E2E delay in Livestreaming: Viewers perspective and different QoS metrics over 4G LTE and 5G NSA/SA networks

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Abstract

Streaming has seen continuous growth in recent years, particularly livestreaming, which is steadily growing in popularity. With this, reliable and low-latency connections are increasingly important for both creators and consumers. Whether you sit on the bus or in the car on your way to work you will most likely have to rely on your 4G or 5G when watching a livestream. While 5G promises lower latency, higher capacity, and a more stable performance compared to 4G, little is known about its impact on livestreaming. What are the differences and could there still be an advantage to having 4G?

This study investigates the End-to-End (E2E) delay between a Sweden-hosted Twitch stream received in Sweden and Australia over 4G LTE and 5G NSA/SA networks. An experiment was conducted in which live broadcasts were measured, combining an on-screen timestamp overlay and network traffic analyzed with Wireshark to assess different Quality of Service (QoS) metrics such as Round Trip Time (RTT), jitter, and potential packet loss. We found that: across both Sweden and Australia, 5G showed lower E2E delay than 4G. Australian reception exhibited a much higher E2E delay compared to Sweden, consistent with the geographical distance from the host. Improvements in QoS on 5G networks (lower RTT and jitter) aligned with the observed E2E results.

1 Introduction

As streaming is increasing in popularity, both consumers and creators rely on well established connections and an increased demand of real-time streaming. With 5G successively expanding across the globe and suppliers promising lower latency, higher capacity and more stable performance than 4G, expectations of achieving the optimal streaming experience continue to rise.

Despite these promises, the usual experience of "live" streaming often includes a perceptible delay from the content creator's moment of upload until the viewer's reception of the transmitted data. This E2E delay can vary depending on network conditions, streaming platform implementations and buffering strategies. Although 4G and 5G differ in infrastructure, often making 5G more superior, less is known about how these differences affect livestreaming performance in the real world as experienced by viewers.

This study will in depth investigate the differences between 4G and 5G based on the E2E delay between creators and consumers. We will also account for the impact of geographic distance, the experiment was therefore conducted in two locations, Sweden where the stream was both hosted and received and in Australia, where the stream was solely received. This allows us to compare not only network technologies, but also how different QoS metrics are affected when the viewer is located far from the source. First, we conduct a basic experiment where we measure the E2E delay from the time of broadcast to the time of reception and subsequently we use Wireshark to analyze the underlying network characteristics that may cause potential delay.

2 Background

In this section, we provide an overview of how livestreaming is experienced through 4G LTE and 5G networks. We outline key architectural differences between the technologies and explain why the introduction of New Radio (NR) interface is expected to improve viewer experience in the 5G Non-Standalone (NSA) network and why the 5G core is expected to improve viewer experience even further in the 5G Standalone (SA) network.

2.1 Livestreaming and Network Requirements

Livestreaming refers to the real-time transmission of video content from a creator to an audience, such as a viewer. Unlike pre-published videos on e.g. YouTube, where playback can be buffered before the video is played, livestreaming requires the video to be transmitted and watched simultaneously. For the viewer, this implies that the Quality of Experience (QoE) is highly dependent on the performance of the underlying network. Even small amounts of delay, jitter or packet loss can impact the smoothness and above all reduce the overall experience for the viewer.

There are several Quality of Service (QoS) metrics to account for, including the E2E delay, RTT, packet loss and jitter as each can significantly impact the viewers interaction and perceived smoothness of the stream.

While we know that the promises of 5G in general includes lower E2E delay and higher capacity than 4G LTE, there's insufficient information on how these improvements translate into real-world livestreaming performance from the viewers perspective.

2.2 4G LTE and 5G Non-Standalone architecture

The 5G Non-Standalone (NSA) that is used today is based on its predecessor 4G Long Term Evolution (LTE) architecture. Therefore, having an understanding of the 4G LTE architecture makes it easier for us to understand the 5G NSA with both its differences and the known positives it provides. As a connection is established through a 4G network the user equipment (UE) will send signals to a base station (eNodeB). The base station belongs to the radio access network (RAN) and acts as an anchor for all incoming and outgoing traffic, as illustrated in Figure 1.

The base station is connected to the Mobility Management Entity (MME) which is a part of the control plane and falls under the core network (EPC). The base station also connects to the serving gateway (S-GW), which has the responsibility of routing and forwarding data packets. The S-GW is in turn connected to the

Packet Data Network gateway (PGW) which in addition connects the EPC to outside networks including the internet and in the case of livestreaming, various Content Delivery Network (CDN) servers.

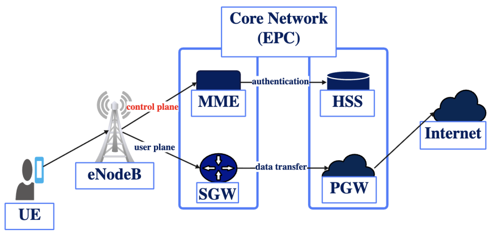

Figure 1: An example architecture of 4G LTE

The main architectural difference between 4G LTE and 5G NSA is essentially the introduction of a new base station in the RAN, called gNodeB. In the most common deployment of 5G NSA, the E-UTRAN and NR Dual Connectivity (EN-DC) as defined by 3GPP [1], the eNodeB remains connected to the EPC as an anchor, while within the RAN network, it coordinates with the gNodeB. The gNodeB then delivers and receives data from the RAN to the UE in a much faster pace than eNodeB, leveraging the benefits of 5G New Radio (NR) interface as seen in Figure 2.

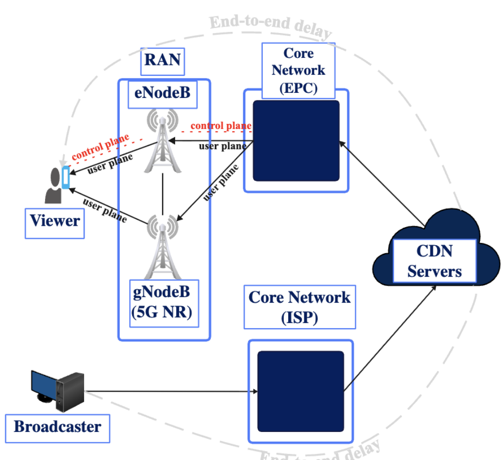

Figure 2: An example architecture of 5G NSA (EN-DC) with viewer at receiving end, and an illustration of the E2E

2.3 The Benefits of 5G New Radio

The New Radio (NR) interface provides several key advantages compared to previous generations of technological interface in the RAN, such as the eNodeB. With theoretical speeds of up to 20 Gbps, it enables significantly higher data rates compared to the roughly 1 Gbps achievable through 4G LTE. Furthermore, the 5G NR interface is designed to reduce latency to around 1 ms under ideal conditions, whereas LTE-only standards generally result in latencies above 30 ms. Such a reduction is expected to have a considerable impact on the perceived E2E delay and is particularly important for livestreaming where interactivity is a critical part of the viewer experience.

Moreover, while low frequency bands provide wide coverage, higher bands enable extremely high data throughput in dense urban areas. Another major positive is the significantly increased capacity and network efficiency, as 5G NR can handle a larger number of connected devices simultaneously, which is a highly valued factor in the IoT era [2].

2.4 5G SA and Australia's Network Evolution

While 5G Non-Standalone builds on existing LTE infrastructure, 5G Standalone (SA) introduces a completely new 5G Core designed to fully exploit the potential of 5G. In Australia, Telstra has deployed one of the world's first commercial 5G SA networks in partnership with Ericsson [3]. Consequently, this marks an interesting shift from relying on LTE internet to a fully dedicated 5G Core, which enables minimal latency and a considerably higher reliability.

With the 5G SA, new capabilities such as network slicing are enabled, where the operator can allocate dedicated parts of the network for different types of services. In practice, this means that latency-sensitive applications like livestreaming can be prioritized separately from, for example, large-scale IoT connectivity, which makes the comparison of Sweden's 5G NSA and Australia's 5G SA very interesting. For Australia, where long distances and diverse service demands pose unique challenges, this type of flexibility is an essential step in ensuring consistent performance across the country.

Ericsson highlights that 5G SA is essential to realize the full benefits of New Radio, including improved E2E performance for applications like real-time video streaming. The introduction of Telstra's 5G SA network demonstrates how mobile operators can evolve beyond capacity and speed improvements, instead offering service-oriented connectivity designed for both consumers and enterprises [3].

3 Method

The subsections under this section will describe how the experiment was executed, what tools and factors that took part, how the QoS metrics were measured, but also some considerations and potential limitations that could have affected the results.

3.1 Tools

To conduct the experiment, a selection of hardware and software tools were selected. For hosting the livestream, we used a stationary computer with a stable ethernet connection supported by fiber optics, in order to maintain focus on the performance of the mobile network technologies. When generating the livestream, the open-source software application OBS Studio was used with a timer overlay inserted on the screen to enable precise measurements of the E2E delay. OBS studio also gives us the opportunity to adjust the broadcast settings such as preferred delay, quality and so on. The preferred delay was set to 300 ms which was taken into account during all experiments. Additionally, the software tool Wireshark was utilized to capture parameters such as RTT, jitter, and packet data during the streaming sessions for examination. Microsoft Excel was then used for evaluating and simplifying the results.

Furthermore, two smartphones capable of 4G LTE and 5G NSA/SA were used as mobile hotspots, providing connectivity to a MacBook via USB tethering, allowing us to track the QoS metrics through Wireshark. To ensure the ability to compare between network providers and global locations, one device was equipped with a physical SIM card from Telenor, while the other used an eSIM from Holafly with supplied internet from Telstra.

3.2 Experiments

The experiment is designed to evaluate livestreaming performance in terms of E2E delay and different QoS metrics while being connected to 4G and 5G networks. Every experiment is 5 minutes long and 4 experiments will be conducted for each specific network, which sums up to 16 experiments in total. A live broadcast will be initiated in Linköping, Sweden using OBS Studio with a timer overlay while transmitting its video content to Twitch.tv. The received video will be compared to the source to measure the actual delay. Simultaneously, Wireshark will capture network traffic to provide deeper insight into the underlying network conditions, such as the QoS metrics. However, Wireshark will only capture traffic from the CDN edge to the viewer, since this is where the cellular networks will be as most apparent, see Figure 2 for context.

The tests will be performed under two main conditions: first using 4G LTE, and then using 5G NSA, but for Australia 5G SA. To account for potential variations depending on distance, the procedure will be conducted in both Linköping, Sweden and Canberra, Australia, each relying on different operators.

The collected data from both the timer overlay and the Wireshark captures will then be analyzed and compared across technologies and locations, in order to assess whether 5G provides measurable advantages over 4G in real-world livestreaming scenarios.

3.3 QoS Metric Extraction

We extracted three QoS metrics from Wireshark captures between the client and CDN edge: (i) per-packet RTT (after filtering out non-stream traffic), (ii) jitter as $|r_i - r_{i-1}|$ over consecutive RTT $= r$ samples (computed in Excel), and (iii) TCP retransmissions identified with *tcp.analysis.retransmission.*

Median and mean values were computed across four different runs per network.

3.4 Considerations

When measuring the E2E delay we had to consider the join-latency-variance. This refers to the inconsistency in the delay experienced by the viewer when first connecting to a livestream. Although this delay cannot be eliminated entirely, by refreshing the livestream a number of times, until we observe reasonable delays, we can potentially eliminate the largest overhead. This overhead might account for several seconds of additional delay, which then can be minimized to only milliseconds of delay.

Furthermore, we had to give thought to the strength of our signal towards the RAN, as this could impact the final results. The Reference Signal Received Power (RSRP) was measured using iPhones inbuilt field-test mode, which shows statistics on our connection with the nearest cellular tower. It provides a numerical value between around -140 to -44 dBm, where higher values indicate stronger signal strength.

3.5 Limitations

During the experiments, one researcher was located in Sweden and the other was located in Australia using a different operator. The Australian SIM was an eSIM from Holafly that roamed on Telstra's network in the Canberra area, while in Sweden we used a SIM from Telenor. Although both operators use equipment provided by Ericsson, the deployment of these might have differed.

As mentioned in section 3.4, we recorded certain radio conditions, such as Reference Signal Received Power (RSRP) and bandselection, which were within our control. However, several other factors were beyond our control, including packet routing and IP handling (e.g. security firewalls).

Another limitation is the time difference between Sweden and Australia, which may have influenced the network conditions. The Swedish tests were run at 10:00 AM, while in Australia it was 6:00 PM, which usually corresponds to a period of higher internet usage.

4 Results

The results will be illustrated using bar charts to get an understanding of the different QoS metrics and how they may vary depending on the network, as shown in Figure 3.

4.1 End-to-End delay

The results of the End-to-End delay measurements between 5G NSA and 4G LTE in Sweden show that 5G NSA, is on average, around one second faster than the LTE network, see Figure 3 (a). However, in one of the experiments for both networks, we observed a contradictory pattern: the delay for the 5G NSA network increased by almost one second, whereas for the 4G LTE network it decreased by a similar margin. This unexpected behaviour could be explained by several factors. One possible explanation could be the measurement variability, such as the differences in the exact moment the livestream was joined, as we explained could be a problem in the methods section: the join-latency-variance. Another contributing factor could be explained by variations in the network conditions at the time of measurement, such as small changes in traffic load or a sudden change in signal quality. Although 5G NSA generally provides lower E2E delay, as shown in Figure 3 (a), these results also highlight that network conditions and the timing of measurement can introduce certain deviations.

Regarding the experiments performed in Australia, the results indicate that both 5G SA and 4G LTE display significantly higher E2E delays compared to the Swedish network measurements, in short, an approximate 3 second difference. This makes sense and can primarily be attributed through the geographical distance between the host server in Sweden and the receiving device in Australia, which consequently increases the RTT. By observing the E2E delay we can see that 5G SA is around 1 second faster than LTE, as seen in Figure 3 (a).

4.2 Quality of Service metrics

The results of the different QoS metrics in the measurements done in Sweden show a marginal difference in RTT and jitter between

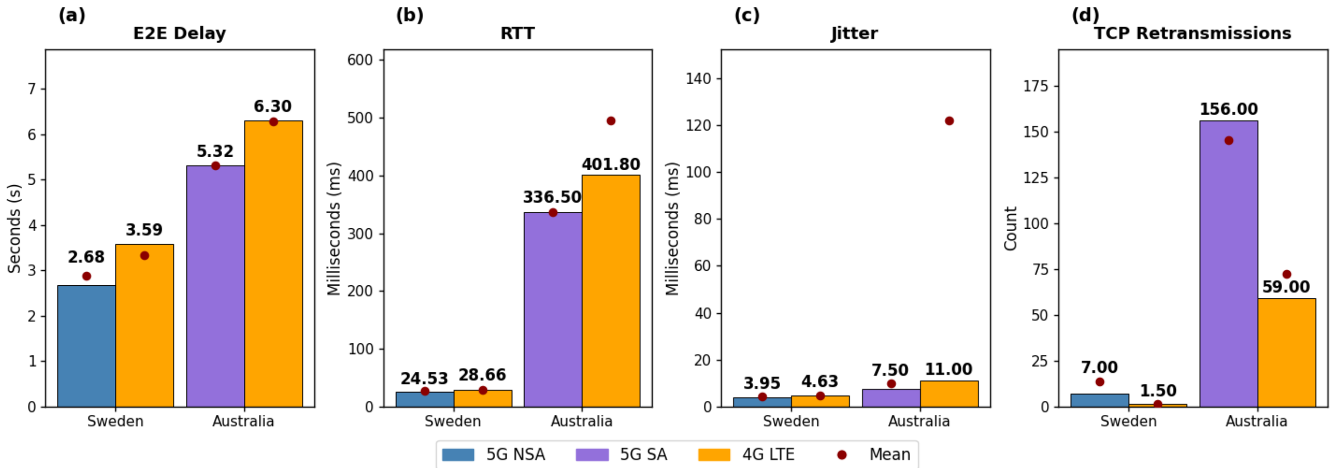

Figure 3: QoS metric results for both countries: (a) E2E Delay, (b) RTT, (c) Jitter, and (d) TCP Retransmissions. Bars represent median values of the experiments, and the red dots indicate mean values.

the two networks. We can see that 5G shows a somewhat lower median RTT at ∼ 25 ms vs ∼ 29 ms (Figure 3 (b)) and a lower median jitter of ∼ 4 ms vs ∼ 4.6 ms (Figure 3 (c)). We did notice a higher 5G RTT in one of the runs, but this is likely due to some temporary condition rather than radio signal quality, since RSRP (-86 dBm) was identical to previous runs.

By observing Figure 3 (d) we can see that the TCP retransmissions seem higher in the 5G NSA network compared to the 4G LTE network. This might be a cause of fluctuations in radio signal quality or handovers between different base stations during transmission in the 5G NSA architecture, which then affects the TCP retransmissions and leads to potential packet losses. It could also correlate with the fact that 5G operates on higher frequency bands, specifically n78 at around 3.5 GHz, opposed to LTE's higher bands, which typically goes to 2.6 GHz *(e.g. LTE band 7)* in accordance with the statistics provided in iPhones Field Test Mode. The use of these higher frequencies makes the 5G signal more prone to interference, which in turn may contribute to more retransmissions. Although these small numbers of potential packet loss should not affect the E2E delay in any significant way.

In contrast to the marginal differences in QoS metrics observed between the two networks in Sweden, the results of Australia show a clearer distinction between its 5G SA and 4G LTE networks, as seen in all of Figure 3. The results show that the 5G SA network outperforms the LTE network in most aspects. Figure 3 (b) indicates that the RTT for the 5G SA network is around 337 ms in median, while the LTE network shows an average of around 402 ms in median value (Australia) for LTE, indicating a noticeable reduction in latency. This same pattern can be seen in the column for jitter: where the 5G network has a jitter of around 8 ms, whereas the LTE network has a higher variability of around 11 ms, but most noticeable is its mean value of around 120 ms, which potentially could indicate that the 4G network is more prone to instability in the jitter department. We can also see a clear distinction when it comes to TCP retransmissions, by observing Figure 3 (d). There are significantly more TCP retransmissions in the 5G SA network compared to LTE. This might be a cause of the high frequency bands that 5G uses as mentioned earlier, where the dense area of Canberra can pose difficulties for higher frequencies. In this case, the 5G SA network operated on band n78 at around 3.5 GHz while the LTE network used band 28, which operates at a much lower frequency of around 700 MHz. The RSRP values for the tests in Sweden and the tests in Australia were nearly identical in each test run, ~ -86 dBm for Sweden and ~ -105 dBm for Australia. This might pose a slight difference in all of the QoS outcomes, but especially the E2E delay, when comparing the different geographical areas.

5 Conclusion

This study set out to compare viewer-perceived end-to-end (E2E) delay for livestreaming over 4G LTE vs 5G NSA/SA networks, but also to examine how geographical distance can influence performance. In both geographical areas, 5G performed with a lower E2E delay than LTE, on average about 1 second faster. In Australia the median of both networks performed with an overall higher latency of about 3 seconds compared to the Swedish networks. This is consistent with the fact that the broadcast was hosted in Linköping, about 15 000 km from Canberra. However, 5G SA still outperformed LTE in Australia by about a second. Differences in QoS metrics (mostly lower RTT and jitter on 5G), help explain these outcomes. Although, additional factors, such as join-latency variance, platform buffering strategies, radio conditions such as band selection also shape the viewer experience. Therefore, future work should incorporate a wider set of measurements, but also telemetry from different points (e.g. broadcaster, more in depth radio perspective) to get a complete view and understanding of what exactly affects the E2E delay.

Overall, our measurements show that current 5G NSA/SA reduces viewer-perceived E2E delay vs LTE, although geography and temporary conditions remain a dominant factor in limiting livestreaming performances.

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