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Supporting The Changing Requirements For Online Gaming

A Technical Paper prepared for SCTE•ISBE by

K. Scott Helms
SVP of Advanced Services
Momentum Telecom
222 Chastain Meadows Court | Suite 100
Kennesaw, GA 30144
404-263-0585
scott.helms@momentumtelecom.com

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Introduction

Gaming enthusiasts have had a somewhat checkered history of interaction with the service providers that are a critical component of their hobby. On one hand gamers have been early adopters of high speed connectivity, but on the other they have also driven calls, complaints, and had higher requirements than the average end user. We've also seen service providers fail to understand what mattered to gamers when they created packages and marketing materials, and as recent as this year network operators have blamed gamers for driving excess capacity usage. In this paper I will focus on real world usage patterns for online gaming by looking at actual traffic of both games and the supporting software that is commonly used like streaming and voice communications. One of the important shifts in gaming has been the rise of these ancillary programs that gamers use, and these drive very different networking requirements. They also increase the need for consistent performance, and perhaps more impactful in the short term is that they increase the visibility for customers of any issues that might be affecting their traffic. What the testing showed was a dramatic increase in upstream usage and a far higher requirement for low latency and reliable packet delivery. What's even more interesting for operators is that these requirements help cement wired broadband solutions as critical for gamers, and as an industry we should begin thinking about gaming in a similar way that we think about video. Creating relationships inside the gaming ecosystem is clearly in our interests as a way of further fending off encroachment by cellular providers who have aggressively moved into the video space.

Areas of specific measurement and testing were selected for their popularity and for the first time we see the same titles, and their requirements, on most or all of the major gaming platforms PC and consoles.

- Online multi-player games
  - Battlefield 1
  - Counter-Strike: Global Offensive
  - Destiny 2
  - Fortnite
  - Minecraft
  - Overwatch
  - Player Unknown's Battlegrounds

- Voice communication platforms
  - Discord
  - Mumble

- Streaming platforms
  - Twitch (Amazon)
  - YouTube Gaming (Google)

- Remote Rendering – Nvidia GeForce Now
  - Greatly increased downstream requirements (>40 Mbps consistently needed)
  - Upstream requirements similar to "normal" gaming
  - WiFi is a specific point of weakness because any variability in the signal can be seen as frame drops

Defining Network Requirements

Providing broadband service for gaming hasn't been a focus for most service providers, but it's something that we should embrace. The gaming community, especially the action and First-Person Shooter (FPS) genres, require higher performance and more stability for their connections than LTE and later 5G networks will be able easily to provide. I focused on the games selected because they are multi-platform, in fact this list includes some of the most popular games on PC, Xbox, and PlayStation. The networking requirements are assumed to be similar, but testing was done exclusively on PCs for the ability to capture packet performance. Games are sorted alphabetically.

One of the critical takeaways of this research is that customers involved in gaming are likely to have specific information about network performance provided by the games they play themselves as well as the ancillary programs they use: BF1, CS:GO, Twitch, Mumble, and Discord.

1. Games

Gaming traffic, other than file transfers for updates and initial installs is relatively light and generally has sustained data rates measured in Kbps. None of the games in this paper needed more than 7 Mbps of peak download and that was for just a few moments while new graphical files were streamed down, not actual game play.

Measurements were performed using packet captures on the PC running the game client. Data was extracted using Wireshark filtering which was then exported in CSV format for detailed analysis and graphing. Latency and packet loss were introduced in controlled amounts by using Clumsy, a utility written for that purpose. Injected latency and packet loss was done on outbound packets from the PC only. In Fortnite changes in latency were seen as cheating attempts so extended testing with that game was impossible with this methodology. It is also important to understand that the games see and measure latency in different ways so these are all relative measurements. Many games do not provide latency information via an in-game display and in those cases the measurements were derived using ICMP to the specific game server. Bandwidth measurements were done by analyzing the packet captures and should be consistently accurate for all layer 3 (IP) traffic and above. Overhead from the lower levels of the network stack were not included. It is important to know that bandwidth usage can change even in the specific games measured and some activities increase the amount of traffic. This is especially true in Destin 2, given the peer to peer connections and "bubble" architecture of the game.

1.1. Battlefield 1 (BF1)

Battlefield 1 is a first-person shooter that regularly has tens of thousands of players in matches across PC, PS4, and Xbox platforms. The game was released October 21, 2016 but still has a healthy population according to a third-party Battlefield tracker across all three active platforms. (https://battlefieldtracker.com/bf1/insights/population?days=30)

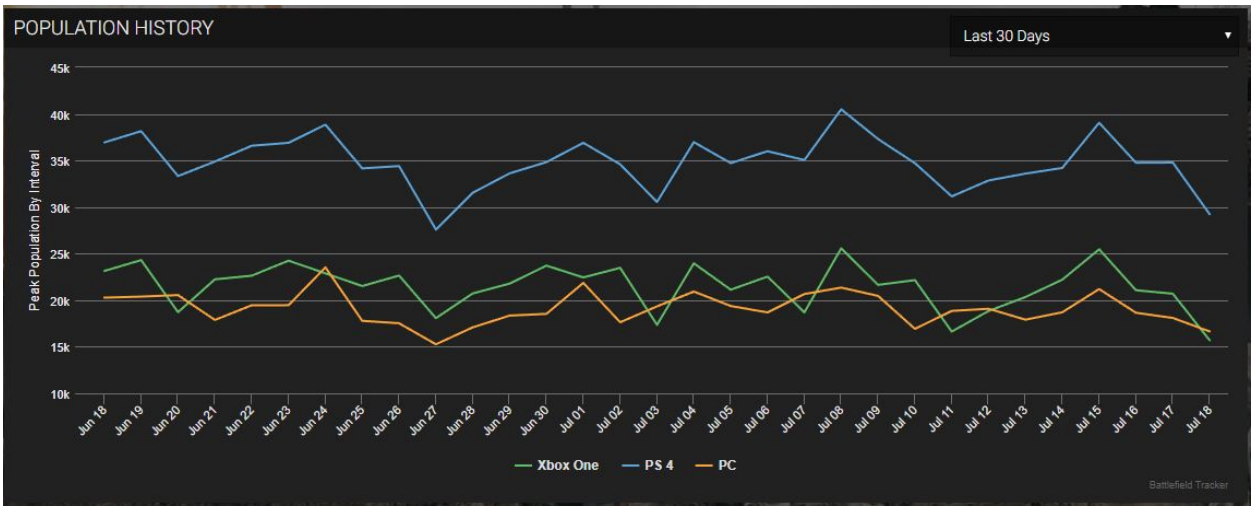

Figure 1 - Battlefield 1 Population

BF1 provides a detailed networking view that measures many of the critical elements related to online gaming. Below you can see the in-game display during latency testing.

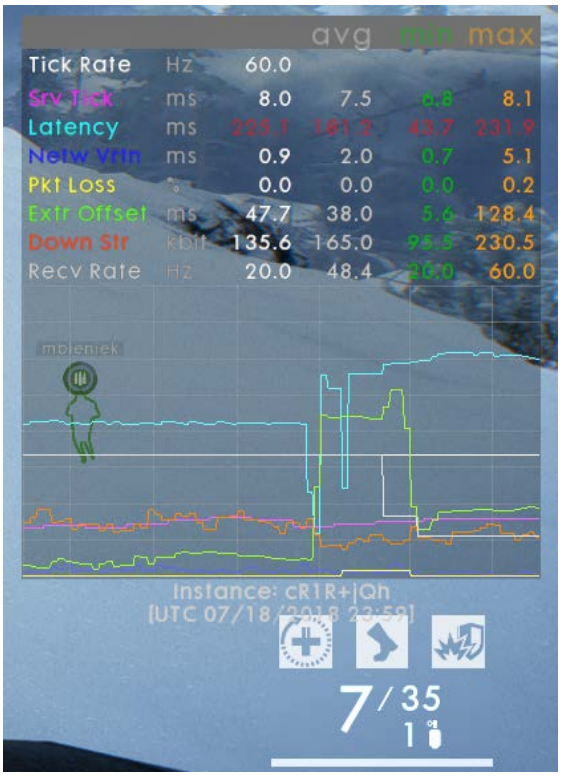

Figure 2 - Battlefield 1 Network Information Display

The display will flag metrics that are outside of acceptable bounds by the game, and in this case we can see that the latency displays in red because it's too high. Latency, even lower than the thresholds I reported, can affect game play in BF1 and most other FPS games because latency affects where a player's shots will land. The impact on accuracy of hit detection is often the first sign of latency. Packet loss has a similar profile but will also often cause issues in movement sometimes called "rubber banding" where a player's in game avatar will appear to teleport back to an earlier position from the player's point of view. Jitter, defined as rapid changes in latency, will have a greater impact on gaming experience than latency of a consistent nature. Often having a moderate amount of latency is better than having lower latency that's frequently fluctuating, even if the average latency is the same or even lower than a connection with consistent packet delay.

The networking traffic is relatively light as you can see from the graph below, but as was just discussed, the game has tight latency and packet loss budgets. The average traffic over several sessions was 222 Kbps down and 101 Kbps up on average with a peak down rate of 510 Kbps and peak up rate of 207 Kbps.

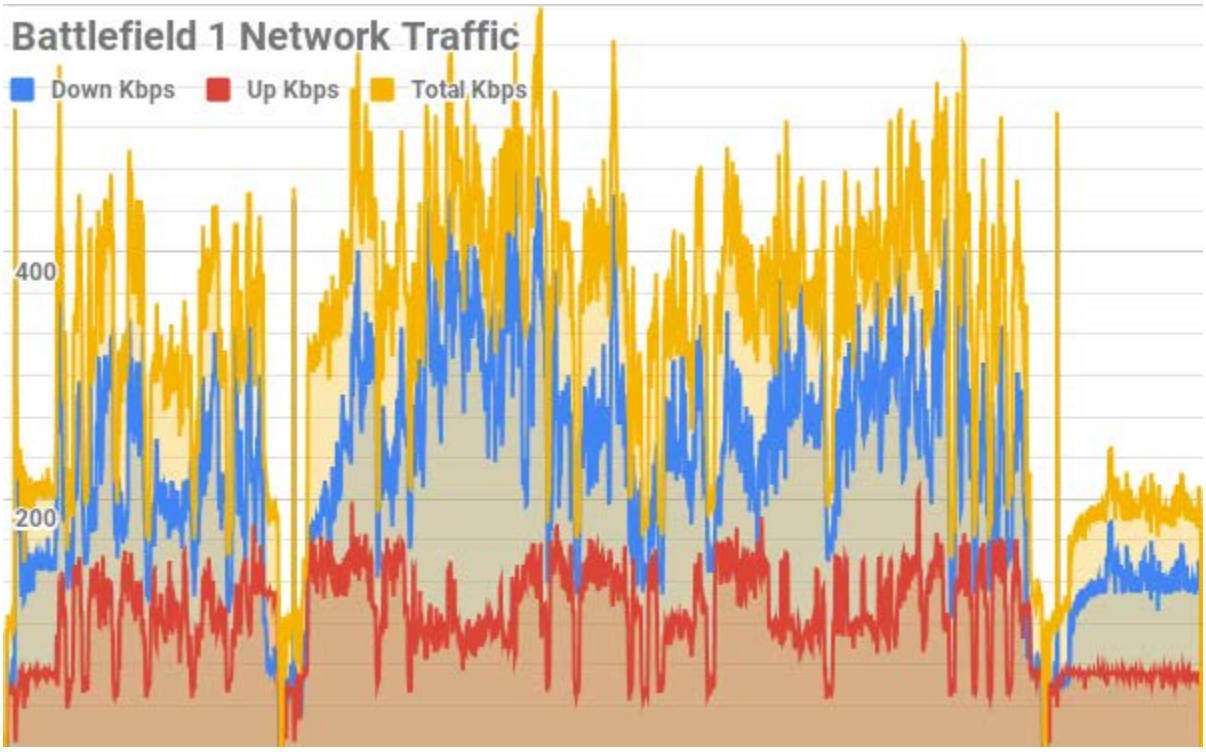

Figure 3 - Battlefield 1 Network Traffic

1.2. Counter-Strike: Global Offensive (CS:GO)

CS:GO is a first-person shooter that was released on August 2012 and it still maintains a highly active player base, though unlike most of the other games on the list almost all them are on PC rather than consoles.

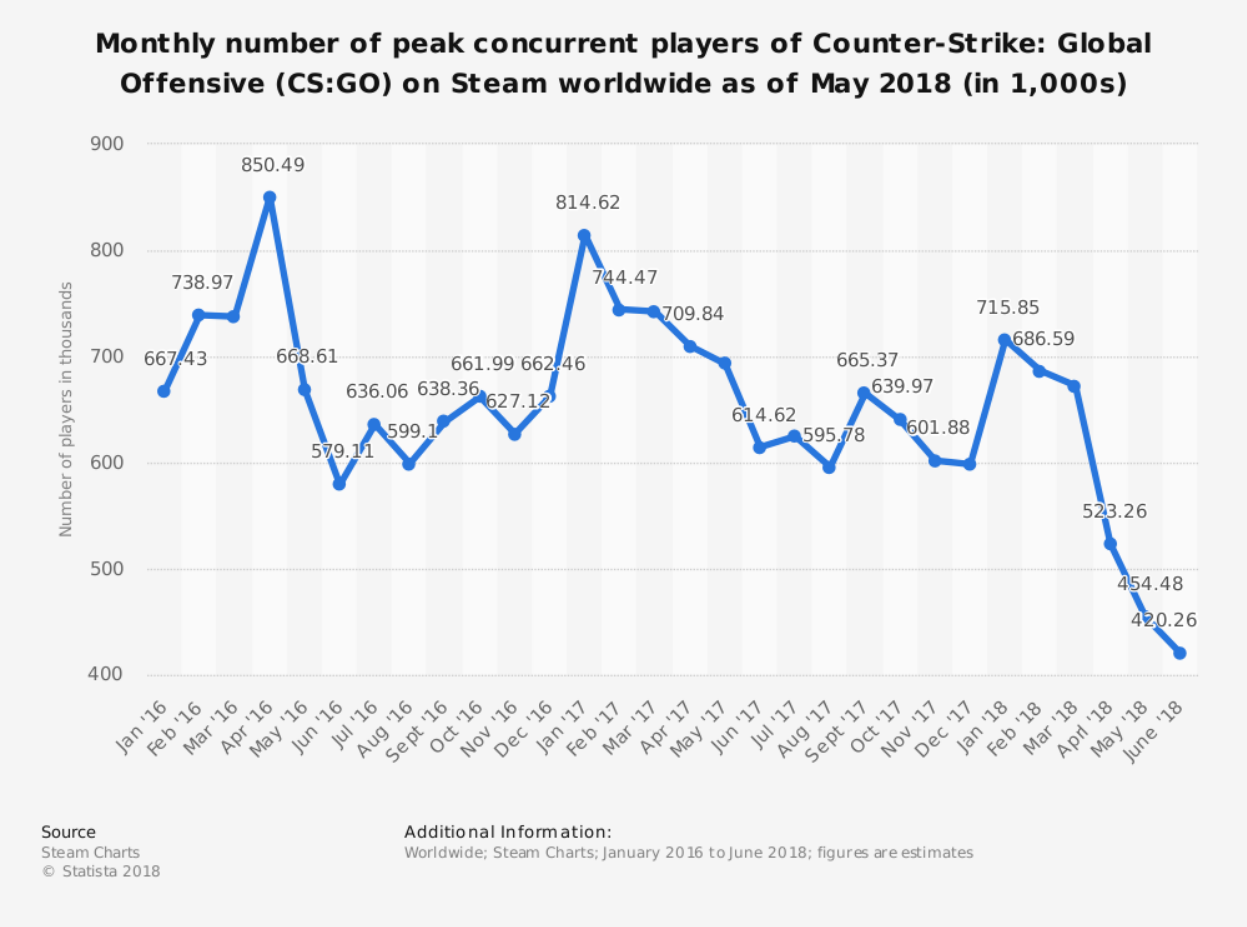

Figure 4 - CS:GO Population (PC)

CS:GO is an older game and has a heavier average download requirement than any of the other games measured. It also has fairly tight latency and packet loss needs. The upstream traffic is also more consistent over gaming sessions with variability as seen in some of the other games.

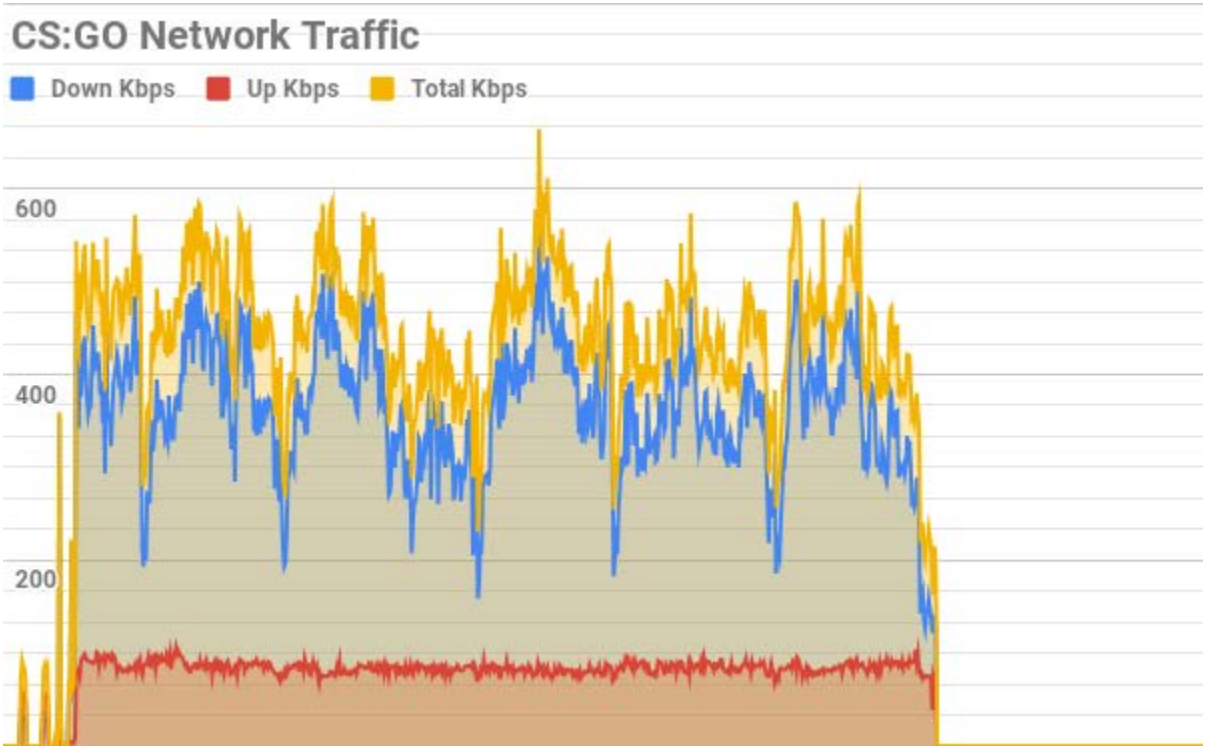

Figure 5 - CS:GO Network Traffic

CS:GO players tend to be very aware of network performance issues and the game includes a display of several performance metrics that include networking.

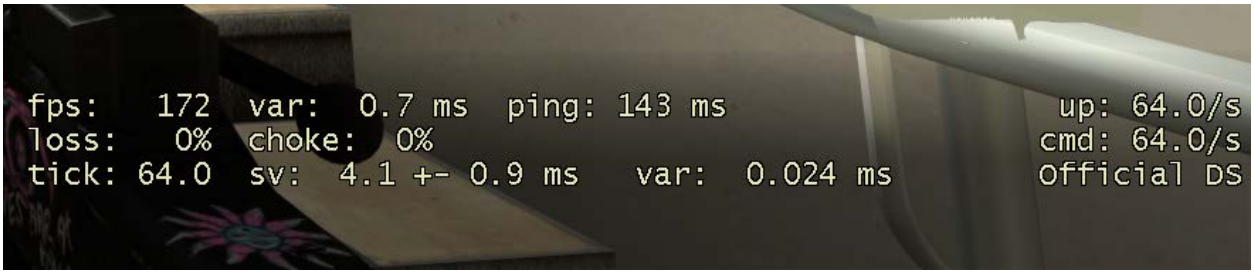

Figure 6 - CS:GO In Game Network Information)

1.3. Destiny 2

Destiny 2 is a Massively Multiplayer Online (MMO) FPS game which consists of both Player versus Environment (PvE) and Player versus Player (PvP) play. July 15 saw 469.4K Crucible (PvP) Players and

628.8K PvE Players across all platforms as reported by DestinyTracker, a third-party Destiny 2 statistics site.

Destiny 2 is unique on this list from a networking perspective. It's the only game measured that allows direct network connections between the players on a team and others nearby in the MMO world. This reduces the network traffic that needs to pass through the game's servers so because much of the traffic flows between team mates. Networks that only allow strict NAT produce a warning and cause the game servers to handle all of the traffic flows.

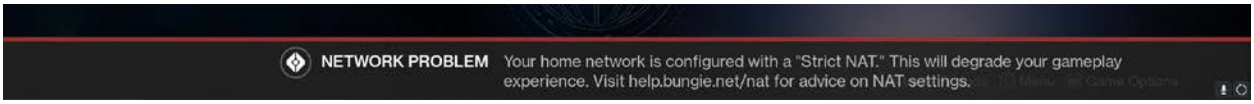

Figure 7 - Destiny 2 NAT Type 3 Warning

This is warning players will see if the network they're playing doesn't allow for direct connections (NAT Type 2 or DMZ).

Destiny 2 doesn't have an in-game display for network performance probably because of the complicated nature of their networking approach which can have direct connections between players on teams as well as just players nearby. Bungie, the developer, describes the approach as "bubbles" where specific numbers of related assets are simulated by the game engine together.

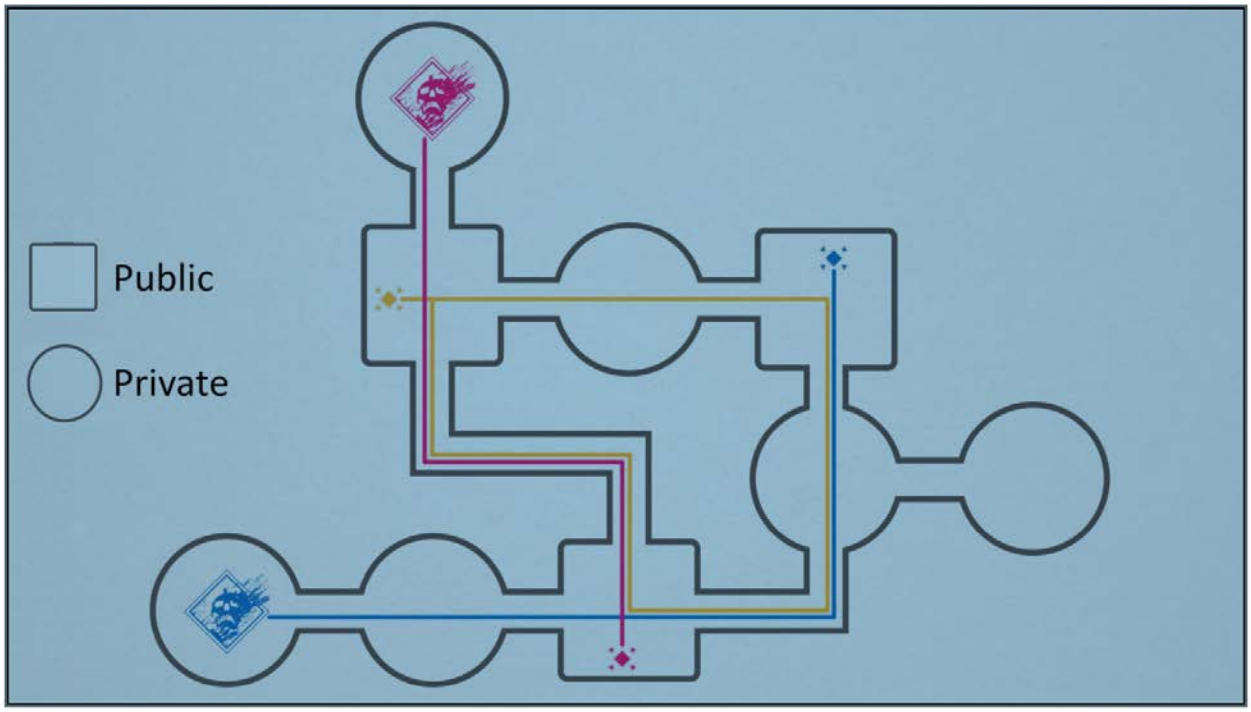

Figure 8 - Destiny 2 Bubble Networking Design

This design in networking means that players who are far away from each other from a networking standpoint will impact each other's performance when they are nearby in the game. Players on the same team in the game are always in the same bubble and packet captures show long term peer to peer connections as a result. This situation has the potential for both intentional and unintentional impacts in the game. PvP matches where each of the players can see the IP addresses of the opposing team is something that seems to be inviting DoS attacks.

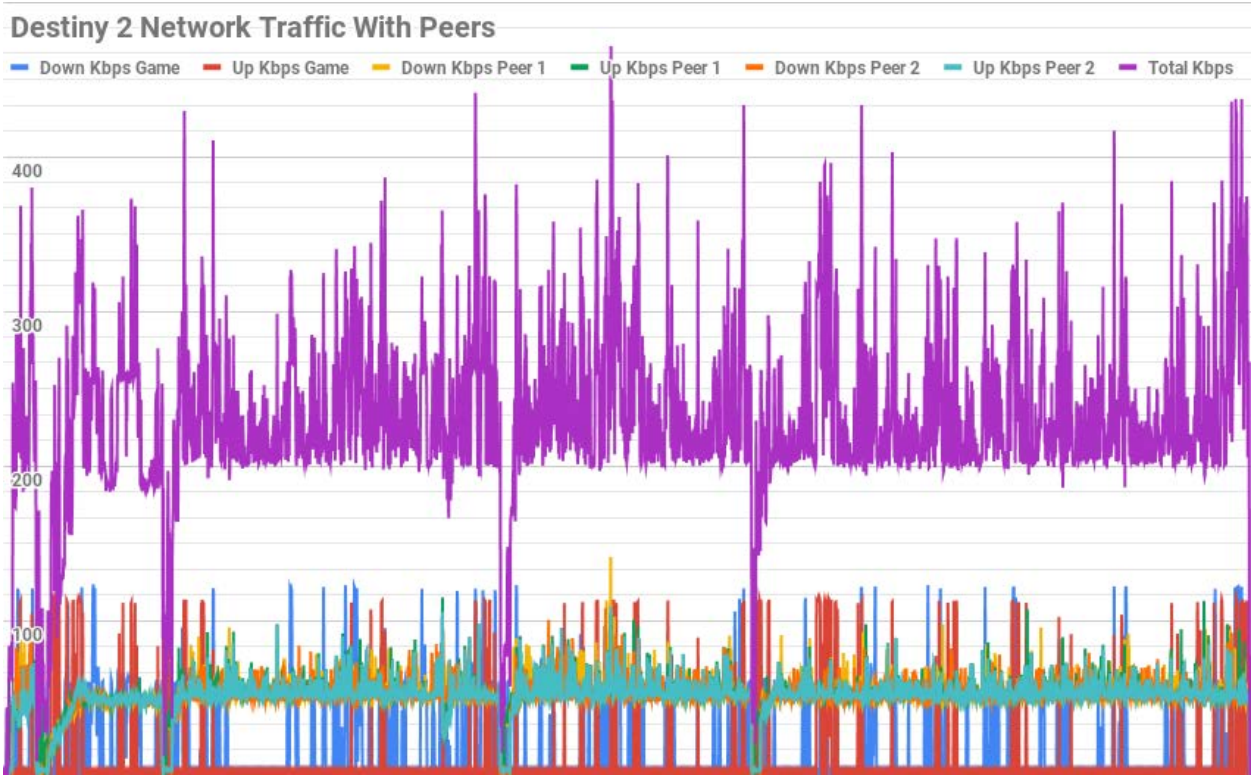

Figure 9 - Destiny 2 Networking Traffic

Here you can see the traffic from a session of three teammates. The individual hosts contribute around 50 kbps of traffic in both directions so actions involving large numbers of players like raids, open world public events, or PvP could involve a lot more transfer. Bungie shots for a 6v25 max "bubble" with the 6 being the number of players and 25 being the number of computer generated opponents at any one time. 6v6 PvP would generated around 600 Kbps from peers in the same "bubble" with another 30 Kbps for the game host system.

1.4. Fortnite Battle Royale

Fortnite is a specific genre of action games called a battle royale. Instead of a first-person view point the game seen in third person, where the player is basically looking over the shoulder of his or her in-game avatar. Fortnite is incredibly popular right now with Epic Games claiming more than 125 million active players. They also generated $318 million in revenue in May 2018. This is remarkable in part because the game itself is free and only generates revenue by selling in-game cosmetic items. Fortnite has surpassed the other big name in the battle royal genre, PUBG, by being more accessible and attracting large numbers of players on many platforms including mobile.

In terms of network requirements Fortnite is very forgiving for an action game, perhaps reflecting their intentions to offer a mobile version early on. The average rates for download traffic were only 32.3 Kbps while the upload traffic was 33.3 Kbps. The max rates were also pretty light, 186.6 Kbps down and 205.9 Kbps up. Latency tolerance is pretty high considering this is an action/shooter title at 175 msec. Packet loss of up to 7% allowed for the game to remain playable, though at that level stuttering could be detected.

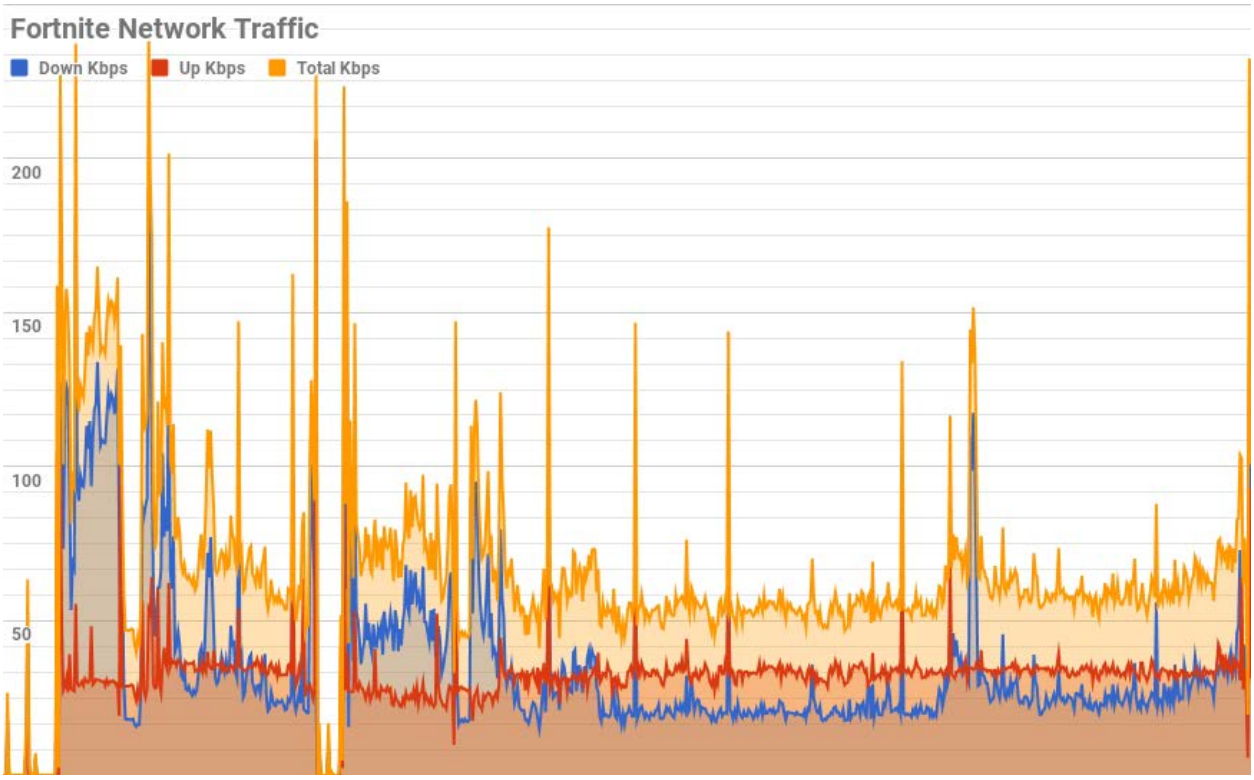

Figure 10 - Fortnite Network Traffic

1.5. Minecraft

Minecraft is the only game that was measured that wasn't in the shooter or action category. It was included because of its overwhelming popularity. It appears on PCs, Macs, mobile devices, and most consoles. Since its launch in 18 November 2011 the game has accumulated more than 150 million copies sold and has 74 million people playing every month. Since this is the oldest game that was measured it's remarkable that there was increase of 20% in active players from 2017 to 2018.

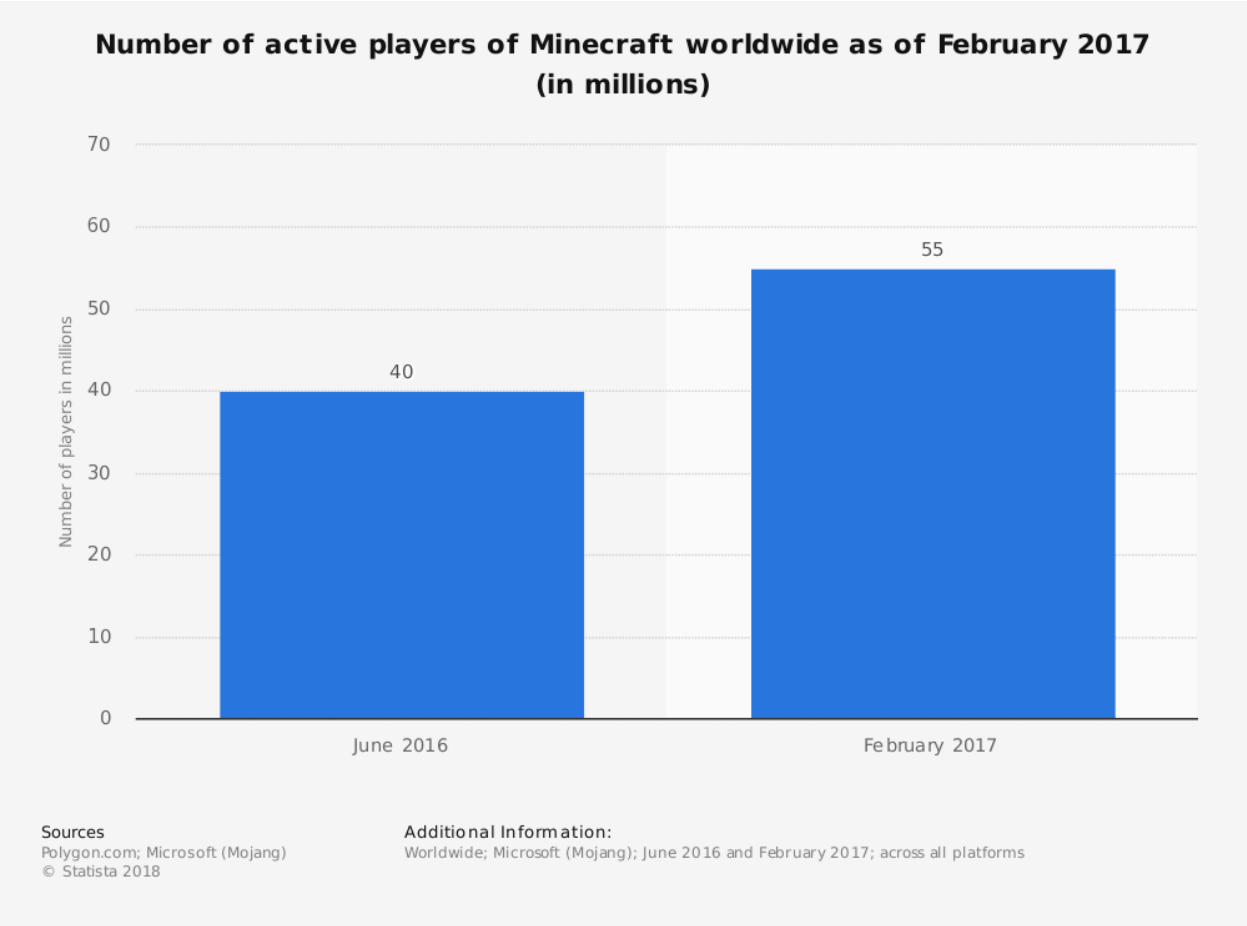

Figure 11 - Minecraft Active Players

Minecraft is a building game with several modes including “vanilla” survival, creative which focuses on building and not escaping zombies, and new modes have been created to help teach kids coding and better connect with history and literature. There are more than 2 million users of Minecraft: Education Edition. Minecraft can be played either in single player or multi-player modes with the single player mode not needing network connectivity to function. For multi-player games the networking requirements are fairly modest, though the transfer of custom art can generate a substantial amount of transfer. Testing showed more than 7 Mbps of peak download transfer and the average down rate was 281Kbps. The upload rates were much lower with an average rate of 31.5Kbps and a peak of 116.35Kbps. The latency threshold was around 250 milliseconds before playing online felt really problematic and packet loss as high as 10% could be tolerated for short stretches of time.

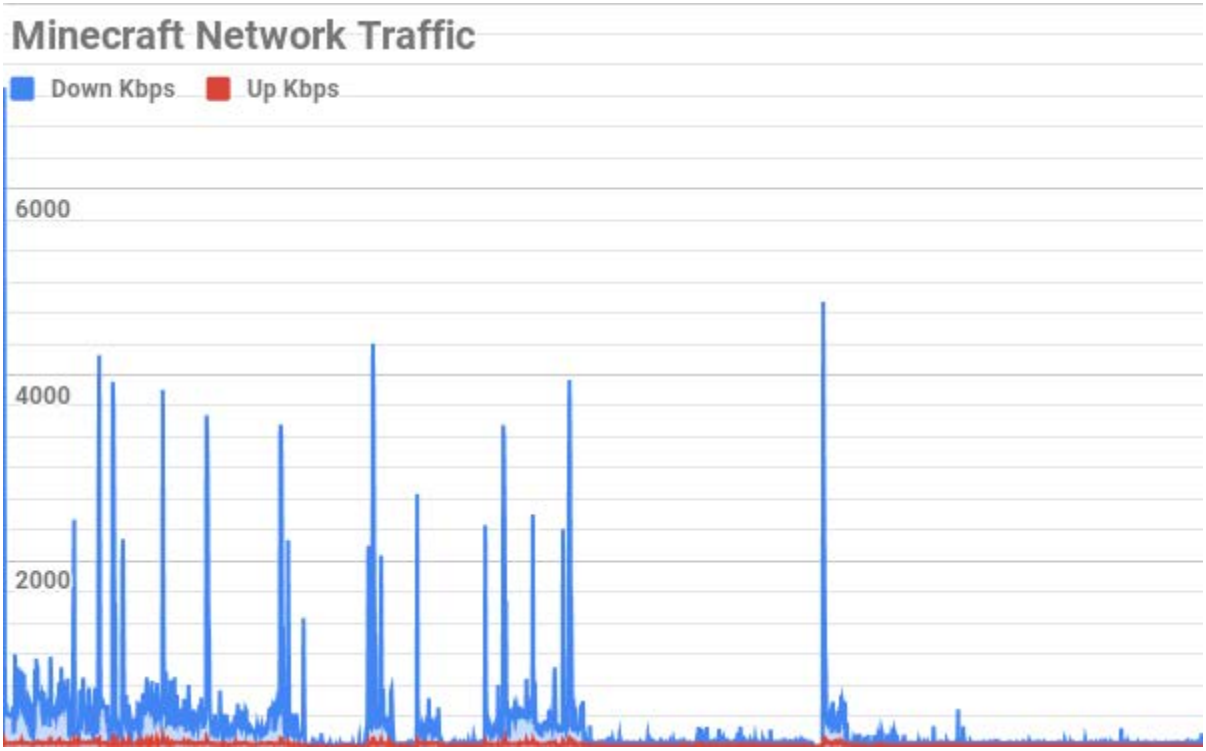

Figure 12 - Minecraft Network Traffic

1.6. Overwatch

Overwatch is a multi-platform FPS with a substantial population. It was released in May 24, 2016 and the active population has risen past 40 million across all platforms.

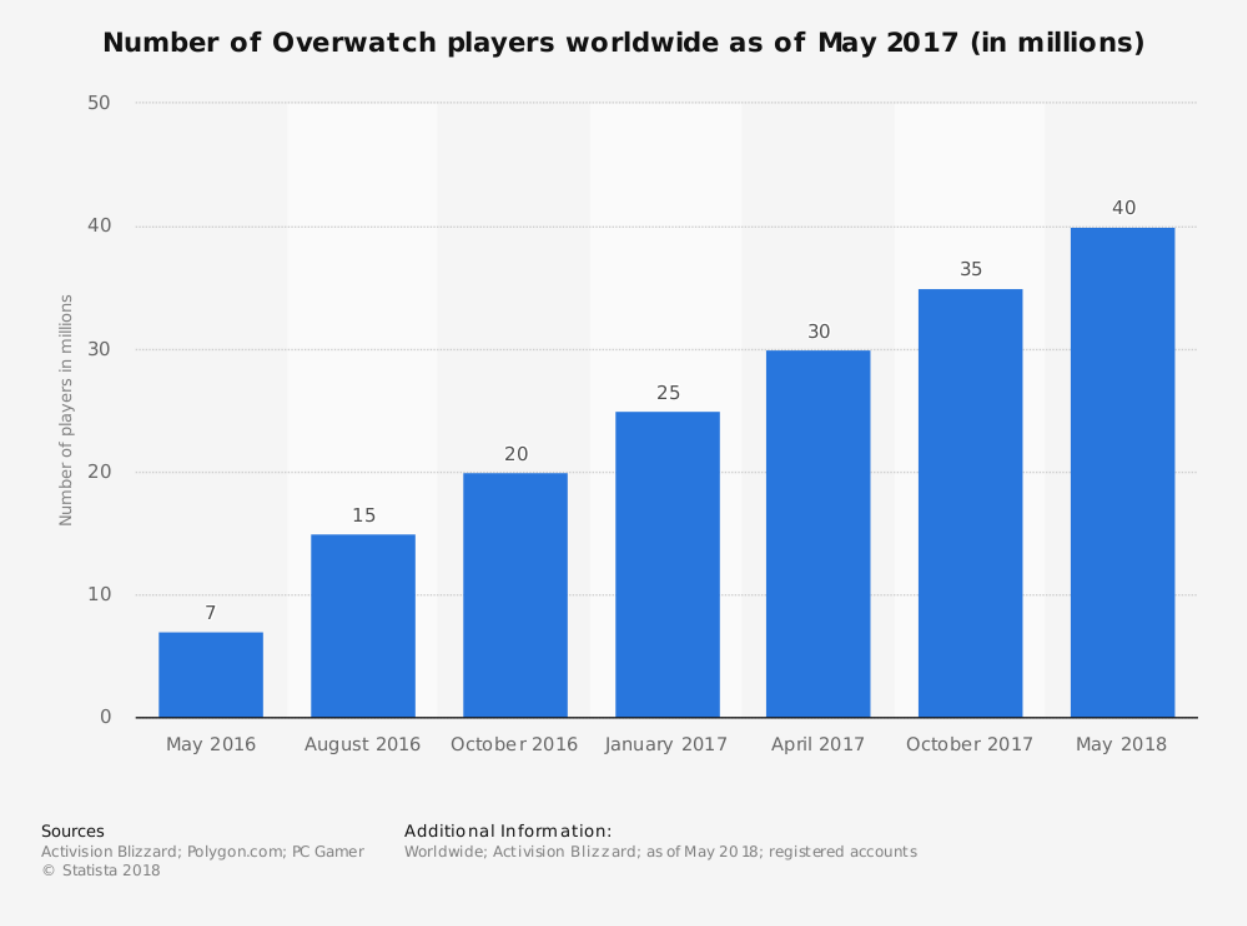

Figure 13 - Overwatch Population

Overwatch shares a similar format to older FPS games but is more forgiving in terms of network requirements. The average download traffic was 249.4Kbps while the upload side averaged at 54.6Kbps. The peak traffic, which on the download side can include streaming of assets, goes quite a bit higher at 3234.2Kbps for short bursts and the upload peaked at 99.63Kbps. Latency tolerance was good for a FPS and even around 140 milliseconds the game felt responsive most of the time. As with other games changes in latency (jitter) have a more negative impact than consistent latency. The game continued to be playable, though I'd recommend sticking to casual or arcade modes, with as high as 6% packet loss.

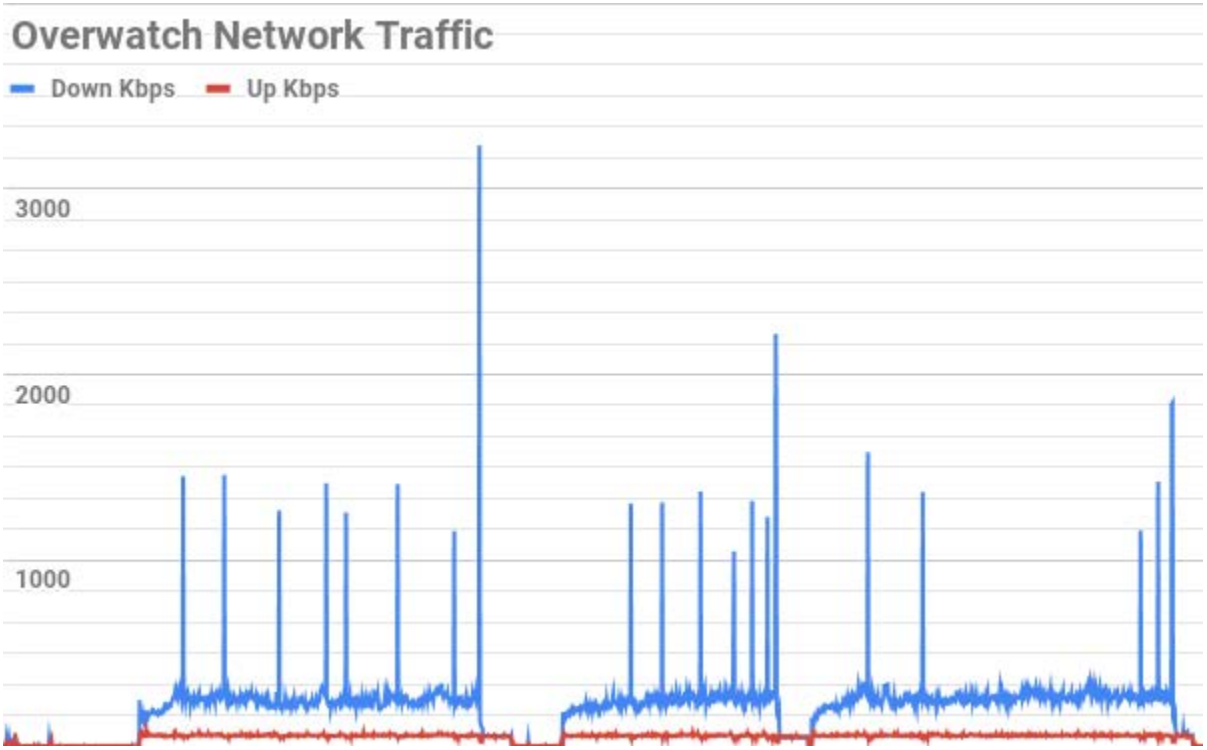

Figure 14 - Overwatch Network Performance

One interesting item with Overwatch is how much the bandwidth decreases between matches. You can see the gaps in the graph above and the times when the game went into matchmaking mode the traffic dropped substantially.

Figure 15 - Overwatch In Game Network Information

1.7. PLAYERUNKNOWN'S BATTLEGROUNDS (PUBG)

PUBG is another battle royal game that can be played in either first or third person mode. It went into full release on December 20, 2017 but players on PC started playing it during the early access phase which started in March of the same year. It has amassed a tremendous following and only recently was surpassed by Fortnite in terms of active streams.

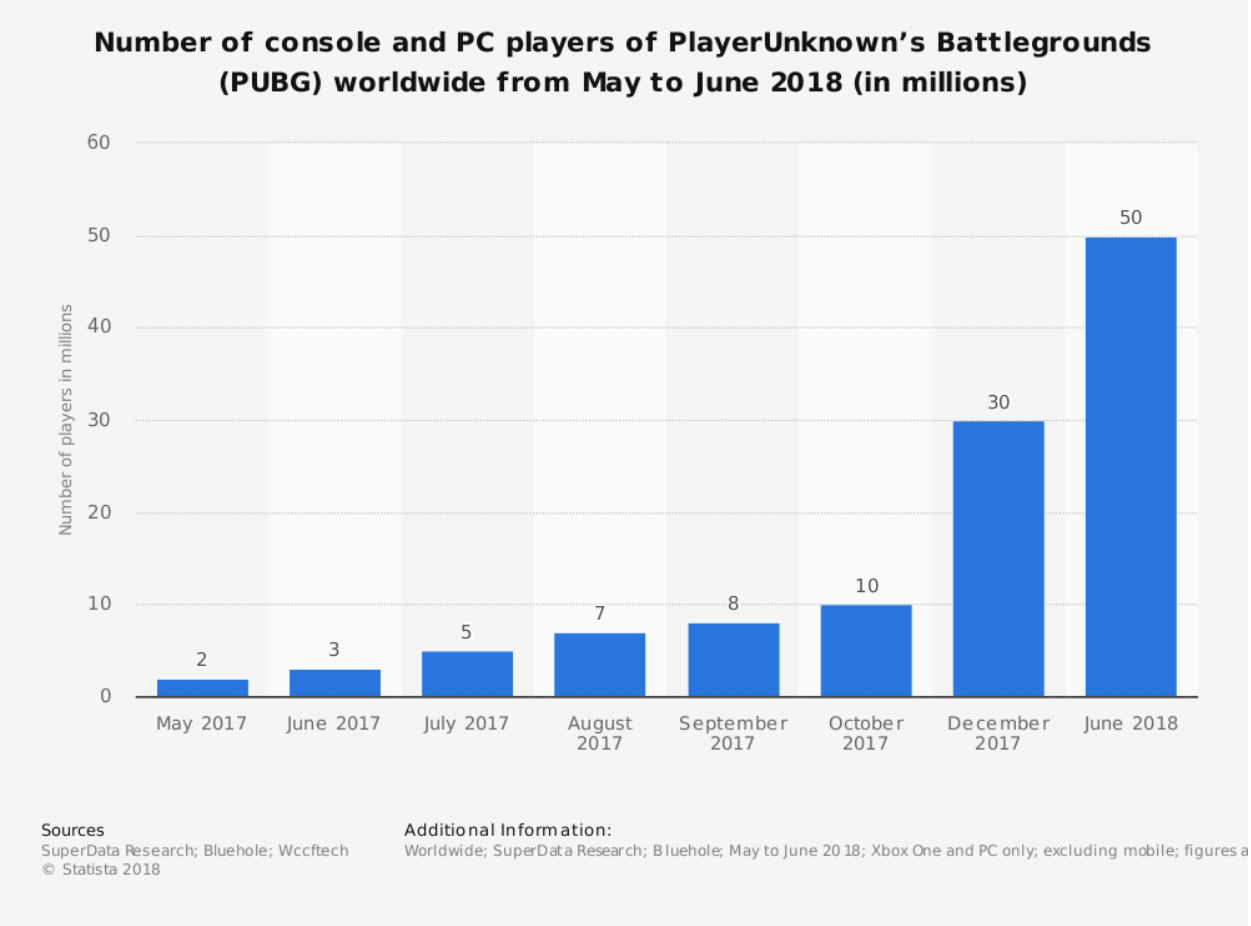

Figure 16 - PUBG Global Population

PUBG competes directly with Fortnite and as the latter's popularity has increased PUBG has seen its growth slow.

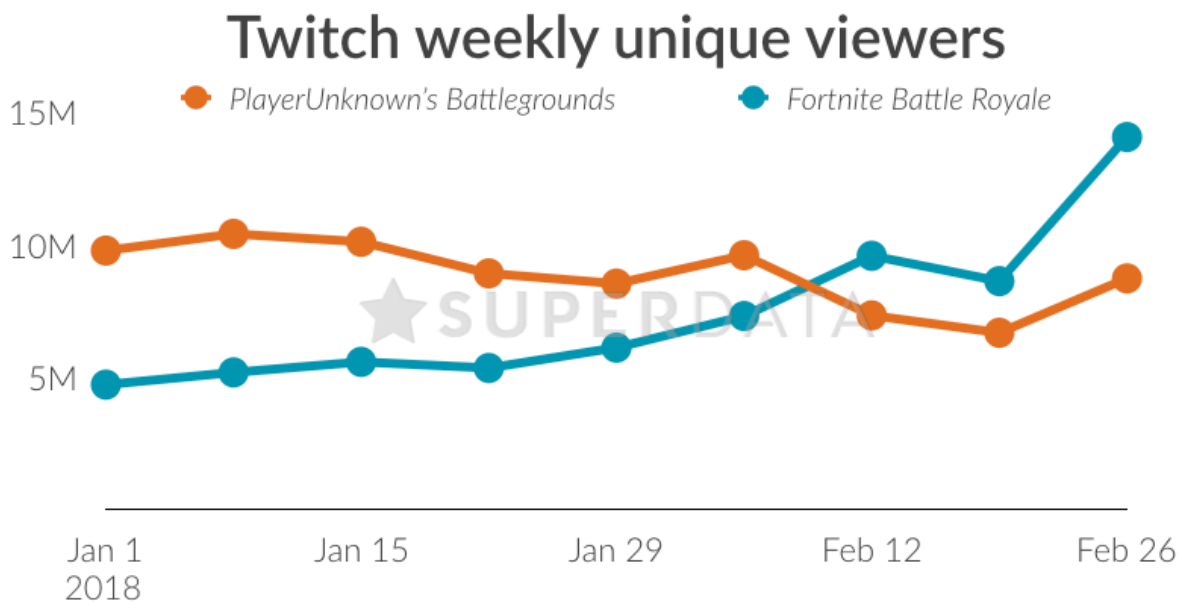

Figure 17 - PUBG Versus Fortnite Streaming Viewers

PUBG has surprisingly low average bit rates. 19Kbps down matched with 34Kbps up is far lower than I expected for this game, however like Fortnite this may have been the result of designs that are mobile friendly. The max rates are also modest with the peak down being 261.68Kbps and the peak up rate being 97.656Kbps. The game tolerates latency moderately well but after about 125 milliseconds of delay the feeling of lag was noticeable. Packet loss tolerance was similar to Overwatch at 6%.

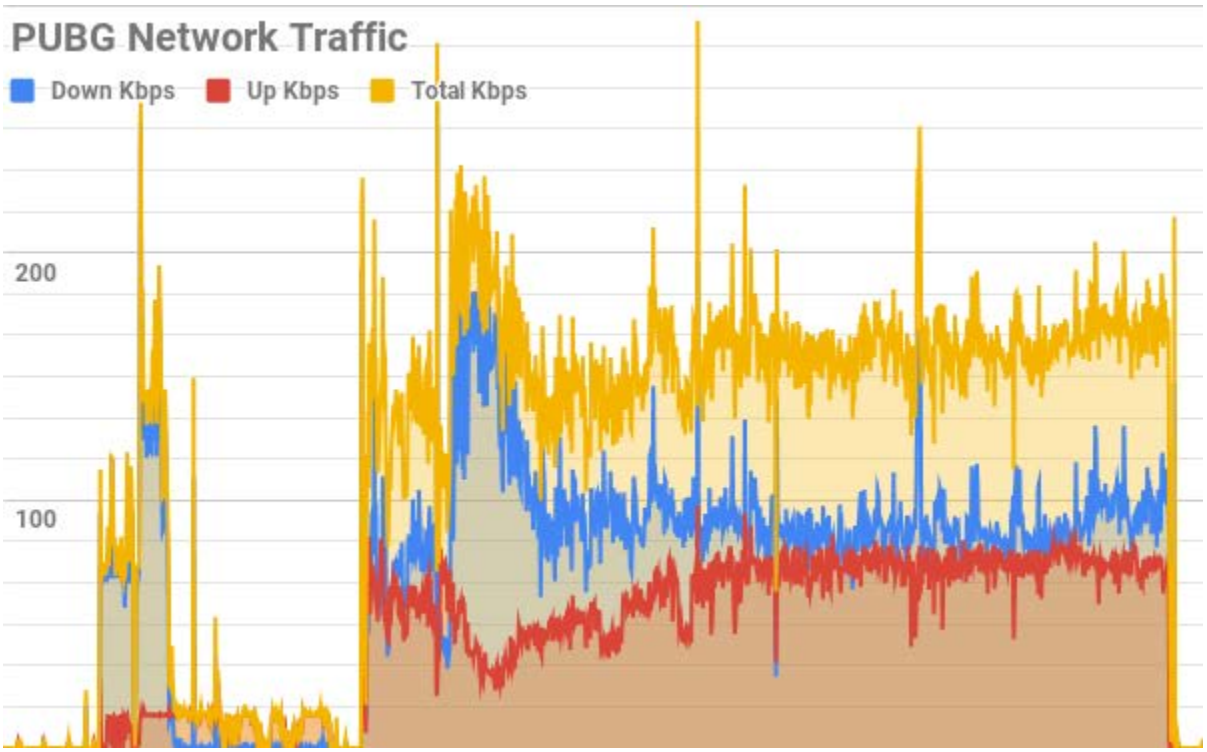

Figure 18 - PUBG Network Traffic

2. Voice Communications Platforms

Voice communications is a key part of most online action and FPS games. In many cases the games provide voice communications and text chat to teammates and others in the game but the popularity of external communications programs, especially Discord, has continued to increase. There are other options for external voice communication and they range from TeamSpeak to Skype in their approaches and focus on gamers. Skype is a very general-purpose voice communication platform, but for small groups it works fine for voice communication. TeamSpeak was once one of the most popular platforms but has faded behind Mumble and especially Discord to the point of now being uncommon. For testing I used a small group of three for each of the voice platforms.

2.1. Discord

Discord is by far the most popular voice communications platform for gamers and it adds a persistent shared chat similar to Slack in terms of functionality, and Discord is free to use. It was released in May 2015 and today has more than 100 million active users and signs up approximately 1.5 million new users a week. Discord is entirely hosted by the developer on Google's cloud infrastructure. Part of the goal behind creating Discord was making a communications platform that was easy for players use and didn't require specialized hosting companies as earlier offerings had. Discord also has mobile apps and that adds to its appeal over some other offerings.

Discord is quite network efficient, even with large numbers of users in channel, however the chat and pictures can add large spikes in traffic. The average download usage was 222Kbps and the average up was 101Kbps with peak download being 6952.91Kbps and peak upload 70.368Kbps. In general, it tolerated latency pretty well with complaints not really occurring until 250 milliseconds of delay. Packet loss was also handled well and Discord tolerated up to 7%. As you can see the spikes were rare, but much larger than the average traffic.

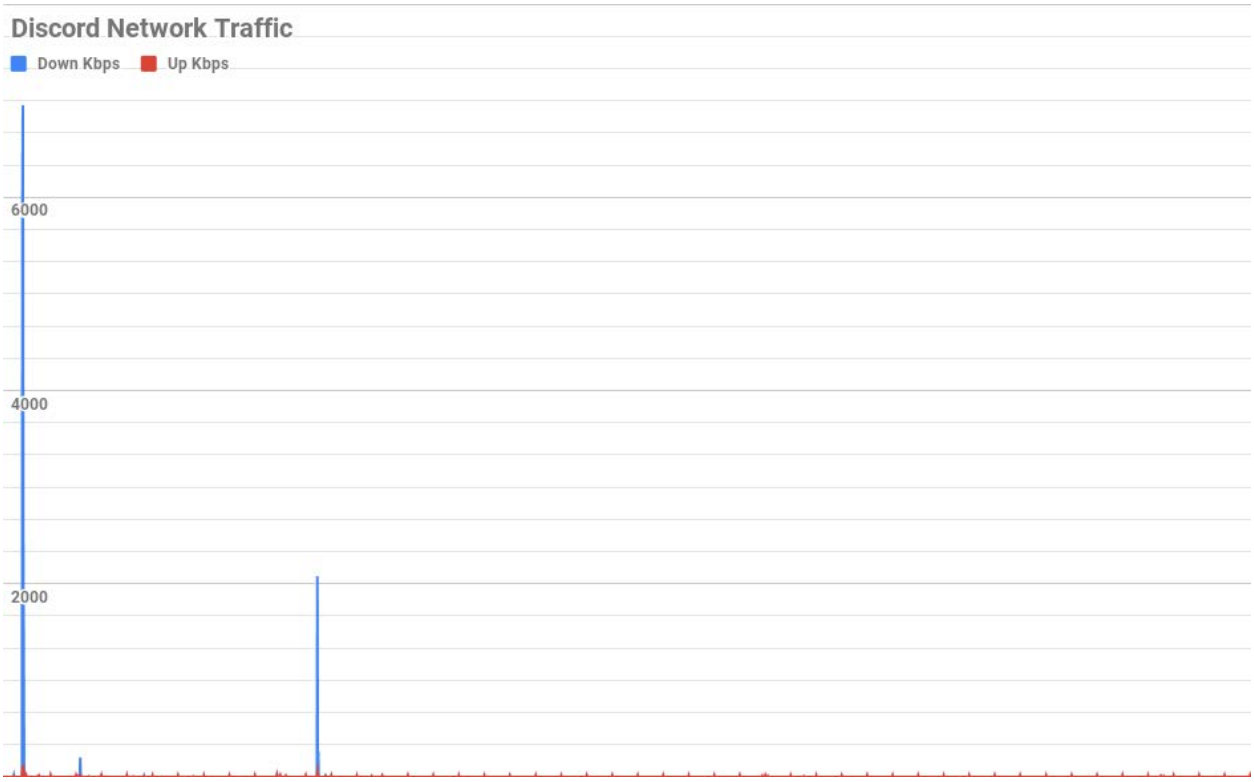

Figure 19 - Discord Network Traffic

2.2. Mumble

Mumble is the distant second in the voice communications genre, but it definitely has its adherents. For one thing Mumble and its server-side component Murmur are fully open source. It's also built around a very low latency and low bit rate codec which gives it a lower bit rate than Discord, often much lower as well as less lag in voice communications. It's impossible to give hard numbers around Mumble users because there's no central place from which to get statistics. Gamers who want to use Mumble either contract with a hosting company to deliver it as a service or install and run Murmur from a server they already have. I don't think Mumble will ever go completely away, but the ease of use of Discord has already made a substantial change in usage.

Mumble is very network friendly and on average only needs 36.5Kbps down and 32.4Kbps up. The peak seen during testing was 123.32Kbps down and 113.464Kbps up. It's a little less latency tolerant than Discord with audio problems showing up around 200 milliseconds of latency and is also less tolerant of packet loss with 5% causing issues. It's worth noting that Mumble appears to have a firm footing with small groups of competitive players where the latency and sound quality are more important than the ease of use from Discord. Make sure to keep in mind the scaling of the bandwidth axis if you compare the graphs of Mumble and Discord traffic.

Figure 20 - Mumble Network Traffic

3. Streaming Platforms

Streaming of games is a relatively new phenomenon and reflects the shift away from traditional forms of media content. Streaming is generally done while the streamer is playing a game and providing commentary at the same time. Many streamers will show their face via webcams in addition to their voice commentary. The number of people consuming streaming, almost all around gaming, is staggering.

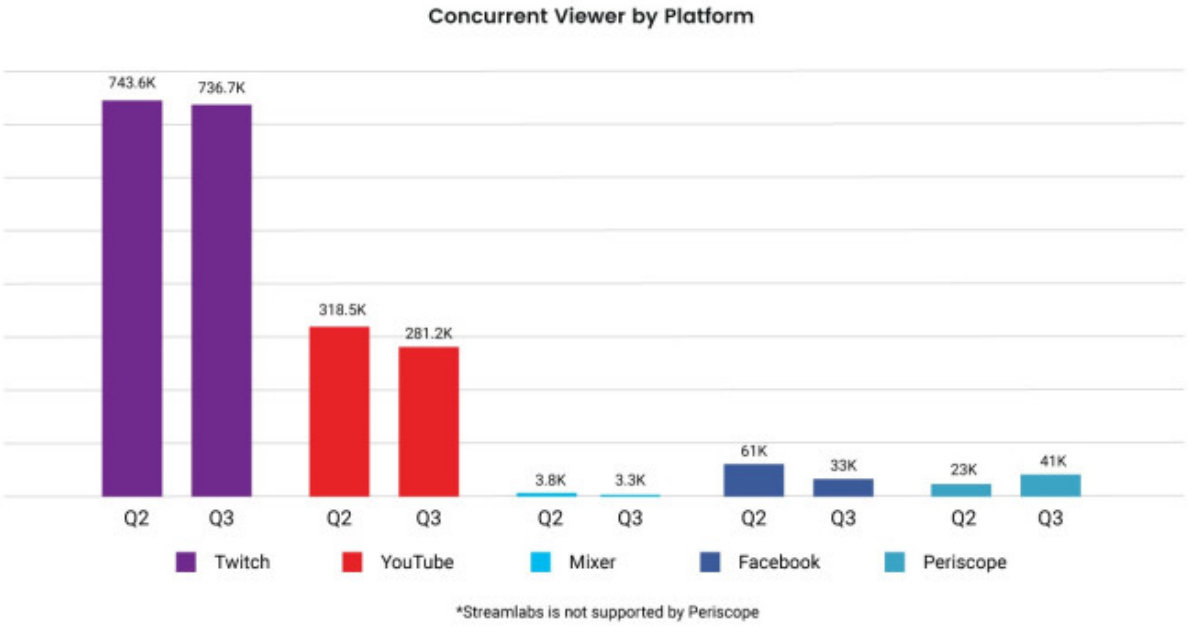

Figure 21 - Concurrent Streaming Viewers by Platform

For the purposes of this paper I focused on the top two platforms, Twitch (owned by Amazon) and YouTube (owned by Google). Streaming is also where gamers begin to substantially diverge from the normal networking requirements of low latency and low jitter but also low bit rates. It also dramatically increases upstream usage. An important note, most of the streaming services look very similar from a networking standpoint. The differences in upload speeds are largely around settings in the streaming client for video bit rate.

3.1. Twitch

Twitch is by far the most popular streaming platform right now. It was launched as a service in June 2011 as a spinoff of a general-purpose streaming site and has since far eclipsed its progenitor Justin.tv. Amazon acquired Twitch in 2014 for $970 million. In terms of network requirements Twitch needs very stable connections and consistent latency especially on the upstream side. Average down speeds were 124.4Kbps while average upload speeds were 5,564.8Kbps. Peaks were also impressive with peak upload speeds of 10,884.5Kbps and peak down of 271.76Kbps. This is a very asymmetrical usage pattern, but in the opposite direction of what the broadband industry has been building for in many cases. Packet loss of greater than 1% made streaming almost impossible.

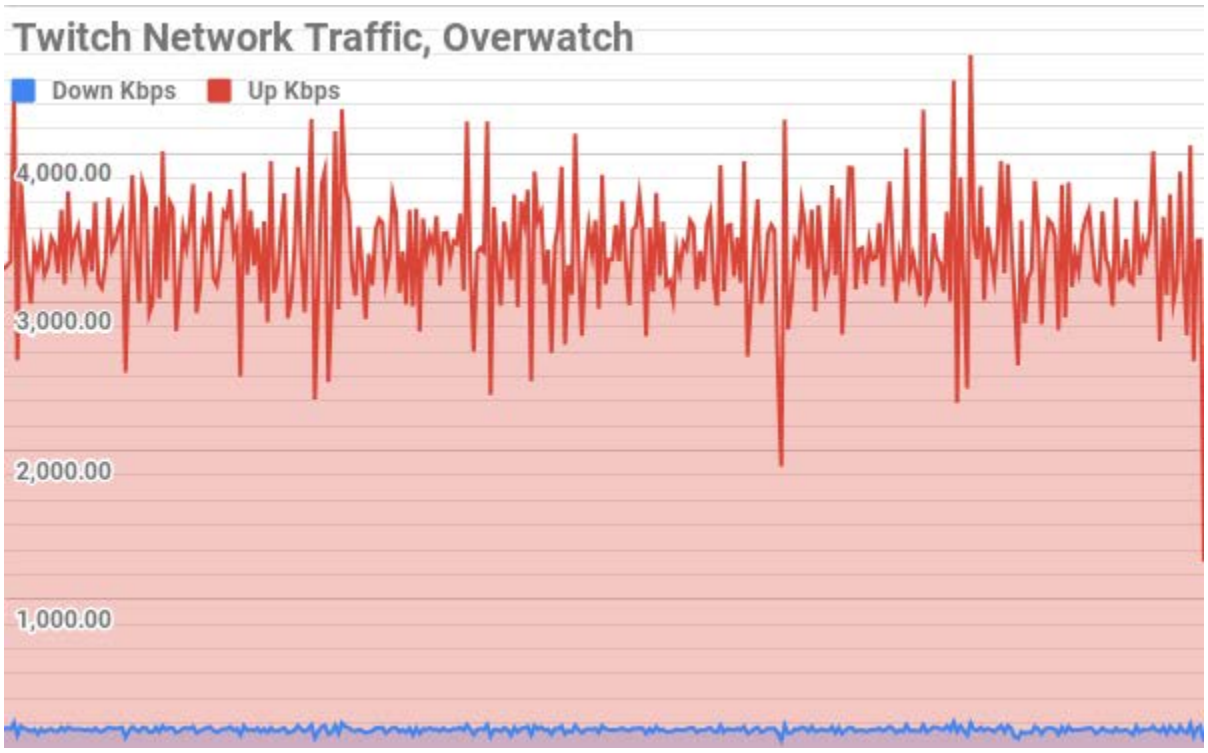

Figure 22 - Twitch Network Traffic

Twitch also provides streamers with detailed networking analytics. If a streamer is using your service and experiencing issues you will likely get detailed information around their problem.

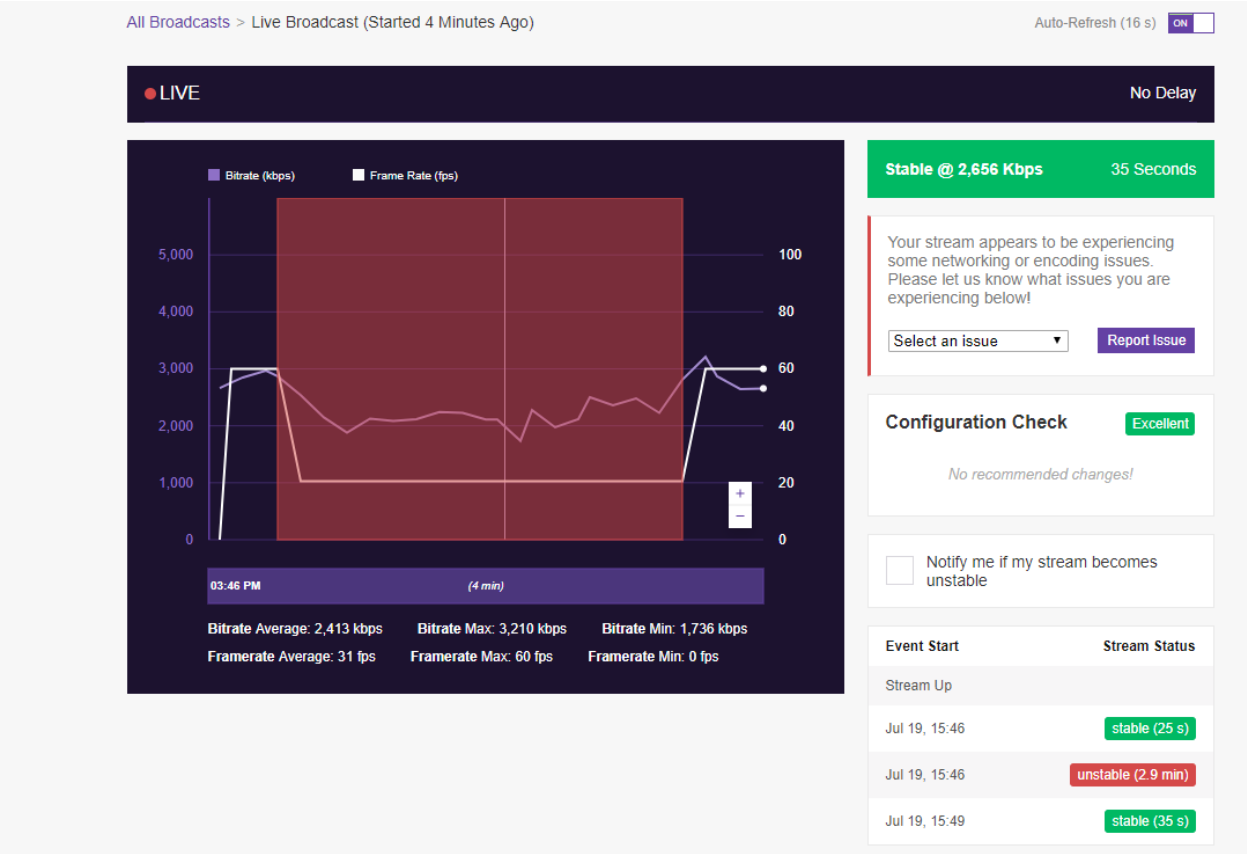

Figure 23 - Twitch Stream Networking Analytics

3.2. YouTube Gaming

YouTube Gaming offers a very similar experience to Twitch from a streaming standpoint, but it also captures all of the videos automatically for replay. The networking requirements are nearly identical. Average download speeds were 119Kbps, average upload speed 3,350Kbps (note this is lower because all the testing was done at the lower video bit rate), while the peaks were 175.22Kbps down and 8,225,87Kbps up.

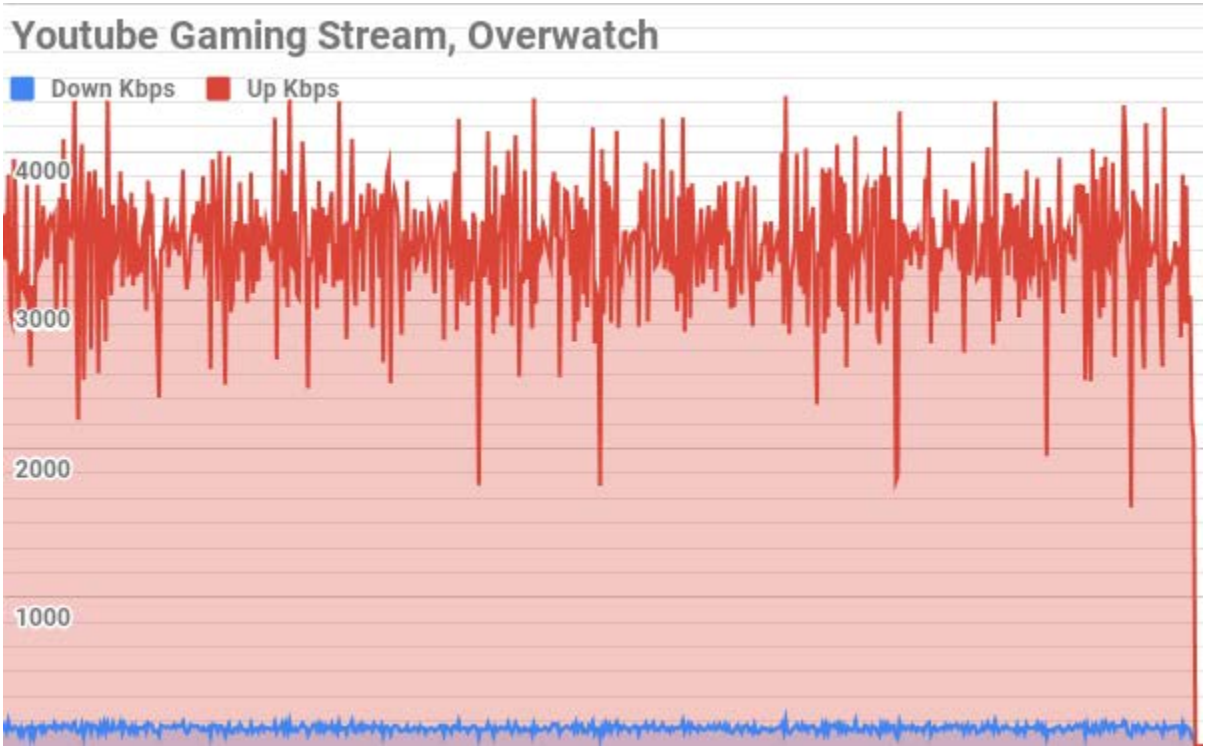

Figure 24 - YouTube Gaming Network Traffic

4. Remote Rendering – Nvidia GeForce Now

Remote rendering is an idea that's been around for a while, but as of yet no company has been able to make it a commercially viable offering. Much of the challenge in the past had more to do with the lack of very highspeed broadband. That looks to be changing with some major companies entering the market including Nvidia and Google. The key ideas behind remote rendering is turn gaming into more of a service similar to Netflix for gaming. One challenge for gaming is that you periodically need to upgrade your hardware whether it be a PC, a consoler, and increasingly this applies to mobile devices. If a remote server is doing the rendering then the local device is simply displaying a video stream and relaying the control information from the player to the remote server. This makes it possible to play very high end games on PCs and devices without dedicated video cards or powerful processors. Nvidia clearly sees the move to gaming as a service as part of their strategy. Nvidia GeForce Now is currently in beta testing. Figure 25 shows an excerpt from a recent Nvidia presentation.

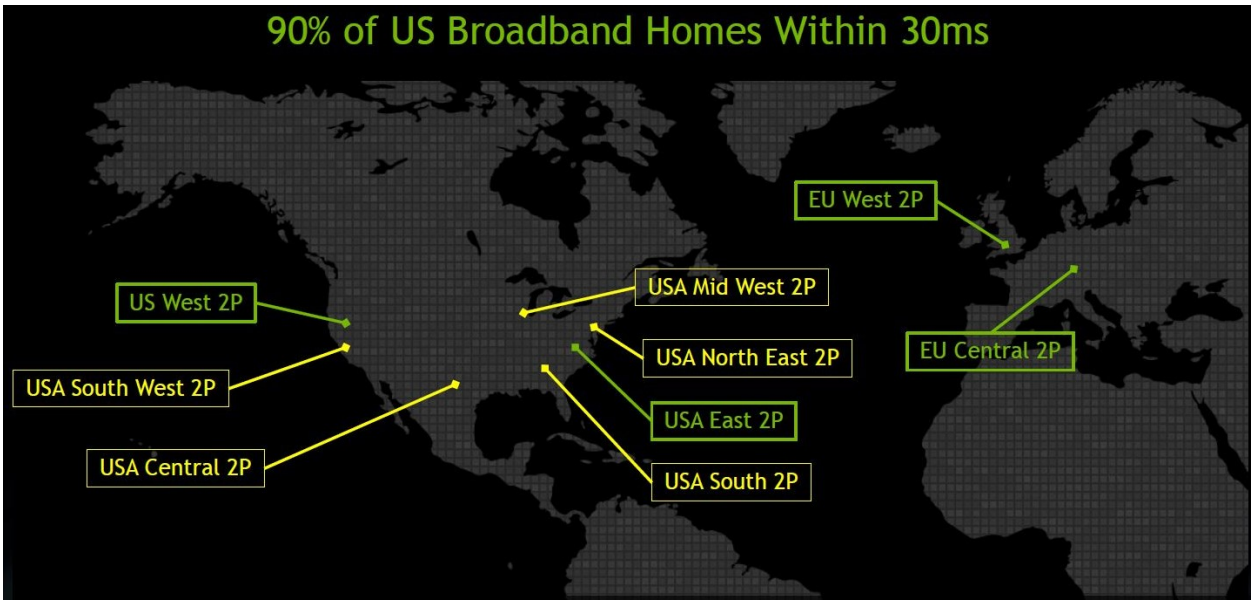

Figure 25 - GeForce Now Datacenter Locations

The speed and latency requirements are substantial. From Nvidia's support FAQ we can see what speeds support what visual qualities.

- 10 Megabits per second – Required broadband connection speed
- 20 Megabits per second – Recommended for 720p 60 FPS quality
- 50 Megabits per second – Recommended for 1080p 60 FPS quality

In testing my 50mbps package was not able to sustain 1080p gaming sessions. The amount of sustained transfer for a gaming session is basically double that of a Netflix ultra HD stream. Testing did not show substantial difference between games, but that could change in the future. The system also provides users with feedback on the quality of their networking connection.

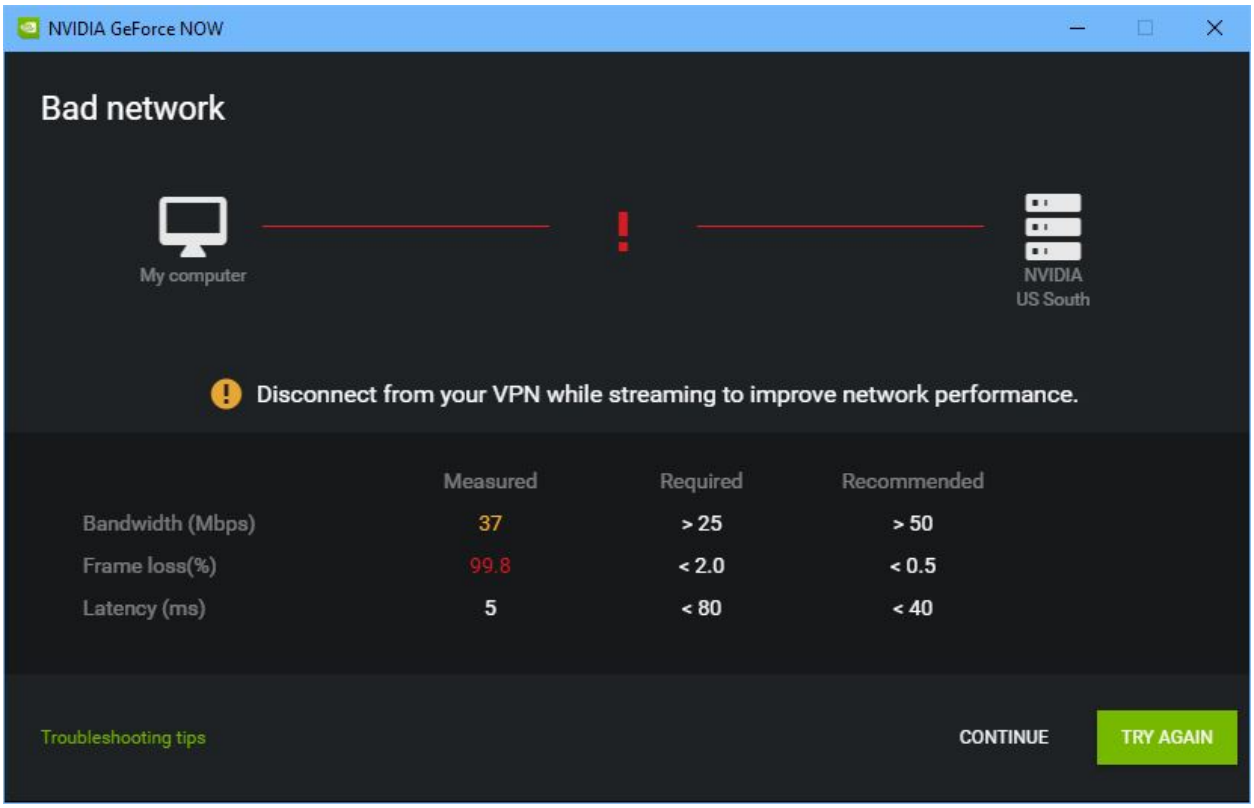

Figure 26 - GeForce Now Network Analytics

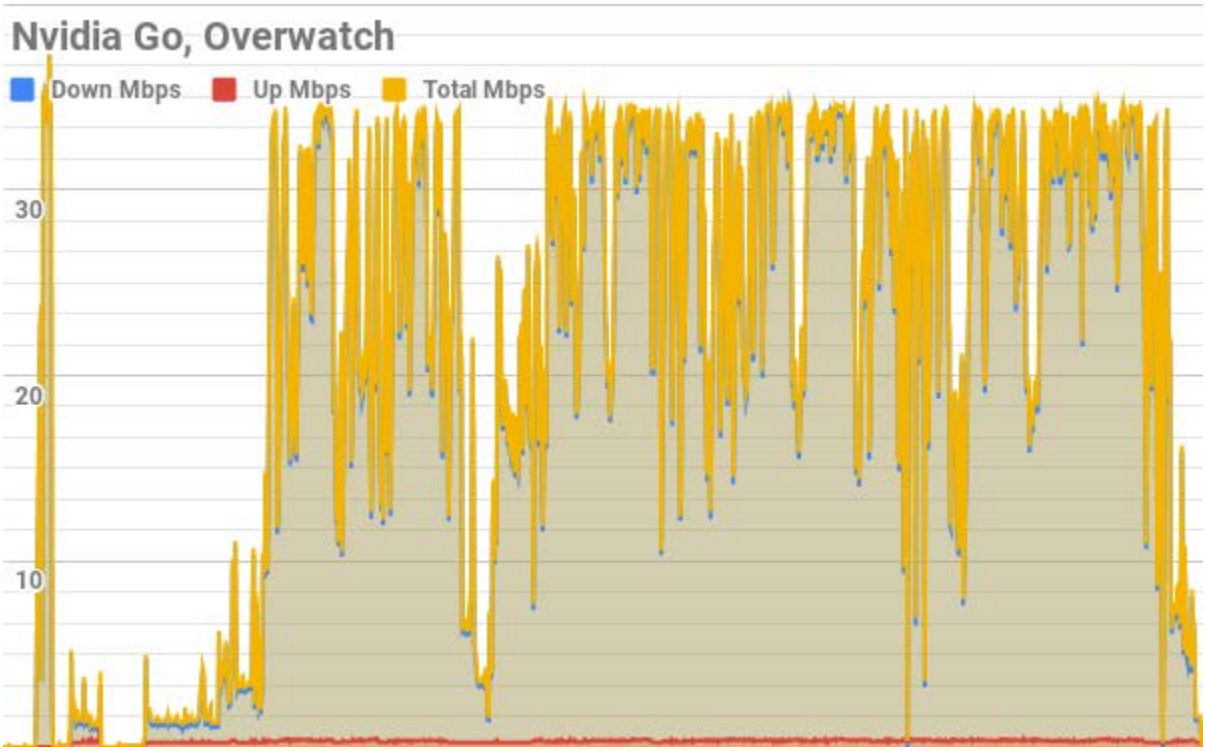

Figure 27 - GeForce Now Network Traffic (Overwatch)

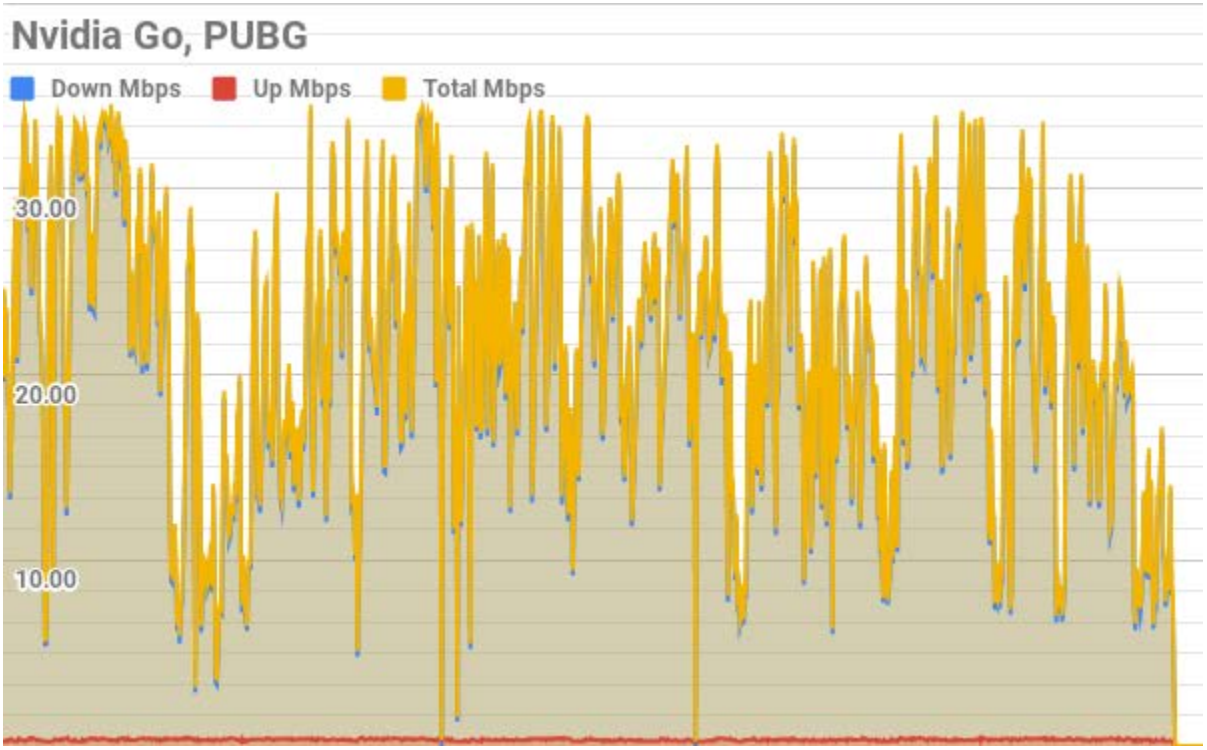

Figure 28 - GeForce Now Network Traffic (PUBG)

Conclusion

Gaming has not been recognized as a key service for customers in the way that streaming video has. Network engineers need to recognize and plan their capacity around the current and near future requirements for gaming and that includes much higher bit rates, especially on the upstream, and optimizing for lower latency and packet loss. It might also include direct peering or other arrangements with gaming providers and CDNs to maximize performance and control costs. Today it's not uncommon for consumers to consider how well an MSO supports Netflix and other OTT video providers in their decision making. I believe that gaming has the same ability to influence decisions if we build our services correctly. Customer support also needs to be educated in supporting the games and auxiliary applications. Most service providers today are comfortable handling questions around why Netflix is slow and we should get comfortable handling the questions around gaming performance and Twitch streaming.

Abbreviations

BF1	Battlefield 1
bps	bits per second
CS:GO	Counter-Strike: Global Offensive

DMZ	Demilitarized Zone, portion of the network without firewall protection
DoS	Denial of Service, a type of attack that knocks out access but doesn't compromise a system
FPS	First-Person Shooter
Kilobits	1000 bits
Latency	Time delay created by packets transiting the physical network
Mbps	mega-bits per second
MMOFPS	Massively Multiplayer Online First-Person Shooter
NAT	Network Address Translation
PUBG	PLAYERUNKNOWN'S BATTLEGROUNDS
PVE	Player Versus Environment
PVP	Player Versus Player

Speeds are in kilobits per second (Kbps) unless otherwise noted. The thresholds are based on personal observation of when the impairment becomes clearly noticeable to the user. Given that there is no empirical method to discern acceptable performance in gaming this opinion and other users in other network conditions may see unacceptable performance at lower thresholds. I have tried to create reasonable values for these measures and I will be providing updates to this information over time.

Tables of Network Characteristics

Table 1 - Network Characteristics, Games

Name	Average Down Kbps	Average Up Kbps	Peak Down	Peak Up	Latency Threshold	Packet Loss Threshold	Method
BF1	222.00	101.00	510	207	130	3%	Game Display
CSGO	343.00	70.00	581.12	105.688	100	4%	Game Display
Destiny 2	32.00	27.90	123.32	113.464	150	6%	Derived from local ping plus injected
Fortnite	32.33	33.33	188.648	205.992	175	7%	Derived from local ping plus injected
Minecraft	281.00	31.50	7093.84	116.352	250	10%	Derived from local ping plus injected
Overwatch	249.40	54.60	3234.2	99.632	140	6%	Game Display
PUBG	19.00	34.00	261.68	97.656	125	6%	Derived from local ping plus injected

Table 2 - Destiny 2 Peer Connections

Average Peer Down	Average Peer Up	Peak Peer Down	Peak Peer Up
50.25	52.25	141.088	114.88
Average Peer Down	Average Peer Up	Peak Peer Down	Peak Peer Up

Table 3 - Network Characteristics - Voice Communication

Name	Average Down Kbps	Average Up Kbps	Peak Down	Peak Up	Latency Threshold	Packet Loss Threshold
Discord	222.00	101.00	6952.91	70.368	250	7%
Mumble	36.5	32.4	123.32	113.464	200	5%

Table 4 - Network Characteristics – Streaming Platforms

Name	Average Down Kbps	Average Up Kbps	Peak Down	Peak Up	Latency Threshold	Packet Loss Threshold
Twitch	124.4	5,564.8	271.76	10,884.5	300	1%
YouTube Gaming	119	3,350	175.22	8,225.87	300.00	1%

Note that speeds in streaming is mostly determined by the audio and video bitrate, especially the video rate.

Table 5 - Network Characteristics – Remote Rendering

Name	Average Down Mbps	Average Up Mbps	Peak Down Mbps	Peak Up Mbps	Latency Threshold	Packet Loss Threshold
GeForce Now	21	0.341	34.26	0.5	40	<1%

Bibliography & References

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Bungie Presentation on Destiny 2 Networking -- http://twvideo01.ubm-us.net/o1/vault/gdc2015/presentations/Truman_Justin_Shared_World_Shooter.pdf

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Statista -- https://www.statista.com/

SUPERDATA -- https://www.superdataresearch.com/us-digital-games-market/

