The influence of interactivity patterns on the Quality of Experience in multi-party video-mediated conversations under symmetric delay conditions

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ABSTRACT

As commercial, off-the-shelf, services enable people to easily connect with friends and relatives, video-mediated communication is filtering into our daily activities. With the proliferation of broadband and powerful devices, multi-party gatherings are becoming a reality in home environments. Theoretical foundations for Quality of Experience (QoE) have identified three crucial factors for understanding the impact on the individual's perception: system, context, and user. While most of the current research tends to focus on the system factors (delay, bandwidth, resolution), in this paper we offer a more complete analysis that takes into consideration context and user factors. In particular, we investigate the influence of delay (constant system factor) in the QoE of multi-party conversations. Regarding the context, we extend the typical one-to-one condition to explore conversations between small groups (up to five people). In terms of user factors, we take into account conversation analysis, turn-taking and role-theory, for better understanding the impact of different user profiles. Our investigation allows us to report a detailed analysis on how delay influences the QoE, concluding that the actual interactivity pattern of each participant in the conversation results on different noticeability thresholds of delays. Such results have a direct impact on how we should design and construct video-communication services for multi-party conversations, where user activity should be considered as a prime adaptation and optimization parameter.

Categories and Subject Descriptors

H.4.3 [**Communications Applications**]: Computer conferencing, teleconferencing, and videoconferencing

General Terms

Measurement, Experimentation, Human Factors

Keywords

QoE, video-mediated communication, multiparty video-conferencing, delay, user study.

1. INTRODUCTION

Video-Conferencing is lately moving from the office to the home, where broadband bandwidth is widely available and devices can now easily join a session. More recent advances are enabling the next logical step: video-mediated group conversations. This paper explores this use case, analyzing the influence of the interactivity of each of the participants in the conversation. Unlike previous research that typically concentrates on system factors, we take into consideration the context and user factors. In particular, we study delay, as a constant system factor, and its effect on the QoE of small gatherings.

The majority of previous research on QoE for remote communication has concentrated on dyadic use cases. For audio-only dyadic communication this has been extensively investigated and 150ms have been established as an industry standard for an acceptable delay [6]. This simple model of optimizing towards a minimal delay is not sufficient for the reality of the internet infrastructure. Currently, the situation is different, since video communication providers operate in the internet, where a multitude of uncontrollable, unknown and unforeseeable network problems can arise. To appropriately configure this complex infrastructure, under varying network conditions, a meticulous and comprehensive study of the different factors affecting the QoE is required. Previous research [11] has indicated that system factors alone are not sufficient to understand the QoE of an individual in a specific situation. This paper aims to advance this understanding by comparing different contexts and different interactivity patterns. In the past, the turn-taking model has been used in dyadic conversations to estimate the interactivity of a conversation [5]. However, this approach is not applicable anymore to multi-party conversations, since a different perception for each participant might arise depending on his/her involvement. We already reported about the investigation of asymmetric delay conditions and general differences between asymmetric, symmetric and dyadic setups [12]. In this paper we make a more fine-grained analysis user interactivity taking into account role-theory as well.

This paper aims to investigate the following novel research questions, regarding delay in multi-party video-mediated conversations:

- Context factors: Where are the lower (just-noticeable) and upper (not-acceptable) boundaries for delay in small-group video-mediated discussions?
- User factors: What influences have conversation roles and interactivity patterns on the perception of delay? Is quality perceived differently by active and passive participants?

2. RELATED WORK

Theoretical models [9, 11] established that QoE is shaped mainly by three aspects: the system, the user and the context. From the

Table 2 System Configuration

System Setup	Desktop PCs (Core i7, 16GB Ram, SSD) Webcam (Logitech HD C920) Headset (Creative Soundblaster Xtreme) Video: 640x480px, 30fps, H264 Audio: Speex Network: Local Gigabit LAN, UDP, RTP
Conditions	•0ms-delay (avg = 75ms, sd = 31ms) •500ms-delay (avg = 564ms, sd = 34ms) •1000ms-delay (avg=1065ms, sd = 39ms) •2000ms-delay (avg = 2058ms, sd= 57ms).

system side, we want to investigate delay, since it is an inherent factor of remote-communication. The dyadic case has been investigated for unscripted scenarios [14] and scripted scenarios [15]. The multi-party scenario has been evaluated for the high-end halo system [4] and for scenarios that use unconventional settings (TV screen, several cameras) [2]. To our knowledge, there has been no investigation of delay effects in an unscripted multi-party video-mediated conversation. From a technical perspective, several studies evaluate realistic network conditions. For example, when connecting two computers between New York and Hong Kong, the round trip delay is up to 776ms for Google+, and 1467ms for Skype. Other systems, like Mebeam [8], have even higher one-way delay of up to 2770ms on average. Contrary to the system, the context is still under research as to which factors should be considered and which their impact is. So far research in video-mediated communication focused mainly on workplace scenarios and high-end systems (especially in its early cases) [4]. This, however, has recently shifted towards the home environment, exploring new scenario and setups for connecting families [1]. One approach is to use scripted conversations, i.e. the participants are told beforehand exactly what to say. Typical tests for scripted conversations are alternated counting, number verification or a script for a service encounter [7]. These tasks reduce variability and influences that might occur in a natural conversation. The revealed lower boundaries are more sensitive, but this might not reflect the actual threshold in a conversation. For unscripted the minimal requirement is to provide a topic for conversation [4], e.g. favorite food. By providing a more specific context, it is likely that the interaction also becomes more similar, ideally with conversational properties under investigation occurring more often. Often goal-oriented tasks are employed, like a decision-making process [7]. An approach to look at the organization of conversations (who speaks when, and how do we manage not to speak all at the same time) is the turn-taking model [10]. It describes how we implicitly arrange our conversations by taking turns of connected utterances. Speech metrics have been used to qualify interactivity of a conversation [5] or the differences of speech synchronization [13].

3. METHODOLOGY

Our study of multi-party video-mediated discussions under delay investigated asymmetric and symmetric delay conditions. We already reported about the asymmetric case which used a slightly different setup (different delay conditions and quiz questions) ths this paper focuses on the symmetric case. The study followed an experimental design with randomized conditions. In our study participated 39 (20 female, 19 males, with an average age of 36 years (min 20 years, max 60 years)). The experiment was conducted in English, in which all participants were fluent. Participants were in groups of 5, except one group with 4

Table 1 Questions and labels

label	**Question**
quality	What is your opinion of the connection you have just been using?'
annoyance	To what extent where you annoyed by delay in the connection?
noticeability	'How noticeable did you perceive the delay in the connection

participants , as one participant did not show up and it was not possible to find a replacement in time. All participants were seated in separate rooms after an introduction round in which we explained our research and the experiment.

The task of our participants was a quiz style question-select answer scenario. The participants had to discuss together the best answer to questions about surviving in the wilderness. The task is based on the team building exercise from [3]. One participant was asked to be the moderator, to submit the final group answers and move the discussion along to keep the 10 minutes time constraint per round. The order of the quiz-questions did not change in the experiment but the order of the delay. Each round of questions was in total 8 times discussed, twice under each condition. After each round we assessed subjective feedback via questionnaires, in this paper we examining our questions related to perceived quality, shown in Table 1. The questions all used a nine-point likert-like scale.

To conduct the experiment and set the desired delay conditions, we used the VMC-TB, presented in [11], the exact technical configuration and test conditions can be found in Table 2.

4. RESULTS

The responses were normally distributed, with respect skewness and kurtosis below 2.

We used a linear model ANOVA to assess whether there was general effect our independent variable delay towards the dependent variables (see Table 1). We performed a pairwise difference test with the pairwise student's t-test to see which tests are significantly different. For the differences between the active and non-active groups (see Section 4.2) the Mann-Whitney U test.

We asked participants to rate the quality of the connection, how annoyed they were by the delay and how much they noticed the delay. The responses to these items are shown in Figure 1. For all items, a lower score means a worse perception, i.e. less quality, more annoyance or the delay was more noticeable.

The analysis revealed that the influence of delay on the quality question was statistically significant ($p < 0.05$). Influence of delay on annoyance was statistically significant ($p < 0.05$). The influence of delay on noticeability was just below the significance confidence of 0.05 ($p = 0.52$). Thus, for the noticeability, we performed a pair-wise comparison of the conditions using a one-

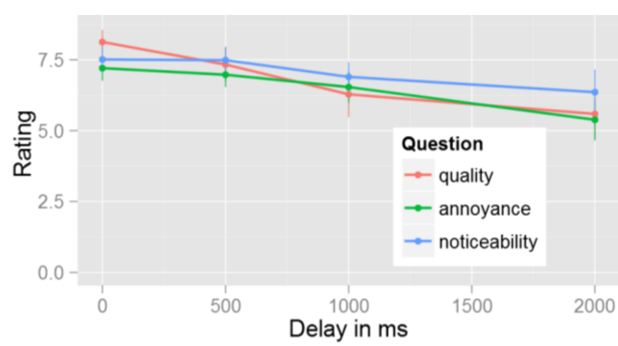

Figure 1 - Average Questionaire Quality Ratings with 95% confidence intervals

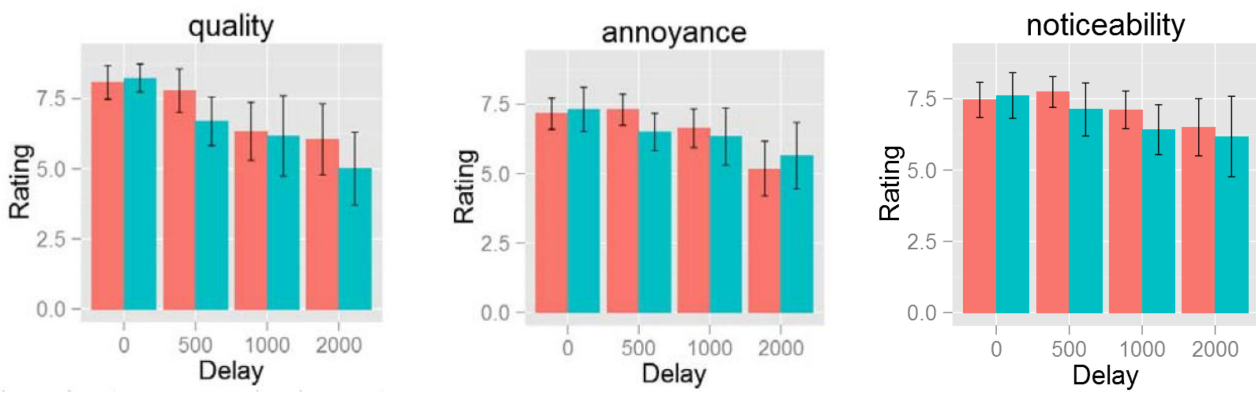

Figure 2 - Average questionaire results clustered by blocks percentage duration of active participants (red), and non-active participants (blue) with 95% confidence intervals.

tailed pair-wise T-Test. This revealed that the noticeability of delay between 0ms and 500ms is nearly identical (p = 0,402), but there is a significant difference between 500ms and 1000ms (p = 0,018) and no statistical differences between 1000ms and 2000ms (p = 0,099). The differences between 0ms->1000ms, 0ms->2000ms and 500ms->2000ms are also statistical significant (p values below 0,05).

4.1 Qualification by Speech Patterns

We further hypothesize that a concrete speech pattern will influence perception. While the approach in previous research was to build an interactivity metric for the whole conversation [5, 13, 15], we use speech patterns to differentiate between our participants. We clustered our participants by speech patterns using k-means into two groups: active and non-active participants.

We divided participants by the amount of speaking time, when compared to the total speaking time of the group. From the automatically generated speech pattern data we computed the percental amount of speaking time each participant had in each round. For the clustering process we offset this value by the standard deviation of all our samples and the deviation of the group of the participant. We then used the k-means algorithm to perform the classification. The elbow-criterion was used to determine that we gain the most explanation of variance with two clusters.

Figure 2 shows the results for the three questionnaire items. We performed a pairwise comparison of the different delay conditions for active and non-active participants. Active participants have a significant drop in the perception between 0ms and 500ms (p = 0,014), but not between the other conditions (p > 0,05). For non-active participants only the difference between 500ms and 1000ms is statistical significant (p = 0,003, for other conditions p > 0,05). The comparison of the differences between active and non-active participants showed that there are indications that the perception of quality is different at 500ms (p = 0,013), but very similar at the other conditions (p > 0,1).

For annoyance, the results follow a similar pattern. Active participants have a significant (p = 0,025) rise in annoyance between 0ms and 500ms while for non-active participants the difference is insignificant. 1000ms is the statistical significant (p = 0,009) difference for non-active participants, being now nearly the same as for active participants. Interestingly the difference between 1000ms and 2000ms is strongly noticeable for non-active participants (p = 0,0003) but not for active participants (p=0,15).

Noticeability is generally less affective by delay. Both groups start with a similar perception at 0ms, going minimal up for non-active participants and slightly for the active one, but for both groups the difference is not significant. Due to the large variance the difference becomes noticeable for active participants between 0ms and 1000ms (p= 0,034) and between 0ms and 2000ms (p= 0,004) for non-active participants. Interestingly the difference for non-active participants happens between 500ms and 1000ms (p= 0,048) but not between 0ms and 1000ms (p = 0,116).

5. DISCUSSION

5.1 Thresholds

Our data from the generalized case (see Figure 1), suggests that noticeable quality degradation sets in between 500ms and 1000ms delay. This is a higher delay than reported in dyadic studies [14, 15] and similar to the study from Berndtsson et al. [2].

Although we observed a clear negative impact of the delay on the assessed quality variables, the variance between the participants was very high. This was also reflected in the discussion afterwards, here an example:

[P3]: "*It wasn't noticeable for me.* "

[P4]: "*I was already on the top of my annoyance level. I AM LIKE, HELLO I AM TALKING HERE, CAN ANYBODY HEAR ME IN THIS PLACE! WHAT IS HAPPENING? And I was sometimes asking, are you hearing me, and everybody was just looking?* "

Contrary to disturbances in audio- and video-streams participants cannot observe a delay directly. It is only indirectly perceivable due to e.g. longer pauses and more double talk. But these are aspects that can also occur in a face-to-face conversation. The interpretation of whether there is a delay problem is thus difficult and different for individual participants. This was also reported by some participants in the debriefing discussion:

[P1]: *The delay wasn't very annoying; I didn't even notice the delay really. I just noticed it because people were saying, there is a delay.*

[P2 asks]*: oh, really?*

[P1]*: yes I didn't notice it. I just thought people were thinking.*

[P2]: *I was very annoyed by it… It was like 4-5 seconds. We were like 5 sentences (ahead) and then you came. "grgh"*

The participants in our experiment were aware that the connection might be delayed. But even though it was known that there might be delay, it was still difficult for some participants to assess whether it was a technical problem.

[P5]: *"People did not seem to hear me, but I wasn't sure whether it was a technical problem"*

For a listener, who was not directly involved this seemed to be easier detectable.

[P6]: "*Sometimes people would interrupt each other and you would notice that it wasn't intentional since they were completely unaware of what the other one said"*

Although the participants gave relatively good ratings, after exploring the recordings, we observed that the delay forces participants to employ additional explicit organization mechanisms. The change of conversation structure and the comments of our participants suggests that with a one-way delay between 1000ms and 2000ms, a conversation without additional explicit organizing mechanisms is no longer possible.

5.2 Comparison between active and non-active participants

The variance we could observe in our responses and the highly different perception reported in the debriefing, suggests that there are other factors at play. The assignment to one participant as the moderator under the assumption this person was likely to take over the leading role. This effect was observed in most of our groups. In some groups, a particularly shy person was chosen by chance as moderator, causing another participant to take over this role. This classification usually results in one or two active participants. In our data analysis we showed that by using the amount of speaking time, we found two groups with distinct perceptions. For the leading roles in the group the noticeable degradations did already occur in between 0ms and 500ms. While for normal participants the difference was still between 500ms and 1000ms.

The results show that to understand the impact of delay the interaction in the context has to be considered in detail. The effects of delay are more present for participants directly involved in the interaction. The more passive listening roles do not occur in dyadic conversations. It also suggests that the timing differences in conversations, like the longer response times, are not perceived so strongly by listening participants.

As we had designed our scenario most of the time the moderator had the active speaking role. In the debriefing participants reflected upon that this was a more difficult role:

[P5]: [topic was higher delay conditions] *for us it was easy, but you* [to moderator] *you needed to keep contro*l.

And it was noticed that if you are not so active due to the video-stream it was still possible to be part of the conversation.

P6: *P7 didn't say much but it was always easy to see if* [he/she] *was agreeing and following along or had a different opinion.*

In a group in which several participants had experience with audio-conferences, they discussed how video helps to make this explicit organization:

[P10]: "*I did audio conferencing … and like the question "are there many silences, people interrupt", well I tell you with audio conferencing, that's all there is! There is a lot of silence, then everybody start talking at the same time, then everybody is silent again, and then two people start talking at the same time, so this is completely different.* "

[P11]: "*I think it also makes a difference, if you know who is going to talk. Because, I tried to say "ok, can you talk, or can you talk" so that we didn't have that.* "

[P12]: "*In audio conferencing, the chair woman, really has to say: "this is the question, now, who wants to talk". Then you really have to point out who is, and you really want to have a reply: "yes, ok, whatever"* "

[P10]: "*If you want to say something, you can raise your hand, on the phone you cannot do that.* "

6. CONCLUSION

We have reported on the first user experience evaluation of a five party scenario with off-the-shelf end-user hardware. We found that the degradation of quality perception was strongly noticeable between 500ms and 1000ms. The results from this study have a similar pattern to another study investigating video-mediated group conversation with different hardware setup [2]. We described how we designed a scenario that allows us to gain insight into role based perception. We provided a novel approach to use turn-taking data to gain insights into the differences in experiencing delay for individual participants in one session. In this setting we were able to classify our participants, based on their actual interaction, into active and non-active participants. The analysis showed that more active participants already perceive the quality degradation between 0ms and 500ms while for non-active participants this drop is between 500ms and 1000ms. We observed as well that communication is possible even with high delays of over 2000ms, but the implicit conversation organization breaks down and is replaced by an explicit one.

The result shows that even though the QoE of active participants suffers under high delay conditions, the overall average QoE might still be satisfactory. These findings give us indications on which participants to prioritize in situations where the resources (bandwidth or computational) are limited in demanding multi-point scenarios.

The breakdown of the implicit conversation structure in many of our groups also suggests that delay levels are more important in informal gatherings than in formal meetings.

7. ACKNOWLDGEMENT

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