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by

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***Abstract*—Players of first-person shooter (FPS) games, such as *Counter-strike: Global Offensive* (CS:GO), seek low latencies in order to play well and have fun. Even network latencies as small as 10 milliseconds may decrease accuracy, score, and Quality of Experience, degredations that may be exacerbated for higher-precision weapons. This paper presents results from 40+ person user study that measures the impact of network latencies on player for the FPS game CS:GO. We setup a testbed where participants played 20+ rounds of CS:GO with controlled amounts of network latency with either a high-precision weapon (an AK-17 assault rifle) or a low-precision weapon (a Nova shotgun). Analysis of the results shows even network latencies under 100 milliseconds degrade player performance (accuracy and score), avatar movements, and Quality of Experience (QoE), with the impact on player performance more pronounced for the higher-precision weapon.**

I. Introduction

Computer games are one of the most popular forms of entertainment in the world, with global sales increasing at an annual rate of 10% or more. First-person shooter games are particularly popular – *Counter-strike: Global Offensive (CS:GO)* (Valve, 2012), the next generation of the popular first-person shooter game Counter-Strike, consistently has a tremendous online population. CS:GO has more than 550,000 daily active players with frequent regional and international tournaments, supporting both casual and professional esports players with significant prize pools.

Prior work has shown even modest amounts of latency can impact game player performance and Quality of Experience (QoE), especially for first-person shooter (FPS) games. However, most previous work has not teased out the impact of latency on different types of weapons. Our past work [1] posits that the effects of latency depend upon characteristics of player game actions, such as the precision required to hit a target with a weapon in a FPS game. Weapons in CS:GO can vary from precise for a gun such as an assault rifle to fairly imprecise for a shotgun. Furthermore, most previous work studies higher-end network latencies (e.g., as high as 150 milliseconds or more) which is not common among today's competitive gamers. In fact, new networking technology providers can deliver client-server latencies under 10 milliseconds, which may be appealing to competitive gamers. How much such ultra-low network latencies might benefit CS:GO players is not yet known.

This paper presents the results from a user study that measures the impact of network latency on CS:GO players, with a focus on low-end network latencies and weapons with contrasting precision. Potential participants were screened for their skill at FPS games, in general, and CS:GO specifically, obtaining a pool of 42 qualified participants. Participants each played 22 rounds of CS:GO, half with a high-precision assault rifle (an AK-47) and half with a low-precision shotgun (a Nova) in a custom game system setup that let us control the amount of network latency and record player performance.

Analysis of the results shows that for CS:GO:

1) Even network latencies under 100 milliseconds matter for player performance and player fun. Player performance can degrade by up to 15% when network latencies go from 0 milliseconds (i.e., a LAN game) to 100 milliseconds (common for players at home). Network latency also decreases avatar movements which means less dodging to avoid being shot and less re-positioning to take a shot. Player Quality of Experience (QoE) tends to follow player performance, with subjective ratings of game quality decreasing by about 0.7 points (on a 5-point scale) for each 100 milliseconds of network latency.
2) The impact of network latency on player performance depends upon weapon precision. For an assault rifle (e.g., an AK-17), latency degrades accuracy by 15% and 2 points per minute for each 100 ms of network latency. The latter translates to about an extra kill per minute – significant since a single kill can create a huge advantage in a competitive game. But for a shotgun (e.g., a Nova), network latency has far less impact on performance, about 1/3rd as much as for an assault rifle. The effects of network latency on avatar movement and QoE are independent of weapon type, however.

The rest of this paper is organized as follows: Section II describes previous work on latency and games related to this paper; Section III describes our methodology, including CS:GO setup and user study design and execution; Section IV presents the user study results and analysis; Section V mentions some limitations of our approach; and Section VI summarizes our conclusions and possible future work.

II. Related work

This section provides an overview of prior research work related to our paper: Counter-strike: Global Offensive (CS:GO) specifically (Section II-A), First-person shooter games more generally (Section II-B), and other games (Section II-C).

A. Counter-strike: Global Offensive

Counter-strike Global Offensive's (CS:GO) (Valve, 2012) longevity in competitive gaming has motivated CS:GO use in related research. Wai-Kiu et al. [2] analyze the impacts of lag on first-person shooter games, and did the experiment with CS:GO. They find latency can affect player shooting accuracy and degrade player performance in CS:GO. Frostling-Henningsson [3] and Jansz and Tanis [4] find Counter-strike players are foremost motivated by social reasons, even for gamers that are also motivated by competition and challenge. Lux et al. [5] use opponent kills to anchor CS:GO match summaries and Makarov et al. [6] find ranking CS:GO players based on their team impact is useful for predicting winners.

While helpful to better understand CS:GO players and their interactions and performance in the game, these papers do not delve into the effects of low-levels of network latency on CS:GO players, nor discern impact based on weapon type, as does the work in our paper.

B. First-Person Shooter Games

Quax et al. [7] show for players of UT2003 that latency and latency jitter under 100 ms can degrade player performance and quality of experience. Amin et al [8] show player experience defines and determines the sensitivity to latency for the FPS game Call of Duty, with competitive gamers more adept at compensating for impaired conditions. Gutwin et al. [9] find even modest latencies can cause significant and substantial degradation in performance for first-person shooter games. Matthias et al. [10] analyse different factors affecting players' perception and performance in multiplayer games and they conclude that latency can have great impact on the subjective users' perception in first-person shooter games.

While beneficial, these works typically studied higher latencies than those in our paper (and higher than usually experienced by competitive game players), and do not identify nor isolate the effects of latency on individual weapons, as we do in our paper.

C. Other Games

For other game genres, Howard et al. [11] indicate that for online cooperative games, a player can be affected by latency of a teammate due to cascading effects on the game outcome. Pantel and Wolf [12] show latencies of about 100 ms can affect car racing games. Dick et al. [10] show via a survey that players generally think about 120 milliseconds is the maximum tolerable latency for a network game, regardless of game genre. Hohlfeld et al. [13] find players of the casual game Minecraft are insensitive to network latencies of up to 1 second. Fritsch et al. [14] find players of the role-playing game Everquest 2 can tolerate hundreds of milliseconds of network latency. Sheldon et al. [15] find some aspects of play in the real-time strategy game Warcraft 3 are not affected by up to a second of network latency.

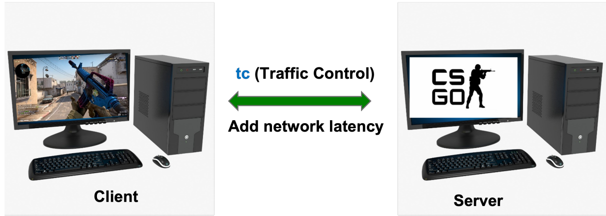

Fig. 1. CS:GO computer configuration.

While useful for comparative purposes, these works generally pertain to games that are less sensitive to latency than first-person games, such as CS:GO – the focus of our study.

III. Methodology

To evaluate the effects of network latency on *Counter-strike: Global Offensive* (*CS:GO*) we setup a client-server testbed for the user study, added controlled amounts of network latency, recruited students to participate in the user study, gathered user data, and analyzed the data for player performance and Quality of Experience (QoE).

Figure 1 depicts the general setup for our user study testbed. The user study was conducted in a dedicated, on-campus computer lab using a client-server architecture. The server hosts the game and is connected via high-speed LAN to the client. The server PC is an Alienware with an 8-core Intel i7-4790K CPU @4 GHz with 16 GB RAM. The client PC is configured for playing games, with specifications and peripherals typical of a high-end gaming setup. The client has an 8-core Intel i7-4790K CPU @4 GHz with 16 GB of RAM and an NVIDIA GeForce GTX 1080 graphics card. The mouse is a Logitech G502 12k DPI with a 1000 Hz polling rate. The client PC has two monitors – 1 monitor displays a reaction time test via a Chrome browser (see below) and another monitor displays the game for CS:GO. The CS:GO monitor is designed for gaming, a 25" Lenovo Legion, 1920x1080 pixels displayed at 16:9 and 240 Hz, with AMD FreeSync and a 1 ms response time. Both server and client run CS:GO (version 10.15.2020) on Ubuntu 20.04 LTS, with Linux kernel version 5.4. The PC connects to a Raspberry Pi 4 configured to act as a network router. The Pi has a 5 GHz 64-bit quad-core CPU with 8 GB of RAM and runs Ubuntu 20.04 LTS with Linux kernel version 5.4 with `tc` [16] to add network latency. Users were given wired headset for game audio.

We assessed the baseline performance for our testbed for key game parameters: a) in-game frame rate, and b) local latency for the time between local input until the monitor shows the resultant output. The client directly connects to the server via a Gb/s switch, so network round-trip time from the client to the server is lower than 1 millisecond.

Table I depicts the results, reporting mean, median, minimum and maximum. For the mean, the standard deviation is given in parentheses. For frame rate, we measured 5 minutes of CS:GO gameplay using FRAPs [17]. From the results, the recorded frame rate is high and stable, typically desired by gamers. For local latency, we used a 1000 f/s camera (a Casio

TABLE I
TESTBED PERFORMANCE.

Measurement	Statistic
frame rate (f/s)	mean: 120.3 (9.6) median: 120 min: 95, max 144
local latency (ms)	mean: 17.7 (2.3) median: 17.5 min: 15, max: 21

EX-ZR100) to capture the moment that a user presses the mouse button and the resulting screen output. We inspect the video frame-by-frame to get the time (t_1) when the mouse was clicked and the time (t_2) when the result was visible. The local latency is then $t_2 - t_1$. We repeated the test 10 times and took the average as the local latency. From the table, the local latency is low, as is typically desired by gamers.

Figure 2 depicts the user study procedure for our IRB-approved study.

Potential participants were screened to ensure some experience with CS:GO so as not to have learning the game subsume any of the latency effects.

Selected participants arrived individually at our laboratory at a pre-set time and signed a consent form.

Participants were then asked to sit at the client PC and adjust the chair position and height so as to be comfortable.

The study begins by having the participant fill out a brief demographic survey and take a reaction time test. The latter has them respond to a visual color change on the monitor as fast as possible, done a total of 10 times and averaged to provide for a baseline reaction time.

The participant then played rounds of CS:GO while, unbeknownst to the user, our script added a fixed amount of latency to the network.

After each round, the participant filled out a short QoE survey and then repeated the previous step – i.e., playing another round of CS:GO with a different, shuffled latency.

The user played for a total of 22 rounds, with the entire process taking just under 60 minutes. Users received a remuneration of $15 for their time.

Finally, we collected the game data from the game log and prepared the setup (cleaned and sanitized) for the next participant.

The QoE survey given at the end of each round was a Mean Opinion Score (MOS) question "Rate the quality of the previous round" on a discrete 5-point Likert scale about the game experience in the preceding round.

Additional latency was added equally to the server uplink and downlink using the Traffic Control [16] Linux utility that gives you the ability to configure the kernel packet scheduler. The added network latency ranged from **0**, **12.5**, **25**, **50** and **100** milliseconds, presented in shuffled order.

The objective measures of performance were gathered from the game logs, collected 5 times per second for every player for every round of game play.

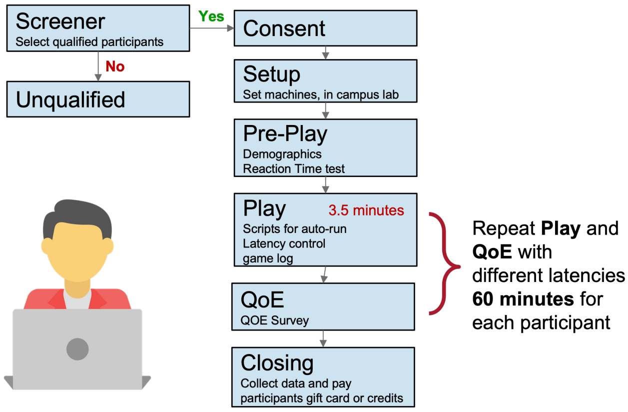

Fig. 2. User study procedure.

TABLE II
WEAPON ATTRIBUTES

Weapon	Mode	Fire rate	Clip	Reload	Damage	Accuracy
AK-47	Automatic	600/min	30	2.43 s	36	21.74 m
Nova	Shotgun	68/min	8	1.8 s	26/pellet, 234/shot	3.2 m

While CS:GO matches often include team strategy, the focus of this study is on the effects of network latency on individual player tactics. As such, a death match free-for-all game mode (no teams) was chosen. Thus, each round had open combat for the user and 20 AI-controlled bots, where everyone fought everyone and the goal was to kill as many opponents as possible. The bot difficulty level was set to 3 (hard) out of 4.

There was no upper limit on player score – the game terminated after a 3.5 minutes.

To assess the effect of network latency on different weapons, the experiment contains 2 parts – 11 rounds with an AK-47 (the most popular automatic rifle) [18] and another 11 rounds with a Nova (the most popular shotgun) [18]. The weapons' specifications are given in Table II. The order of the weapons is shuffled. Players were equipped with only one weapon at a time and had unlimited ammunition.

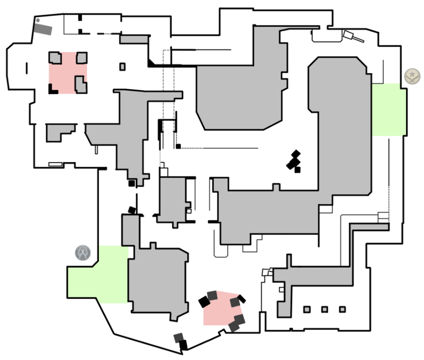

Fig. 3. User study CS:GO map – Mirage.

To maximize combat time compared to wandering around the map, the third smallest [19] and most popular [20] map "Mirage" was used, shown in Figure 3. The user and the bots spawned at random locations on the map that were not currently in view of anyone else.

The CS:GO settings were pre-configured at the server with the experiment controlled by scripts on the client – this meant when starting each round, users immediately joined and launched into the game, bypassing normal game lobbies and weapon selection phases.

IV. Analysis

This section first summarizes participant demographics (Section IV-A), then the effects of network latency on: player performance (Section IV-B) and Quality of Experience (Section IV-C).

A. Demographics

Forty-two (42) students participated in the user study. Table III presents the participant demographics. The participants were mostly male, with the sample likely skewed by the larger fraction of males (65%) at our university. The average age was 20, typical of our university undergraduates. All participants had experience with first-person shooter games. The participants' average total time spent playing CS:GO was about 2100 hours. The average self-rating for first-person shooter games (FPS) was 3.8 and the average CS:GO self-rating was 3.3, both on a 5 point scale (1-5). Average reaction times were relatively low, around 200 milliseconds, as is typical of avid game players.

TABLE III
Participant demographic information.

Users	Age (yrs)	Gender	FPS Self-rating	CS:GO Self-rating	CS:GO Hours	Reaction-time (ms)
42	20 (2.0)	37 ♂5 ♀	3.8 (1.1)	3.3 (1.2)	2109 (703)	209 (18.4)

B. Player Performance

1) Accuracy: Figure 4 depicts weapon accuracy versus network latency on the x axis. The y axis is the weapon accuracy (percent). The circles are the means for all users for that latency condition, bounded by 95% confidence intervals. The blue dashed line shows a linear regression for the mean values of the Ak-47 (an assault rifle, a high-precision weapon), and the red dashed line shows a linear regression for the mean values of the Nova (a shotgun, a low-precision gun). Table IV gives the linear regression parameters. Based on the statistical significance and R^2 values (and visually), the regression fits the mean values well for the AK-17, with an R^2 of 0.83 and $p = 0.03$, and only moderately for the Nova, with R^2 of 0.56 and $p = 0.15$. As a take-away, an increase in network latency by 100 milliseconds degrades accuracy for the AK-47 assault rifle by 15%, with negligible impact on Nova shotgun accuracy for the same latency range.

TABLE IV
Linear regression for accuracy (units are percent).

Weapon	y-intercept	Slope	R^2	p
AK-47	0.23	-0.0003	0.83	**0.03**
Nova	0.20	-0.0001	0.56	0.15

TABLE V
Linear regression for score (units are points).

Weapon	y-intercept	Slope	R^2	p
AK-47	15.76	-0.016	0.88	**0.019**
Nova	14.68	-0.003	0.18	0.48

2) Score: Figure 5 depicts player score versus latency. The axes and points are as in Figure 4, but the data is the score ($2 \times kills + assists$) per minute instead of accuracy. Table V gives the linear regression parameters. The regression fits the mean values well for the AK-17, with an R^2 of 0.88 and $p = 0.02$, but less well for the Nova, with an R^2 of 0.18 and $p = 0.48$. As a take-away, an increase in network latency by 100 milliseconds degrades score for the AK-47 assault rifle by 12%, with negligible impact on the Nova shotgun score for the same latency range.

3) Movement: Figure 6 depicts player movement versus latency, inferred by `WASD` keypresses per minute recorded in the log files. The axes and points are as in Figure 4, but the data is the movement actions. When using the Nova shotgun, players move about 20% more, likely because the weapon's shorter effective range means a player must be positioned much closer to an opponent to shoot them. Both linear regressions fit the mean values well, with an R^2 of 0.59 and $p = 0.13$ for the AK-47 and an R^2 of 0.85 and $p = 0.03$ for the Nova. Overall, network latency decreases player avatar movements. This, in turn, means it shortens survival times since a player has a harder time avoiding being shot, and makes it harder to move into position to shoot opponents. The effect of latency on movement is slightly greater for the Nova shotgun than for the AK-47 assault rifle.

C. Quality of Experience

Quality of Experience (QoE) was assessed by a subjective, 5-point survey question at the end of each round (1-low to 5-high). Figure 7 depicts the results. The x axis is the network latency in milliseconds and the y axis is the rating. The circles are the means for all users for that latency condition, bounded by 95% confidence intervals. The green dashed line is a linear regression fit through the mean values for the AK-47 assault rifle and the dark red dashed line is for the Nova shotgun. Table VI gives the linear regression parameters. Both regressions fit the means well, with little visual difference between QoE degradation for the AK-47 compared to the Nova. As a take-away, latency degrades player QoE by 0.5

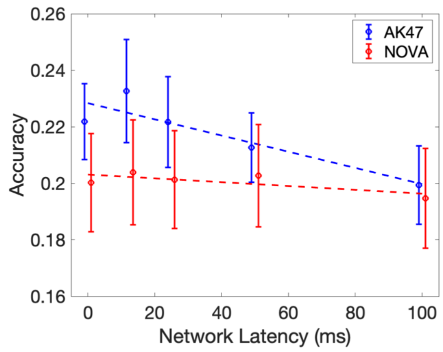

Fig. 4. Accuracy (means with 95% confidence intervals).

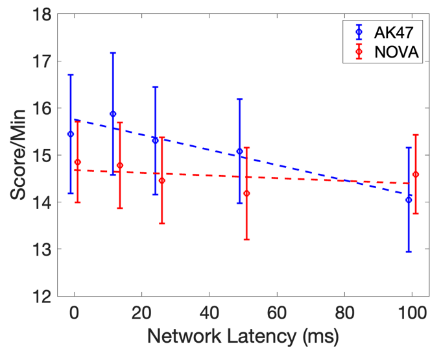

Fig. 5. Score (means with 95% confidence intervals).

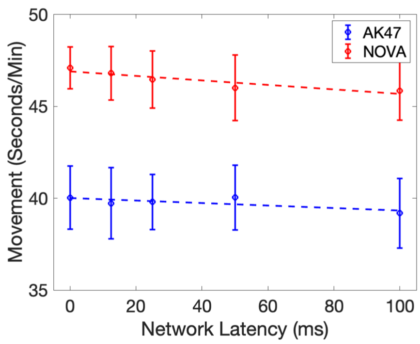

Fig. 6. Movement (means with 95% confidence intervals).

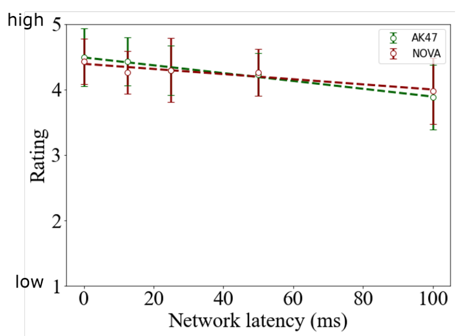

Fig. 7. Quality of Experience (means with 95% confidence intervals).

point for each 100 ms on a 5-point scale, and the degradation is similar for both weapons.

TABLE VI
LINEAR REGRESSION FOR QOE (UNITS ARE POINTS, 5 POINT SCALE).

Weapon	y-intercept	Slope	R^2	p
AK-47	4.49	-0.006	0.98	**<.001**
Nova	4.39	-0.0039	0.88	**.018**

V. LIMITATIONS

Only 5 of the participants in our study were female, and the rest were male. This is fairly representative of our sample pool, but that is because our university has considerably more males than females. More importantly, our results may not represent the performance of female players in CS:GO. Similarly, our participants are young and, while again representative of our sample pool, span a considerably narrower range compared to CS:GO players overall.

Our user study intentionally assess the effects of latency on individual player performance. However, CS:GO is often a team game, where groups of players (typically 5 per team) work together to defeat the opposing team. The impact of latency on CS:GO team efforts, perhaps even team strategies, was not assessed.

Serious game players often customize the software settings on their computers and games to suit their personal play preferences. For example, players may alter the mouse sensitivity or change the graphics resolution from the system defaults. These custom changes presumably improve the specific player's experience and may improve their performance. However, we did not allow any personal changes to the computer or game settings since such customizations create a difference in test conditions between users.

CS:GO games normally have only human players and not AI-controlled bots, so absolute player performance numbers may differ for human versus human games. However, the relative effects of network latency should be similar since the AI-controlled avatars move with the same game physics as do human-controlled avatars, with the primary difference aiming accuracy and firing speeds, impacting player deaths only, not accuracy nor score (kills, assists).

VI. CONCLUSIONS

Network latency has been shown to degrade player performance for many games by making it take longer for a game action at a client to be updated by the game server over the Internet. While the effects of network latency have been studied for many games, in general, and for first-person shooter (FPS) games, specifically, what is not known is the the impact of low-levels of network latency for different weapons for the popular FPS game *Counter-strike: Global Offensive (CS:GO)* (Valve, 2012). Understanding the effects of latency on a game, and for a FPS game on the weapons, is important for: a) players to adjust playstyles appropriately (e.g., to choose an appropriate weapon) or to decide to upgrade their system (e.g., get a low-latency network connection), and b) developers in order to deploy latency compensation techniques when appropriate and motivate engineering that might decrease network latency.

This paper presents results of a forty-two (42) person user study that evaluates the effects of latency on first-person shooter game players. We setup a testbed that controls network latency, collecting objective data (from game logs recording player actions and performance) and subjective data (Quality of Experience, via post-round surveys). Each of the 42 participants played a customized game mode of CS:GO for about 1 hour total, experiencing 11 different network latency conditions, with network round-trip times ranging from 0 to 100 milliseconds.

Analysis of the results shows player performance – encompassed by accuracy, score and movement – is significantly impacted by network latency. As a take-away, an additional 100 milliseconds of network latency reduces both score and accuracy by about 15% for the AK-17 assault rifle. However, the impact of latency on score and accuracy is less pronounced for the Nova shotgun. For player movement actions, latency has similar effect for both the assault rifle and shotgun. With 100 milliseconds of network latency, Quality of Experience (QoE) degrades by about 11%, from a high of 4.5 (on a 5 point scale) down a half a point to about 4.0 at 100 milliseconds.

Future work could explore the effects of latency on other weapon types common to FPS games, such as a sniper rifle, pistol or hand-held weapon, such as a knife. Another alternative plan could use our methodology on other games (e.g., the FPS game Valorant), or even other game genres and game platforms, such as cloud-based game streaming systems (e.g., Google Stadia). In both cases, there is also merit in additional study on the effects of latency compensation – e.g., time warp or dead reckoning.

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