Cascading Impact of Lag on Quality of Experience in Cooperative Multiplayer Games

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***Abstract*—Playing online games should be fun. One of the primary causes of player frustration in online games is *lag*, or delay in exchange of game state data [1]–[8]. Current lag mitigation strategies are based on the assumption that a player's Quality of Experience (QoE) is influenced only by her own lag [9]–[12]. We systematically show that this assumption is incorrect, because in an online cooperative game the change in QoE of one player due to their lag can have a cascading effect on the QoE of the other players. Our results are obtained through a novel experimental framework based on previous QoE and online game research.**

Understanding a player's QoE as a cascade function that includes other players' network conditions provides valuable information for designing cooperative online games. Based on our observations, we recommend changes to the current approach to lag mitigation in cooperative games. We argue that the primary objective of lag mitigation should not be to reduce the lag of all players. Instead the primary objective should be to reduce the lag of the most lagged player within each cooperative group.

I. Introduction

Playing online games should be fun, yet game forums are filled with player complaints of poor in-game experience. The most frequently cited cause is *lag*, or delay in exchange of game state data [1]–[8]. When gamers refer to lag, they are referring to effects that can be caused by network latency, network latency jitter, and network packet loss. Multiple factors contribute to game lag, such as slow client machines, overloaded game servers, and network delays [13], [14]. When high levels of lag are present, player views of the global game state diverge [15]. The result is players' inability to observe and control game actions, which makes it hard for them to perform well and to remain immersed and engaged with the game [1], [16]–[18].

Academic research has formalized the impact of lag on players experiences in games [1], [2], [6], [19]–[21]. In response, a number of solutions have been proposed to mitigate lag's impact, through latency masking techniques, widely distributed game infrastructure, and improved game hardware [9]–[13], [22], [23]. In spite of these advances, lag in games remains a problem. We posit that a major reason players remain frustrated by lag is that neither studies on the impact of lag, nor mitigation solutions, consider the effect of one player's lag on other players' Quality of Experience (QoE).

Many online games are *cooperative*, in that players work as a group to achieve a common in-game objective. The increase of popularity and diversity of cooperative play modes in FPS and MMO games suggests the importance of group play to the success of games in those genres [24]. Understanding that one person's lag can have a cascade effect allows lag mitigation techniques to be developed in a more robust way.

978-1-4799-6882-4/14/$31.00

We design an experimental framework to measure effects of lag on a group of players through a suite of subjective and objective QoE metrics, including survey responses, brainwave patterns collected using an EEG headset, and game controller input. Using this framework, we study player interactions in controlled group game sessions in Mass Effect 3, an online cooperative multiplayer shooter game. In our experiments we manipulate network-induced lag, the hardest source of lag to mitigate in practice [14], [25]. Our approach is novel in that we vary the lag of *only one group member* at a time to characterize its *impact on other players*.

Our results show that one player's lag can have a cascading impact on the QoE of others. This result runs contrary to the driving principle in lag mitigation that only a player's own lag affects her QoE. Based on our observations, we recommend changes to the current approach to developing lag mitigation techniques in cooperative games. We argue that the primary objective of lag mitigation should not be to reduce the lag of all players. Instead the primary objective should be to reduce the lag of the most lagged player within each cooperative group.

The rest of this paper is organized as follows. Section II describes previous research related to user QoE in networked games. In Section III we describe background on QoE metrics and lag mitigation techniques. Section IV describes the methodology of our study and Section V presents its results. Finally, we conclude and present directions for future work in Section VI.

II. Related Work

The effect of network latency and packet loss on the experience of a single user is well studied. Previous research shows that high latency, high jitter, and moderate packet loss negatively impact the experience of a single user [6], [9], [26]–[32]. Some types of online games have been shown to be more sensitive to lag than others [9], [27]. In particular, First (and Third) Person Shooters, such as Mass Effect 3, tend to be the most sensitive [27].

The QoE of players in multiplayer games has been previously tested using four general approaches, namely: simulations of user interactions through artificial intelligence (AI) bots in competitive tasks, observational studies in real-world applications, in applications developed for the specific research, and as by-products of studies focused on single individuals' QoE [2], [3], [19], [20], [33], [34]. A shortcoming of these studies, addressed by our work, is their limited focus on the QoE of players who experience lag without considering other group members as well.

Several studies also used subjective and objective metrics to study player QoE. Notably Quax *et al.* used subjective surveys and objective measures of player score [28]. Lee *et al.* assessed user frustration through facial electromyography (fEMG) measurements of the corrugator supercilii muscle, responsible for involuntary frowning [35]. As described in Section IV, we use EEG, which allows us measure brainwave activity, which has been shown to indicate a level of player attention and engagement.

Closest to our work is a study by Beznosyk *et al.*, where a player without lag was studied, while collaborating with a player suffering from lag [36]. The game studied by Beznosyk *et al.*required *collaboration* where players have to work together directly to reach the in-game goals, rather than *cooperation* where they do not. This is an important distinction. In collaborative games if one player is unable to participate, it is impossible for the other player to complete in-game goals. In cooperative games, such as Mass Effect 3 studied in this work, players may work together to reach game goals or can achieve all goals individually without working together. To the best of our knowledge, ours is the first work to study the effect of one player's lag on others' QoE in a *cooperative* game. This general model of cooperative action is also present in other types of online interactions such as video conferencing, screen sharing, and online education.

This paper builds upon the work presented in [37] by adding an in depth analysis of the research, including related works, the game studied, our methodology, and the detailed results.

III. Background

To provide context for our study, we describe the cooperative model of Mass Effect 3, describe our QoE framework, and present an overview of current lag mitigation techniques.

A. Cooperation in Mass Effect 3

Our study examines player QoE during matches of Mass Effect 3, a popular cooperative multiplayer Third Person Shooter game [38]. This game features a team of players who cooperate to defeat computer-controlled enemies. Mass Effect 3 encourages player cooperation through a two-part combination attack system, although it is not required to reach the game objectives. In this system, one player can use an in-game power which will "mark" an enemy. When a second player uses a complimentary power on the marked enemy, additional bonus damage is applied to the enemy. This bonus damage is attributed to the first player and so his score will tend to be higher for what is actually a group effort.

B. QoE Defined

QoE is a set of metrics that represent a player's emotional, cognitive, and behavioral responses during an activity [15], [39], [40]. QoE represents the player's total experience and is measured across several dimensions, whose relative importance depends on the system studied [40]. Generally speaking, low QoE indicates player frustration.

QoE is measured using multiple component metrics [15], [39]. We adapt the treatment of QoE developed by Wu *et al.*, based on Concentration, Enjoyment, Sense of Being, Performance Gains, and Exploratory Behaviors [39]. Each metric can have both objective and subjective measures, which quantify its different aspects. Because of the difference between a player's perception and reality, certain QoE metrics may show a strong signal in either the subjective measures, the objective measures, or both [15], [39]. For example, while people's ability to subjectively identify the pitch of a musical note may differ, a tuning device will objectively characterize vibration frequency regardless of the user's perception.

In designing our experimental framework we have identified the subjective and objective measures for each QoE metric as follows:

1) Concentration: Concentration is a metric of a player's ability to focus on the game. When a player is focused on a task, Concentration is high. In our study the subjective measure of Concentration is a survey question asking the player to rate how Engaging the match was. A high Engaging rating indicates a high level of Concentration. The objective measure of Concentration is an Attention rating gathered by a electroencephalography (EEG) device worn by the players during game matches [41]. When a player has a high level of Attention their Concentration is high. Our EEG device reports measurements of Attention on a five point scale [41].

2) Enjoyment: Enjoyment is a metric of a player's feelings of happiness during a match. As the subjective measure of Enjoyment, we used a survey question asking a player to rate how enjoyable the match was. The objective measure of Enjoyment was Time Dilation, which was established through a survey question asking the player to indicate if the match felt shorter, longer, or about the same length of time compared to other matches. When a player indicates that a match was shorter than usual, when it was not, a high Enjoyment is indicated [42].

3) Sense of Being: Sense of Being is a metric of a player's feeling of being part of the game world. When a player has a suspension of disbelief and the feeling that the character they control is a direct representation of themselves then their Sense of Being is high. The subjective measure of Sense of Being is a survey question asking the player to rate how Immersive they found a game match to be. If the player finds the match to be highly Immersive then their Sense of Being is high. The objective measure of Sense of Being is a Calmness rating gathered by the EEG device, called Meditation by the device developers [41]. The Calmness rating is an indicator of what is commonly considered a feeling of being "in the zone." When the Calmness rating is high then Sense of Being is high.

4) Performance Gains: Performance Gains is a metric of the player's ability to achieve in-game objectives. A question asking the player to rate Impairment when controlling their character is used as a subjective measure. When the player feels she was prevented from achieving in-game goals her Performance Gains are low. The objective measure of Performance Gains is the Match Score, which is based on the player's actual ability to score hits on game enemies and perform cooperative tasks within the game. A high Match Score indicates that the player experienced Performance Gains during that match.

5) Exploratory Behaviors: Exploratory Behaviors is a metric of the player actively learning about the game environment. The subjective measure of Exploratory Behaviors is a survey question asking whether the player tried a New Play Style in the match. A player trying a New Play Style indicates positive Exploratory Behaviors. The objective measure for Exploratory Behaviors is provided by analyzing the key log for the match to determine changes in player controller use. When control inputs indicate a rise or decline in specific behaviors, such as use of special in-game abilities, the player has explored new ways to play the game.

C. Lag Mitigation

Lag mitigation techniques in use today attempt to reduce the impact of lag on the lagged player only [9]–[12]. Four of the most common lag mitigation techniques are *behavior prediction*, *time delay*, *time warp*, and *visual trickery* [9]–[12]. Behavior prediction, for example dead reckoning, is used at both the server and client machines to adjust the game state to predicted states before state updates are received. As a result, the game appears to be continuous even when state updates are delayed. Time delay introduces artificial delay to equalize the latency experienced by all players. Time warp allows servers to reorder user input based on client timestamp, rather than arrival time on the server. Both time delay and time warp improve fairness, although they tend to decrease player immersion and engagement. Finally, visual trickery is an umbrella term for techniques that manipulate the game world to mask delay of game state updates. For example, enemy hits are visualized to players before enemy health is deducted on the server. While these techniques work well when lag is low, at higher levels of lag visual trickery can significantly misrepresent the game state and lead to user frustration.

Mass Effect 3 uses behavior prediction and visual trickery. Behavior prediction is observable by seeing characters travel in invalid directions, like continuing upward into the air at the end of a ramp. Visual trickery is used to indicate damage done to an enemy before that damage has been verified, which is visible when testing by noting the real time damage done by multiple people and then comparing to the server's decision on who did the damage. We show, that these methods do not entirely prevent the impact of lag of one player on the QoE of others.

Game developers may also attempt to reduce lag on network paths through architectural decisions. For example, lag is lower when servers are located closer to users and game communication are prioritized, or take place over custom transport protocols [22], [43], [44]. Finally, matchmaking of players into groups with low relative latency tends to improve group experience. However, matchmaking does not help players who want to play with a specific group of their friends [17]. Similarly to lag mitigation in game design, these architectural techniques are designed only to reduce the impact of lag on the lagged player.

IV. Methodology

To understand the impact of lag on the QoE in a group setting, we performed an Institutional Review Board (IRB) approved study of groups of players engaged in a cooperative online game. The methodology of our study builds on previous work in Sociology and Computer Science [16], [39].

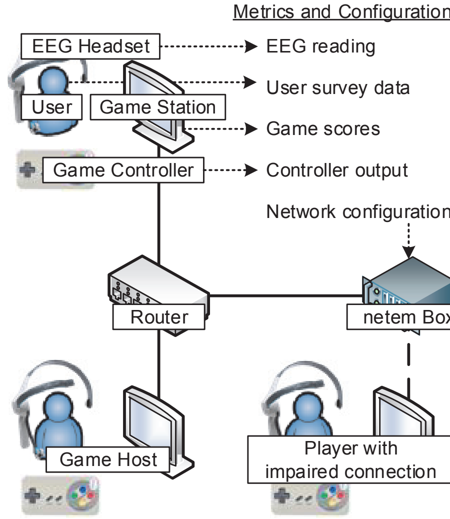

Fig. 1: Experiment Setup

TABLE I: Emulated Network Lag Factor Sets

Emulated Location	RTT	Total Jitter	Total Loss
Same Room	0ms	$\pm$0ms	0%
Same City	60ms	$\pm$30ms	1%
Same State	120ms	$\pm$60ms	2%
Same Country	180ms	$\pm$90ms	3%

Figure 1 shows our experiment setup. During group game sessions, players were co-located on identical, adjacent computers, which allowed free verbal communication simulating normal headset based online communications. Groups of three players were chosen from a pool of 15 participants and asked to participate in a total of 160 game matches, during which we varied the level of lag applied to one player's network connection. Each participant played in 12-20 matches and no two participants played together in more than eight matches. During each match we collected objective QoE metrics using EEG devices, key loggers, and records of game score. After each match we collected subjective metrics through a short survey.

Study participants were a self-selected group of volunteers, students and non-students, of both sexes, with age range 18-38 years. These players were briefed on the general nature of the study, including that the network conditions to one or more computers may be changed artificially at some point in the study. Participants were also made aware of the effective cooperative play combination attack strategy discussed previously.

We varied one player's network lag between matches using netem through four factor sets, shown in Table I. These sets emulate network lag representative for a player located in, respectively, the same room, city, state, and country as the other group members [45], [46]. Mass Effect 3 uses a peer-to-peer server architecture. In order to ensure that no players other than the intended one had lag to the server, one of the unlagged players was chosen as the game host.

V. Results

The collected data show that the QoE of one player can be impacted by the impaired network conditions of another. This is counter to previous assumption that a player's QoE is only impacted by their own network conditions [2], [9], [19]. Additionally the data show that subjective and objective QoE metrics have different response profiles for the lagged and unlagged players.

We examined our results for linear correlation. Due to the difficulties in assessing non-linear correlations in limited data, a much larger data set might be able to quantify more precisely the correlations we found, as well as find any that might exist in the cases, where we did not find a linear correlation.

A. Impact of Lag on The Lagged Player

Figures 2, 3, 4, 8 and 9 show box plots of QoE metric distributions for the lagged player in game matches affected by increasing levels of lag, shown on the x-axis. Our data show that the QoE of the lagged player decreases with increasing severity of lag across all metrics of QoE. This result is consistent with trends shown in prior work and validates the choice of QoE metrics in our study [2], [3], [19].

B. Impact of Lag on The Unlagged Players

Figures 5, 6, 7, 11 and 12 show box plots of QoE metric distributions for the unlagged players in game matches affected by decreasing connection quality for the lagged player, shown on the x-axis. *Our data show that the QoE of the unlagged players can be impacted by poor network conditions of the lagged player.*

To quantify the relationship between the lagged player's QoE and the QoE of unlagged players we calculated the correlation for each QoE metric between lagged and unlagged players. Table II shows the Pearson r^2 value, which estimated the fraction of the variance in the unlagged players' QoE values that is explained by the values in the lagged player's responses.

TABLE II: Correlations of Change in QoE Metrics

QoE Metric	Correlation (r^2)	p-value
Engaging	≈ 0.38	$< .015$
Attention	≈ 0.52	$< .003$
Enjoyable	≈ 0.56	$< .002$
Immersive	≈ 0.56	$< .002$
Match Score	≈ 0.62	$< .001$

The correlation values in Table II indicate that a significant portion of unlagged players' QoE is impacted by lagged players loss in QoE. The moderate r^2 values indicate that the unlagged players are not as strongly affected as the lagged player, but are still somewhat affected.

Table II also shows the p-value test for statistical significance. A p-value below 0.05 typically indicates that it is likely the correlation is not due to random chance. All of our p-values are below 0.015 which indicates that the correlations are statistically significant.

In more detail, our results show that not all metrics were correlated in the same way between the lagged player and unlagged players. For the three subjective measurements of Engaging, Enjoyable, and Immersive (Figures 2-7) we see an inverse correlation between the amount of lag and the QoE for all players. In all three cases increased lag led to a decrease in QoE for both the lagged and unlagged players.

The objective metric for Performance Gains, Match Score (Figures 9 and 12), behaved in a non-monotone manner. In the case of Match Score there is a slight increase in QoE when there is a slight amount of lag. As the lag continues to increase past a threshold value, the QoE then drops while the lag increases. Previous research work also notes this phenomenon [9]. Because the player that was lagged was always the player who gained bonus points from the cooperative two part attack strategy, the lagged player tends to have an overall higher score. We plan on controlling for this score differential in future work.

The objective metric for Concentration, Attention (Figures 8 and 11), did not behave in the same manner as the subjective Engaging metric (Figures 2 and 5). Attention showed a strong correlation between lagged and unlagged players and was non-monotonic and an inverse relationship. When the Attention of the lagged player increased, the Attention of the unlagged players decreased. Because there is a dearth in research using brainwave measured levels of Attention, future work must be done to understand why this metric behaves this way.

The metrics not presented (Time Dilation, Sense of Being, Calmness, Impairment, Play Style, and keylog analysis) showed a lack of correlation between the lagged and unlagged player and so they neither support nor contradict our results and we omit these graphs for space consideration.

C. Player Inability to Link QoE to Lag

Figures 10 and 13 show the players' rating of how much network impairment decreased their experience during game matches. For this response, a 5 indicates that the player did not think lag caused any decrease in experience.

Despite several metrics that showed the unlagged player?s decline of QoE with increased lag of others, player responses to whether lag affected their experience did not correlate to the level of others' lag. The unlagged players were not able to correctly attribute their change in QoE to changes in the amount of lag in the group, even though all participants had been briefed that lag would at some point be introduced into the system as part of the study.

Lag is often listed as the most frustrating factor in online gaming [7], [8], [13], and so it is particularly important to note that lag of other players contributes to user frustration in a cooperative game. Asking players to self-report QoE degradation caused by lag will fail to account for the cascading effect of lag discovered in our study. Our results suggest that if a small percent of players have high lag, their lag mitigation should be prioritized before it degrades the QoE of the majority of well-connected players.

VI. Conclusions and Future Work

Cooperative online games should be fun for all players. Prior to this work there has not been a systematic way of evaluating the relationship between one user's lag and others' QoE in a cooperative network application. We have developed a novel methodology to study that effect and collected data on group QoE in over 160 cooperative game matches. Our results illustrate the cascading impact of network lag through a statistical correlation between changes in QoE of the lagged player and of other group members. The results of our study

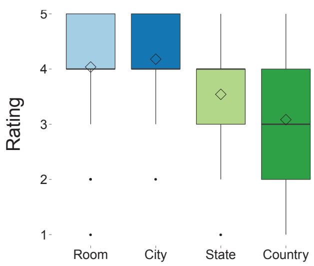

Fig. 2: Engaging – lagged player.

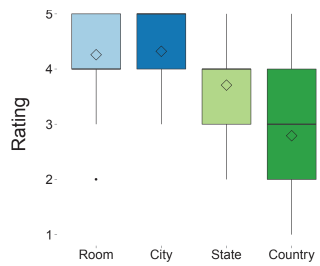

Fig. 3: Enjoyable – lagged player.

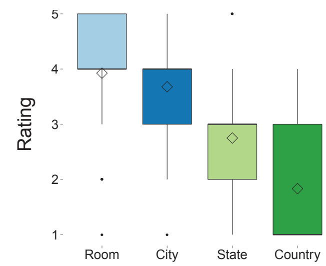

Fig. 4: Immersive – lagged player.

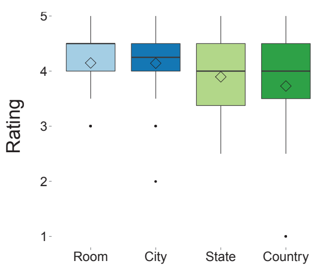

Fig. 5: Engaging – unlagged players.

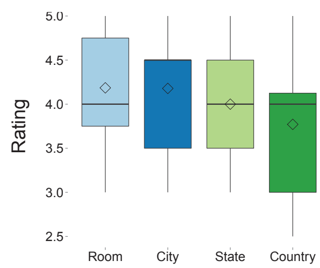

Fig. 6: Enjoyable – unlagged players.

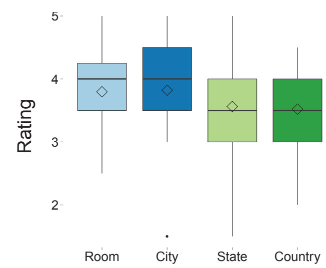

Fig. 7: Immersive – unlagged players.

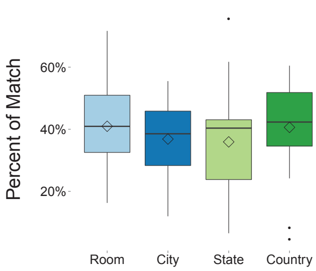

Fig. 8: Attention – lagged player.

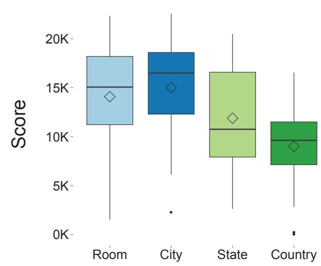

Fig. 9: Score – lagged player.

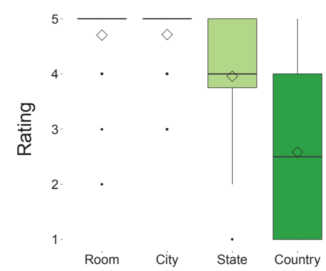

Fig. 10: Net. impairment – lagged.

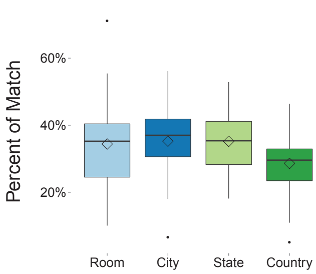

Fig. 11: Attention – unlagged players.

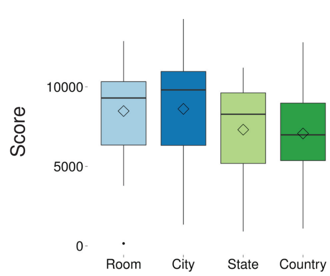

Fig. 12: Score – unlagged players.

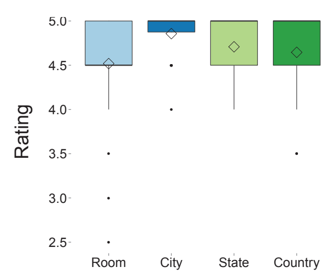

Fig. 13: Net. impairment – unlagged.

are significant, because they demonstrate the inadequacy of existing lag mitigation techniques in a cooperative setting. While our existing results pertain only to lag mitigation techniques employed Mass Effect 3, we expect our future study of other modern multiplayer games to show similar trends.

Shortcomings of existing lag mitigation techniques have been noted by John Carmack, the creator of Doom, as a serious challenge for future technologies [23]. Recent studies have also shown the high sensitivity to lag of cloud-based games, which lack context for client-side lag mitigation [35]. We believe that our results open a new avenue for exploring lag mitigation techniques that could eliminate the impact of one user's lag on the QoE of others.

As a first step to lag mitigation taking into account all users' QoE, games should be aware of the relative lag experienced by players within a cooperative group. Smart edge servers and traffic proxy solutions could both decrease latency to back-end servers and keep track of user lag [14], [35]. Datacenter request prioritization mechanisms, such as D^2TCP, could then be used to decrease the relative server processing delay of lagged players, as opposed to artificially delaying traffic of the well-connected players [47]. Finally, QoE objectives could be taken into account when managing lag of multiple game session using solutions such as Ensemble Routing [48]. Our recent work proposes mechanisms for resource management in widely distributed deployments that meet group QoE constraints [49]. These and other game architecture advances could effectively mitigate the impact of lagged users on group QoE in cooperative applications and potentially bridge the gap between current lag mitigation approaches and user frustration.

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