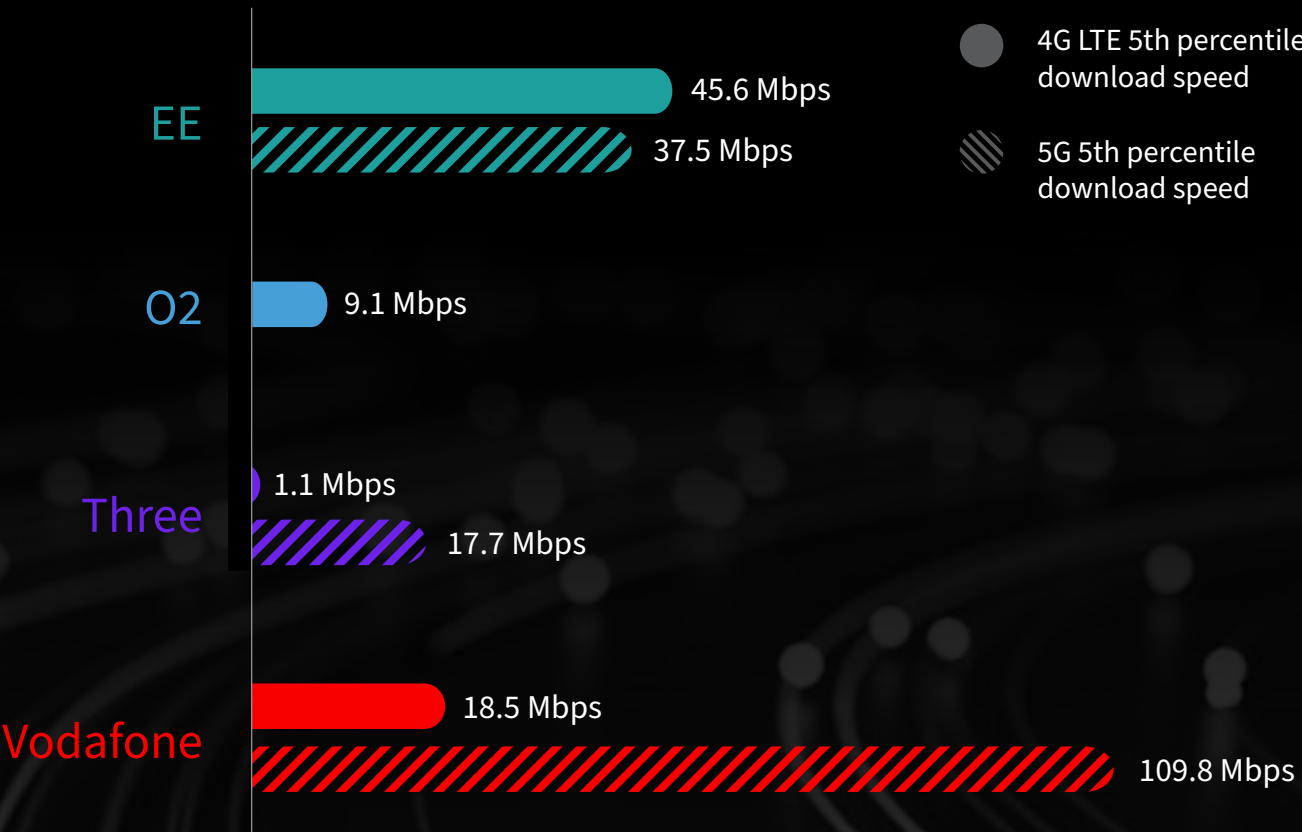
To that end, we're also showing the slowest or "worst case" download speeds we recorded for each operator on both 4G LTE and 5G. These were speeds found during only 5% of our tests and don't necessarily need to be factored into a typical gaming experience. Instead, consider this a worst-case scenario to keep in mind for your most important matches in central London, from Final Kick 2020 to Fortnite or any other game you might enjoy.

	Casual games in SD	Multiplayer online games in HD
Recommended median download speeds	10+ Mbps	35+Mbps
Recommended latency	<60ms	

As you can see, Vodafone's 5G speed was the standout, with the operator's worst-case (5th percentile) download speed on 5G clocking in at a remarkably fast 109.8 Mbps that would easily support any type of game. EE also delivered a strong worst-case download speed of 37.5 Mbps that would support both casual games in SD and multiplayer online games in HD. Interestingly, EE's worst-case download speed on 4G LTE in central London was actually faster than its worst-case speed on 5G, suggesting that both the 5G and 4G LTE networks of EE provide strong service in general.

Three's worst-case speed download speed of 17.7 Mbps on 5G wasn't nearly as fast as that of either EE or Vodafone and didn't reach Google's recommended speed benchmark of at least 35 Mbps for online games in HD. It's worth noting, however, that Three's worst-case download speed of 17.7 Mbps on 5G was significantly faster than its worst-case speed of 1.1 Mbps on 4G LTE.

While gamers shouldn't find these worst-case speeds very often (about 5% of the time), they do offer an important barometer for how 5G is advancing the end-user gaming experience. It's also important to note that we expect this type of worst-case speed scenario to continue to improve over time as 5G matures and expands.



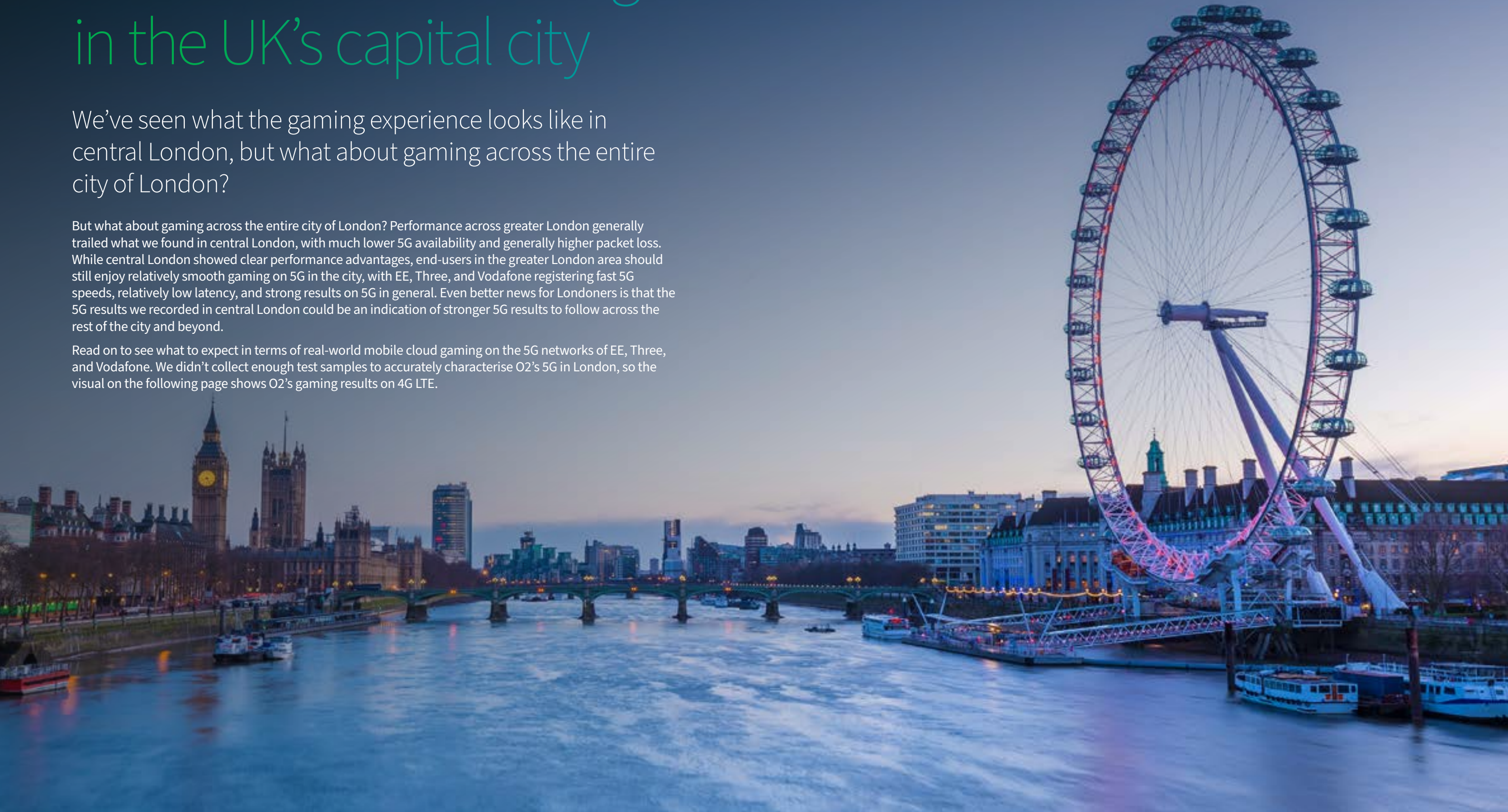
A high-level look at 5G gaming across greater London:

what 5G can mean for gamers in the UK's capital city

We've seen what the gaming experience looks like in central London, but what about gaming across the entire city of London?

But what about gaming across the entire city of London? Performance across greater London generally trailed what we found in central London, with much lower 5G availability and generally higher packet loss. While central London showed clear performance advantages, end-users in the greater London area should still enjoy relatively smooth gaming on 5G in the city, with EE, Three, and Vodafone registering fast 5G speeds, relatively low latency, and strong results on 5G in general. Even better news for Londoners is that the 5G results we recorded in central London could be an indication of stronger 5G results to follow across the rest of the city and beyond.

Read on to see what to expect in terms of real-world mobile cloud gaming on the 5G networks of EE, Three, and Vodafone. We didn't collect enough test samples to accurately characterise O2's 5G in London, so the visual on the following page shows O2's gaming results on 4G LTE.



EE shows outstanding 5G availability, fast speeds, and low latency in greater London, but gamers might see minor issues during precision-based games like Call of Duty.

	5G availability	5G median download speed	5G latency	5G jitter	5G packet loss
Central London	77.5%	135.2 Mbps	45.0ms	2.5ms	2.6%
City of London as a whole (Greater London)	28.8%	138.1 Mbps	46.0ms	2.5ms	3.7%

EE stood out for registering the highest 5G availability in the greater London area at 28.8%, which was over five times higher than that of either Three or Vodafone. That said, EE’s 5G was far more widespread in central London, which wasn’t necessarily unexpected. EE’s 5G median download speed in the greater London metropolitan market was extremely impressive at 138.1 Mbps and similar to its speed in central London. The main differences between EE’s performance in greater London compared to that in central London were its 5G availability and packet loss results. While EE’s packet loss of 3.7% on 5G was relatively high, gamers in greater London should be able to play casual games in SD with without much trouble, while fans of multiplayer online games like Call of Duty could experience some minor issues. The bottom line is that if and when EE’s 5G results from central London extend to other areas of the city, end users should be able to enjoy generally smooth gaming of any type. It’s also important to keep in mind that as one of the first operators to launch 5G in the UK, EE has shown extremely strong results that we expect will only get better as its 5G network matures and expands.

O2’s speeds and latency on 4G LTE were good enough for most casual games, but the operator’s packet loss results could cause issues.

	5G availability	4G LTE median download speed	4G LTE latency	4G LTE jitter	4G LTE packet loss
Central London	-	43.3 Mbps	39.0ms	5.0ms	10.0%
City of London as a whole (Greater London)	-	43.5 Mbps	43.5ms	5.0ms	10.0%

*We didn’t collect enough test samples to accurately characterize O2’s 5G results in London, so we’re including the operator’s 4G LTE gaming-related results.

O2 didn’t register enough 5G during our testing to accurately measure its performance on 5G, so O2 customers in both greater London and in central London will currently have to rely 4G LTE for mobile cloud gaming. The good news is that O2’s speed, latency, and jitter results on 4G LTE were strong enough for good gaming of any type, but the potentially bad news is that the operator’s packet loss of 10% could cause some issues, especially for online games in HD. In short, O2 gamers will likely be able to enjoy some casual games on 4G LTE with little trouble, but gamers could see issues with more precision-based online games in HD. It’s worth noting that while O2’s 5G availability was limited across the 16 cities we tested in the UK, we did find strong results on O2’s 5G in one city (Belfast) that portend good things ahead, and we expect the operator’s 5G to expand to London and elsewhere going forward.

Three provides strong gaming results on 5G across greater London and within central London, but its packet loss on 4G LTE shows room for improvement.

	5G availability	5G median download speed	5G latency	5G jitter	5G packet loss
Central London	20.0%	79.1 Mbps	17.0ms	2.4ms	1.6%
City of London as a whole (Greater London)	5.2%	133.8 Mbps	27.0ms	2.1ms	1.1%

Three’s 5G provided impressive gaming results across greater London and in central London, but the operator’s 5G availability of 5.2% in greater London showed clear room for improvement. That said, Three delivered an excellent 5G median download speed in greater London, and the operator’s latency, jitter, and packet loss results on 5G were generally outstanding. That said, Three’s packet loss of 7.6% in the London metro area (and 8.9% in central London) could cause issues for gamers. The bottom line for Three gamers is that 5G could be the key to smooth gaming across London as a whole or in central London, with the operator generally registering much better results on 5G compared to those on 4G LTE.

Vodafone gamers should find a much better experience on 5G compared to 4G LTE, with stronger 5G results across London as a whole and in central London.

	5G availability	5G median download speed	5G latency	5G jitter	5G packet loss
Central London	39.6%	178.9 Mbps	34.0ms	1.1ms	0.0%
City of London as a whole (Greater London)	5.2%	181.8 Mbps	38.0ms	0.5ms	0.1%

Vodafone users will likely find a much better gaming experience on 5G compared to that on 4G LTE across greater London. Vodafone registered the fastest 5G median download speed in the city at 181.8 Mbps, which was significantly faster than its speed of 15.8 Mbps on 4G LTE. Vodafone also provided outstanding 5G jitter results and near-perfect packet loss of just 0.1% on 5G. In contrast, Vodafone’s packet loss on 4G LTE in greater London was a potentially problematic 8.9%. While Vodafone’s 5G availability of 5.2% left room for improvement and was much lower than its 5G availability in central London (39.6%), the bottom line is that Vodafone’s 5G users should find a generally smooth experience for any type of game, and in even better news, we expect the operator’s 5G availability to expand across the city going forward.

Conclusion: Looking ahead to 5G and the gaming experience in central London and beyond

The promises of 5G include greater capacity, much faster speeds, and lower latency, among other advantages. Taken together, those benefits should eventually lead to dramatic improvements for cloud gaming on mobile devices, especially when we reach a point where latencies become consistently lower than what we're seeing today. The faster speeds of 5G should allow for more advanced and faster video rendering, which would allow gamers to stream more complicated online games on their mobile devices with ease. And when those faster speeds are coupled with ultra-low latencies and reduced packet loss and jitter, the gaming experience on a smartphone or other connected device could be akin to playing a game on a heavy-duty gaming PC or a console.

While we haven't quite reached that point yet, it's important to keep in mind that we're already seeing encouraging 5G speeds and 5G availability, as well as dramatic improvements to 5G packet loss and jitter on some networks—especially in central London. In short, the 5G landscape is changing fast, and the operators are making great progress, but it will take time before gamers can put away their consoles and start entering Esports competitions on smartphones.

That said, the results we saw in central London offer an encouraging proxy for what's likely to come, with the broader 5G availability, faster 5G speeds, and stronger 5G results in general likely expanding to the rest of London and other cities as we move further into 2020 and beyond. For now, the good news is that the future of mobile cloud gaming in London is clearly bright. We'll continue testing the networks to keep an eye on how 5G can impact your real-world mobile cloud gaming experience.





For more information, visit

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