Investigating the Usability and Quality of Experience of Mobile Video-Conferencing Apps Among Bandwidth-Constrained Users in South Africa

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Abstract

In response to Covid-19 and global lockdowns, we have seen a surge in video-conferencing tools' usage to enable people to work from home and stay connected to family and friends. Although understanding the performance and the perceived quality of experience for users with bandwidth caps and poor internet connections could guide the design of video-conferencing apps, the usability of video-conferencing applications have been severely overlooked in developing countries like South Africa, where one-third of adults rely on mobile devices to access the internet and where the per-gigabyte data cost is some of the most expensive in Africa. Considering these numbers, we conduct a two-prong study where 1) we measure bandwidth consumption of different Android apps through bandwidth measurement experiments and 2) we conduct interviews with bandwidth-constrained users to better understand their perceptions of mobile video-conferencing apps. The key benefit of this study will be to inform organisations that seek to be inclusive about these tools' relative usability by letting them know about the factors influencing users' quality of experience.

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Acknowledgments

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1 Introduction

In 2019 the global video-conferencing market size was 5.32 billion USD, and it was expected to reach 10.92 billion USD by 2027 [23]. However, in March 2020, video-conferencing applications saw a record 62 million downloads [4, 76]. Most of the growth due to an increase in the adoption of video-conferencing apps due to global lockdowns and mandated work-from-home orders [4, 76]. According to Arthur Goldstruck [54], head of World Wide Worx, the previously forecasted revenue growth of doubling over eight years was overturned entirely by this surge in demand for video-conferencing apps in the first quarter of 2020 due to the Covid-19 pandemic.

Since the start of the pandemic, we have seen video-conferencing applications become indispensable as they are leveraged globally by medical teams [80], used by teachers for online teaching [71], used for remote funerals [31, 60] etc. In line with global trends, the surge in demand for video-conferencing apps was also evident in the South African market [26]. According to the report *'A global view of how consumer behavior is changing amid COVID-19'*, South Africa saw a 20% - 29% increase in the use of video-conferencing for social and professional purposes in 2020 [26].

Despite the advantages of ensuring people stay productive and connected, McGloin [56] states that we need to examine new opportunities and challenges to ensure we apply the best practices to these channels. One of the challenges to ensure a high-quality video-conferencing experience is the need to have a high-speed internet connection to provide reliable and smooth audio and image transmission [78]. However, in developing countries such as South Africa, where the majority of people connect to the internet via their mobile devices [43], guaranteeing reliable end-to-end connections over wireless networks, such as Wi-Fi and cellular networks, is difficult [79, 84]. This is due to interference, congestion [79] and sub-optimal interconnection between ISPs [41].

When it comes to connectivity in South Africa, *'The State of the ICT Sector Report 2021'* indicates that only 9.1% of South Africans have internet access at home whereas 58.7% have internet access via mobile devices [22]. When looking at mobile penetration, South Africa has a 91,2% smartphone penetration rate as of 2019 [5], with Android being the most popular operating system claiming 83.69% market share in the country during January 2021 [19]. According to Research ICT's *Africa's Mobile Pricing (RAMP) Index*, South Africa has some of the most expensive mobile data in Africa, ranking 33rd out of 46 countries per gigabyte data cost [36].

However necessary, the performance of video-conferencing applications is not well understood - especially over poor networks. Existing measurement studies do not focus on mobile applications. Performance studies primarily focus on performance in high bandwidth environments, not on mobile networks and environments where reach and connectivity is poor.

Taking internet penetration and the cost of data into account, the need to have a high-speed internet connection, limits users with bandwidth caps and poor internet connections, preventing them from partaking in the advantages these tools offer.

1.1 Aim of the Study

This paper presents a study of how bandwidth caps and poor internet connections influence usability and quality of experience of mobile video-conferencing applications. Additionally, we also take a look at the data consumption of these tools over mobile networks. We focus on mobile applications and their respective mobile web applications for the usability and quality of experience section of the research. Due to South Africa's high mobile penetration rate and large Android market share, the measurement experiments only focus on the data usage between Android mobile applications. The study measures usage, usability, and perceived quality of experience (QoE) of the most reported popular video-conferencing applications at the start of the pandemic in South Africa [7, 8]. These applications include Zoom, Google Meet, Microsoft Teams and WhatsApp.

1.2 Research Questions

To further explore the research objectives for this study, we formulated the following research questions:

- How do users with bandwidth constraints, and poor internet connections utilise video-conferencing apps, and what are their pain points?
- How do users with bandwidth constraints, and poor internet connections perceive the quality of experience of these tools?
- How does usability differ between the different applications for users with bandwidth constraints and poor internet connections?
- How does bandwidth usage differ between the Android video-conferencing mobile applications?

For our research, we define a bandwidth-constrained user as a consumer limited by their infrastructure and/or finances to partake in the advantages of the internet. These users are restricted to 1) how often they can use the internet, 2) what they can use the internet for, and 3) how they use the internet. When referring to the term poor internet connection, we refer to areas where mobile connection is limited to 3G or connectivity is intermittent. Lastly, when referring to the term bandwidth, we do not refer to the technical definition, but the popular definition of bandwidth and as such the bandwidth usage/consumption of the end user.

1.3 Dissertation Structure

We organised the dissertation as follows:

Chapter 2 covers the background of the study and related research. Chapter 3 gives an overview of the methods used in the research and justification thereof. These include network measurement methodologies and approaches for evaluating usability and quality of experience as perceived by the end-user. Chapter 4 provides an overview of the findings of the bandwidth measurement experiments. Chapter 5 describes the results of the interviews and usability testing. In Chapter 6, we discuss our findings and the implications thereof. Chapter 7 presents the conclusions of the study.

2

Background and Literature Review

During the global pandemic, digital technologies have become critical for connecting people and enabling continuity of regular life. Due to this, computers and smartphones have become a tool for substituting in-person activities. Understanding the bandwidth usage and evaluating the usability of the most popular video-conferencing applications is important as, beyond the pandemic, the new normal will include more extensive use of video-conferencing apps [22]. But how will it impact users with bandwidth constraints? Understanding the usability and bandwidth usage will help inform organisations, institutions, and individuals on what tools they should use to ensure people with poor connections and internet constraints can actively participate. By doing this research, we hope to inform companies building these apps about usability constraints and how limitations faced by bandwidth-constrained users. The literature review done in this chapter focuses on four main aspects: 1) Internet access in South Africa and background on bandwidth-constrained users, 2) Background of video-conferencing applications, 3) Related research on video-conferencing measurements, and 4) Quality of Experience and Usability.

2.1 Bandwidth-constrained users in South Africa

While the adoption of internet-capable mobile devices [17] is fast improving, internet usage in South Africa is limited due to unequal coverage [22], the cost of data [36, 64] and a lack of digital literacy [48, 77]. All these factors present a barrier to participating in the advantages the internet offers, thus introducing a barrier to using video-conferencing applications to stay connected.

The latest *Internet Access in South Africa* report indicates that as of 2017, 82.4% of South Africans earning more than R30 000 per month have access to the internet, while internet penetration is below 30% for those earning between R3 000 and R 6 000 [3]. Phokeer *et al.* [65] conducted a study of mobile data usage in South African townships. Their study found that users in resource-constrained communities usually do not have the choice of connection type to access the Internet. They found that the more privileged users will have access to a Wi-Fi connection (if offered freely to the community). In contrast, others will have to rely on mobile data connectivity, where the cost can be relatively restrictive. Research highlights that despite South Africa's data costs being among the highest globally [36, 64], in 2019, 58.7% of households nationally had access to the internet using mobile devices [5, 22]. In rural areas, 44% of households accessed the internet using a mobile device [22].

Jonathan Donner [39] states in his book *After Access* that 'usage-based pricing' or 'pay-as-you go' creates a 'metered mindset' among bandwidth-constrained users and that these users constantly remain aware of the incremental cost of using their devices. Donner [39] states that users joining the internet via mobile devices are unlikely to 'surf the internet' but that they instead 'dip and sip', saying that their experience is looming, ambiguous and persistent constraint. Chetty *et al.* [34] studied bandwidth caps and the constraints it imposes on users. Their study found that users with metered bandwidth tend to avoid high-bandwidth sites at the beginning of the month to stretch their caps to the end of the month when the meter starts running again. Additionally, they found these constraints create a need for tools that show people how they are using their bandwidth as users are not sure which online behaviours were depleting their data [35]. Their research emphasises the need to understand how much bandwidth different applications use.

When it comes to the national population coverage in South Africa, coverage for 3G increased from 99.7% in 2019 to 99.8% in 2020 [5, 22]. Whereas the national population coverage for 4G/LTE increased from 92.8% in 2019 to 96.4% in 2020 [5, 22]. M-lab's *2020 Worldwide Broadband Speed League* [12] report indicates that the average national broadband speed in South Africa in 2020 was 19.94 Mbps, ranking 87th globally. The report analysed more than 557 million broadband speed tests worldwide. Bench-marking South Africa's internet speed with the internet speed in BRICS countries, they found that South Africa had the lowest speed test ranking for fixed broadband [12, 22]. In a study, *Characterizing technology use in Nairobi, Kenya* [83], Wyche *et al.* found that slow internet speeds impacts users in resource-constrained settings, and that their interactions are more planned, purposeful, and deliberate.

Considering the above research, we can see bandwidth-constrained users are limited by their finances due to the cost of data. We also note that infrastructure, geographical location and the environment surrounding, such as national coverage and slow internet speeds, presents a barrier for users to partake in the advantages of using video-conferencing. Chetty *et al.* [34] and Donner [39] highlight that these users are restricted in how they use the internet and how often they use the internet. This has a knock-on effect on what they can use the internet for.

2.2 Video-conferencing

To ensure a high-quality video-conferencing experience, one needs to have a high-speed internet connection to ensure reliable and smooth audio and image transmission [78]. However, as per section 2.1, we saw that in South Africa, users do not always have access to a reliable end-to-end connection. To understand how these apps perform over mobile networks and how the performance affects bandwidth-constrained users, we will first consider how these platforms function.

Video-conferencing applications operate as cloud services to facilitate the communication of two or more participants by simulating face-to-face communication via audio and video streams [30]. Commercial video-conferencing uses *client-server* architecture where the user starts a *client* when they join a video conference. The *client*, typically a native application or browser-based web application, then sends the user's video and audio input to the video-conference server through a local connection such as Wi-Fi. The server receives a continuous stream from each connected *client* and forwards it to the other *clients* [30]. Video-conferencing apps support numerous use-cases, such as one-on-one calls between friends, professional meetings with multiple participants, and conferences with hundreds of participants [30].

Table 2.1 gives a brief overview of some of the features of the tools analysed in this paper, whereas table 2.2 provides an overview of the minimum bandwidth requirements for using the different video-conferencing applications.

Application	**Maximum Participants**	**Maximum Call Duration (Free Plan)**
Zoom	100	Group calls: 40 minutes One-on-one: 30 hour limit
Microsoft Teams	300	60 minutes
Google Meet	100	Group calls: 60 minutes One-on-one: 24 hours
WhatsApp	8	No information available

Table 2.1: Participant and call duration limits per video-conferencing application [24, 16, 14, 11].

Application	**Peer-to-peer Video Calling**	**Group Video Calling**
Zoom	600 Kbps	800 Kbps/1.0 Mbps
Microsoft Teams	500Kbps	500 Kbps/1 Mbps
Google Meet	1 Mbps (SD)	1.5 Mpbs with 5 people (SD)
WhatsApp	No information available	No information available

Table 2.2: Bandwidth requirements for standard definition video calls (up/down)[9, 10, 15, 11].

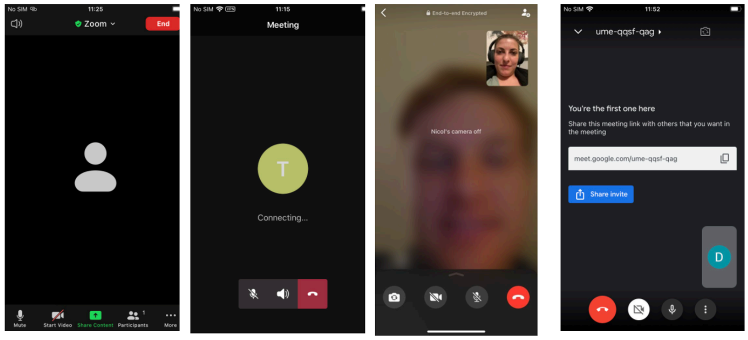

Figure 2.1: Android interface for the different video-conferencing applications. From left to right: Zoom, Microsoft Teams, WhatsApp and Google Meet.

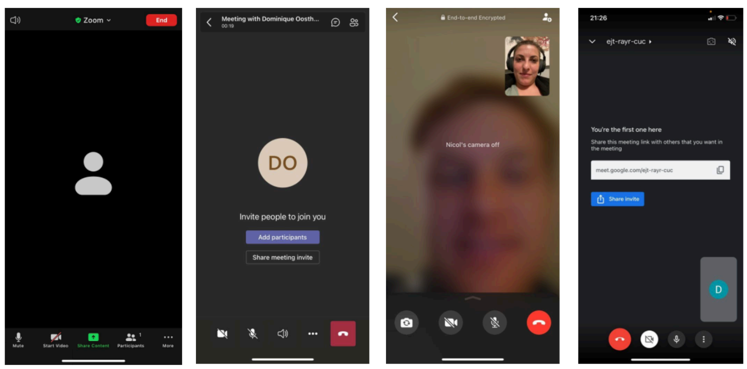

Figure 2.2: iOS interface for the different video-conferencing applications. From left to right: Zoom, Microsoft Teams, WhatsApp and Google Meet.

2.3 Network measurements in Africa and bandwidth usage experiments

When looking at the performance of video-conferencing platforms, it is essential to understand the environment in which they function. To better understand how video-conferencing software performs over mobile networks, we will consider the state of the internet in Africa.

In the past decade, various researchers have conducted studies to understand the state of the internet in Africa. Phokeer *et al.* [65] found that users in townships use cellular data networks relatively more than Wi-Fi networks. This emphasises that users in townships are more dependent on mobile data for connectivity. Additionally, research about the performance of fixed-line and mobile broadband providers in South Africa indicated that mobile broadband consistently outperformed fixed broadband in terms of bandwidth and that a lack of interconnection among ISPs played a significant role in the performance experienced by users [35].

Various companies and organisations have made efforts to improve the browsing experience of users in developing counties. Examples include Google AMP (Accelerated Mobile Pages) and Facebook FreeBasics. Google AMP is an open-source project designed to improve the performance of the mobile web [2]. When Google AMP in Africa with news websites was evaluated, it was found that the performance gain in terms of page load time and page size came with a violation of net neutrality policies as the search engine favoured content that used Google AMP [64]. Facebook's FreeBasics Program is another initiative where, in collaboration with mobile operators. Sen *et al.* [72] analysed the FreeBasics architecture and exposed its poor performance in comparison to its paid counterparts. When compared, Sen *et al.* found that the root cause for this performance loss was due to factors like network path inflation and throttling policies in forced by Facebook and telecom service providers.

When looking at previous literature about the performance of video-conferencing apps, assessments of the performance of video-conferencing systems have been conducted as these technologies evolved. A measurement study of mobile video calls focusing on Skype, Google + and FaceTime over Wi-Fi and cellular networks found that mobile video call quality is highly vulnerable to packet loss and packet delays [84]. Concluding that with strong Wi-Fi/cellular connections, modern smartphones are capable of encoding, transmitting and decoding high-quality video in real-time. Limitations of their research include that it only focused on two-party video calls using older technologies.

Another study, evaluating of the performance of Zoom, Microsoft Teams and Jitsi on computer-based video-conferencing systems found that there are significant differences in the resource usage of the different video-conferencing systems [30]. Results indicated that, on average, Zoom had the highest resource usage and performance variability compared to Teams and Jitsi. Additionally, they found that Zoom's average bandwidth usage ranges from 306 Kbps for six clients to 332Kbps [30]. In comparison, Jitsi uses on average 216 Kbps for two clients, whereas Team's average bandwidth usage does not exceed 26 Kbps in all cases [30]. Their study, however, was conducted over high bandwidth networks, and it primarily focused on computer-based applications.

Unlike Yut *et al.* and Bieringa's studies, our study focuses on mobile applications built with newer technologies. We also measure their reliability and utility in a developing country where internet connections are volatile and interconnection among ISPs is lacking.

Considering the above, it is worth exploring the performance of video-conferencing apps over mobile networks and understanding how bandwidth constraints influence the quality of experience and usability of these tools.

2.4 Quality of Experience and Usability of video-conferencing Applications

Previous literature defines the field of Human-Computer Interaction (HCI) as a field "concerned with the design, evaluation, and implementation of interactive computing systems for human use and the study of major phenomena surrounding them" [61]. The role of understanding users' subjective experiences with new technology has become a core focus for HCI, yet, despite this, human-centric computing approaches have not been introduced to interactive multimedia environments until recently [82]. To understand user experience and satisfaction of video-conferencing applications, it is essential to understand the relation between usability and Quality of Experience (QoE) from a networking perspective. *ISO 9241-11* [46] defines usability as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use". In contrast, QoE measures the subjective perception of the quality of an application, and the degree of delight or annoyance with a service [45, 58, 70]. Previous literature notes that usability and QoE each have their own unique set of evaluation methods, which, when evaluating applications, should be considered.

2.4.1 Measuring Quality of Experience (QoE)

Historically, researchers have measured QoE through objective or subjective assessments [68, 86]. The objective technology-centric approach of using the technical network performance metrics (Quality of Service) has been the standard for demonstrating the usefulness of video-conferencing applications by relating QoE to system factors [73, 82, 68]. Examples of these metrics/system factors include the bitrate, delay, network loss rate, traffic jitter, link delay, conversational condition, and loss concealment mechanisms [27, 70]. Empirical findings from previous research highlight the limitation of objective QoE assessments, indicating that systems excelling in QoS can fail user adoption and have a poor QoE. They stress that it is due to the gap between human-centric and system evaluation and a lack of insight into the totality of dimensions of a user's experience [55, 82, 86].

On the other hand, subjective QoE assessment requires users to self-report their perceived satisfaction [86]. Even though a subjective user-centric approach provides a more holistic understanding of the factors influencing the QoE than QoS measurements, few studies have explored the quality factors influencing user experience and satisfaction through a user-centred approach

[73]. Researchers have made an effort to map user behaviour relative to technical network characteristics and QoS, but previous research on QoE and QoS is isolated and fragmented [73]. Shin [73] state that it is imperative to develop reliable and usable methods of determining accurate experience/satisfaction measures of information communication technologies. *Zhu et al.* [86] argue that QoS and QoE need to integrate through developing user-focused measurements.

According to Martinez and Segall [55], HCI offers tools "to complete the development of a structured QoE system of assessment and implementation where users are involved". Martinez and Segall [55] state that the challenge for HCI research in this field would be to understand the external factors that can influence a user's experience and identify the reasons behind a good and bad experience.

For this study, it is essential to understand user preferences and satisfaction by considering its technical limitations. Therefore this study adopts the subjective QoE assessment approach. In subjective assessments where users self-report their satisfaction, QoE is often expressed on a five-point scale to obtain the Mean Opinion Score (MOS), a numerical indicator of the perceived quality [47, 75, 86]. The value of the worst quality is 1, and the best quality is 5, as shown in table 2.3. The minimum threshold for acceptable quality is equal to a MOS rating of 3.5 [47].

Quality	MOS Score
Excellent	5
Good	4
Fair	3
Poor	2
Bad	1

Table 2.3: QoE five-point MOS quality scale.

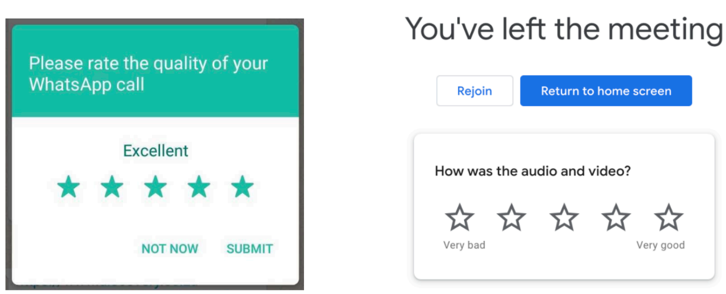

Figure 2.3: Example of MOS after a video call. On the left is the rating scale for WhatsApp, and on the right the rating scale for Google Meet

As MOS is the "de-facto" metric used to quantify perceived quality, it is vital to understand the limitations of using MOS. According to Hoßfeld *et al.*, [45], summarising the results of subjective assessments as MOS values hide information related to user variation, and simply using the standard deviation to assess the variation does not give a clear indication of what is going on.

2.4.2 Measuring Perceived Usability

The *International Organisation of Standardisation (ISO)* [46] defines usability as the "extent to which a system, product or service can be used by specified users to achieve specific goals with effectiveness, efficiency and satisfaction in a specified context of use". Whereas the *Institute of Electrical and Electronics Engineers (IEEE)* [1] defines usability as "the ease with which a user can learn to operate, prepare inputs for, and interpret outputs of a system or component". Usability testing is the "process of learning from users about a product's usability by observing them using the product" [29]. A common approach to usability assessment is to test an app with a sample of users performing a set of pre-determined tasks [38]. This method yields the most reliable and valid estimate of an application's usability [38].

Several studies have been conducted around the perceived usability of video-conferencing apps. These studies, however, focus primarily on usability within specific environments and do not take into account varying perspectives around how these tools are utilised, specifically in bandwidth-constrained settings. Pal and Vajirasak Vanijja [62] conducted a study where they looked at the perceived usability of Microsoft Teams as an online learning platform during COVID-19 in India. Their study used the System Usability Scale (SUS) and Technology Acceptance Model (TAM) to determine the perceived usability of the video-conferencing application [62]. Within the educational landscape, they concluded that Microsoft Teams has a usability score of 77.2 and that usability does not vary depending on the consumption platform [62].

The SUS is based on a simple, ten-item questionnaire and is one of the most popular methods for assessing perceived usability by HCI researchers [52, 50]. As seen in table 2.5, half of the questions in the questionnaire have a positive tone (the odd number items), and the other half has a negative tone (the even number items). For each of the questions, users rate each question from 1 (strongly disagree) to 5 (strongly agree) based on how much they agree with the statement [52]. The first step in determining the SUS score is to determine each item's score contribution. For the odd number questions, the score contribution is the scale position minus 1. For even number questions, the score contribution is five minus the scale position. To obtain the overall SUS score, one must multiply the sum of the item score by 2.5 [52, 50]. The SUS score ranges from 0 very poor perceived usability to 100 excellent perceived usability [52]. Table 2.4 gives an overview of the complete curved grading scale, showing the range of SUS scores for each grade and the corresponding percentile range.

Grade	**SUS**	**Percentile Range**
A+	84.1 - 100	96 - 100
A	80.8 - 84	90 - 95
A-	78.9 - 80.7	85 - 89
B+	77.2 - 78.8	80 -84
B	74.1 - 77.1	70 - 79
B-	72.6 - 74.0	65 - 69
C+	71.1 - 72.5	60 - 64
C	65.0 - 71.0	41 - 59
C-	62.7 - 64.9	35 - 40
D	51.7 - 62.6	15 - 34
F	0 - 51.6	0.14

Table 2.4: Curved grading scale for the System Usability Scale (SUS) [52].

Existing research shows that SUS can easily be adapted for different contexts and has a high degree of reliability [52, 63]. However, according to Brooke, it is impossible to specify the usability of a system without outlining who the intended users are and defining the environmental characteristics in which the system will be used [32]. In the study *"The System Usability Scale and*

Non-Native English Speakers" Finstad [40] found that non-native English speakers had trouble understanding the word "cumbersome", which might have implications for the reliability of SUS. The study concluded that replacing the word with "awkward" generally clarified the statement for participants [40, 52]. Bangor *et al.* [28] have confirmed that the word "cumbersome" can be replaced by "awkward," and that rather than using the term "system", using other terms such as "product," "application," or "website" does not change the results.

Number	**Question**
1	I think that I would like to use this system frequently.
2	I found the system unnecessarily complex.
3	I thought the system was easy to use.
4	I think that I would need the support of a technical person to be able to use this system.
5	I found the various functions in this system were well integrated.
6	I thought there was too much inconsistency in this system.
7	I would imagine that most people would learn to use this system very quickly.
8	I found the system very cumbersome to use.
9	I felt very confident using the system.
10	I needed to learn a lot of things before I could get going with this system.

Table 2.5: Original System Usability Scale (SUS) questionnaire.

3

Research Methodology

3.1 Overview

In this study, we explore how poor mobile internet connections and bandwidth caps affect QoE and usability of the most frequently used conferencing tools namely Zoom, Microsoft Teams, Google Meet and WhatsApp. Additionally, we unpack how bandwidth usage differs between the Android mobile apps of these service. To explore the research objectives, we formulated the following research questions.

- How do users with bandwidth constraints, and poor internet connections utilise video-conferencing apps, and what are their pain points?
- How do users with bandwidth constraints, and poor internet connections perceive the quality of experience of these tools?
- How does usability differ between the different applications for users with bandwidth constraints and poor internet connections?
- How does bandwidth usage differ between the Android video-conferencing mobile applications?

We employed a mixed methodology to conduct a two-prong study to answer these questions. Our two-prong study consisted of 1) a set of experiments to measure data usage of different apps and 2) interviews and usability testing with bandwidth-constrained users to better understand their perceptions of video-conferencing applications. A mixed-methods approach focuses on combining or using various combinations of qualitative and quantitative methods in the same project [59]. The purpose of using mixed methods is to validate our findings and to create a clearer picture of how bandwidth-constrained users are affected. The quantitative data provide descriptive statistics around data usage. However, the qualitative data obtained from the interviews and usability testing allows us to gain deeper insight into the quantitative data and helps us understand what the impact of the bandwidth usage of these apps are.

3.2 Applications analysed in the study

When we determined which applications we should analyse in our study, we noted that data analytics firm, SensorTower, reported that Zoom, Microsoft Teams, Google Meet, and WhatsApp were some of the top downloaded apps globally in April 2020 [6]. During March/April 2020, when South Africa went into its first lockdown, SensorTower reported that Zoom, Teams, and Google Meet were the most downloaded video-conferencing apps in the business category. Whereas WhatsApp was the most downloaded communication application in the South African Play Store [7, 8]. Gauging the validity of SensorTower's data, we found that various studies utilise SensorTower's data and insights when citing app engagement and performance. [81, 66, 49].

3.3 Part1: Bandwidth Usage Measurements

3.3.1 Bandwidth Usage Measurement Tools

For the bandwidth usage section of the research, we conducted multiple data measurement experiments. The purpose of the bandwidth measurements was not to compare bandwidth usage over multiple devices and networks but rather to compare the apps' bandwidth usage when we have a fixed device and network configuration.

For the measurement experiments, we used PCAPdroid, an Android open-source network monitoring and capture tool that enables users to capture phone traffic without having to root the devices [21]. Before deciding to use PCAPdroid, we experimented with different applications like GlassWire [13], MobiPerf [18] and Packet Capture [20]. GlassWire and MobiPerf could only capture data in intervals of 3 hours, while Packet Capture uses a local VPN server which does not allow Zoom calls to work when connected to the VPN. PCAPdroid gave us accurate data usage estimates, which WhatsApp's data usage statistics confirmed. An example of the test is shown in (Fig. 3.1 and Fig. 3.2).

Platform	Packet capture	Call start time	Call end time	Minutes	MB
Google Meet Assistant A	PCAPdroid	16:31:00	16:43:00	0:12:00	89.1
Google Meet Assistant B					87
WhatsApp Assistant A	PCAPdroid	16:46:08	16:58:00	0:11:52	15.1
WhatsApp Assistant B					15.1
MS Teams Assistant A	PCAPdroid	16:17:00	16:29:00	0:12:00	113.9
MS Teams Assistant B					115.4
Zoom Assistant A	PCAPdroid	16:02:00	16:14:00	0:12:00	172.3
Zoom Assistant B					166

Figure 3.1: Tests we conducted prior to the experiments to see what platform provides the most accurate results. WhatsApp's consumption matches the call log consumption as per figure 3.2.

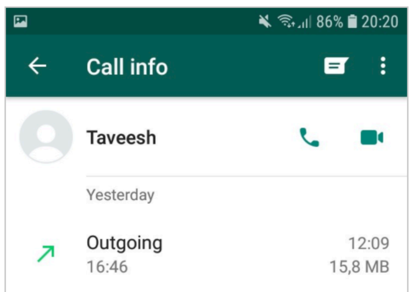

Figure 3.2: WhatsApp call log for tests we conducted prior to the experiments.

3.3.2 Call configuration

To measure the bandwidth usage of the different apps, we conducted one-on-one and group calls across different call configurations. Table 3.1 gives an overview of the various call configurations per application analysed in this study. The purpose of obtaining data usage of the different apps was to create a comparison framework on the data usage of the various applications.

Call Configuration	**Zoom**	**Teams**	**Meet**	**WhatsApp**
One-on-one audio-visual call over Mobile Data	x	x	x	x
One-on-one audio call over Mobile Data	x	x	x	x
One-on-one audio-visual call over Mobile Data where one participant switches off incoming video	-	x	-	-
One-on-one audio visual call over Mobile Data with data saving mode on	-	-	-	x
Group call over Mobile Data	x	x	x	x
One-on-one audio-visual call over Wi-Fi	x	x	x	x

Table 3.1: Different configurations used for our calls. An 'x' against an app indicates the particular configuration is available in the app.

3.3.3 Measurement Experiments Setup

As the experiments did not require actual participants, we recruited research assistants to assist with this section of the study. Myself (Assistant A) and a research assistant from the University of Cape Town's Networking Lab (Assistant B) conducted the experiments for the one-on-one calls. We recruited additional students from the Human-Computer Interaction (HCI) lab, family, and friends for the group calls. As per Carofiglio *et al.*'s [33] research on characterising the relationship between applicaton QoE and network QoS we kept the group size for the group calls consistent at 6 participants. For the group calls, we only analysed the data usage of Assistant A and Assistant B and not of all the participants in the call. Table 3.2 gives an overview of the network information and average upload and download internet speed of Assistant A and Assistant B. Table 3.3 provides a breakdown of the devices used during the video calls.

Assistant	Connection Type	Network Info	Avg. Upload Speed (Std. dev)	Avg. Download Speed (Std. dev)
Assistant A	Mobile data	MTN 4G	14.34 Mbps (5.24 Mbps)	16.88 Mbps (8.17 Mbps)
Assistant A	Wi-Fi	Faircape Fibre	14.96 Mbps (1.73 Mbps)	17.38 Mbps (1.76 Mbps)
Assistant B	Mobile data	Cell C 4G	1.019 Mbps (0.76 Mbps)	6.16 Mbps (4.42 Mbps)
Assistant B	Wi-Fi	MWeb Fibre	4.27 Mbps (3.07 Mbps)	15.50 Mbps (6.73 Mpbs)

Table 3.2: The network information for Assistant A and Assistant B. The table includes an overview of the average upload and download speed per user per connection type as well as the standard deviation of the upload and download speed.

Assistant	Device Info	Year	Processor	OS
Assistant A	Samsung J5	2016	1.4GHz quad-core	Android 6.0
Assistant B	OnePlus 6T	2018	Qualcomm Snapdragon 845	Android 9.0

Table 3.3: Device specifications for research Assistant A and research Assistant B.

For the experiments, we asked the research assistants to connect to the call using mobile data (unless specified otherwise in the configuration setup) and their own personal Android mobile device. Using their own personal devices ensured sufficient diversity for the purpose of our research, as it simulated more real-life scenario. We decided to use older and relatively cheaper devices to simulate the experience of bandwidth-constrained users. Although we could not control upload and download speeds and network coverage, keeping the device and network consistent enabled us to control some of the variables which could impact performance and data usage. We are, however, aware that network type, network coverage, network performance, and device performance could influence the results. Therefore, it is important to note that this study is not a networking performance study, and more extensive research should be conducted to measure the bandwidth usage of these apps over different networks and device types.

3.3.4 Experiment Structure

Before the commencement of the experiments, the research assistants had to download PCAPdroid, Zoom, Microsoft Teams, Google Meet and WhatsApp on their mobile phones.

For each of the experiments, each participant had to perform the following steps to join the call and capture bandwidth usage:

- Measure their internet upload and download speed using Speedtest.net
- Open PCAPdroid
- Select the target application (Example: WhatsApp)
- Click the play button to start the packet capture
- Join the video call with a selected configuration (Example: Audio-only)
- Stop PCAPdroid's capture and save the CSV file containing the captured packets in a shared drive once the call ends

Qi *et al.* [67] reported in 2015 that the average video chat duration is 6 minutes. Video chat, however, intensified due to Covid-19 restrictions and as people replaced some of the in-person aspects of their life with video-conferencing. Looking at Zhang *et al.* [85] and Gao *et al.* [42]'s QoS measurement studies, we found that they set experiment duration to 15 minutes. We used the insights obtained from their research to inform our methodology to set the video call duration to 15 minutes for each experiment call conducted.

Apart from call duration, it is also important to note that we performed all the calls under varying real-time mobile networks. We chose to perform these experiments in a real-time environment to observe and validate the performance within real-life conditions; thus, external traffic could impact results. Due to internet speed variations and bandwidth usage varying over a period, we replicated the experiments to estimate the variability of the results and to increase the accuracy of the bandwidth usage estimates. We repeated each one-on-one call configuration three times per app. We conducted each repetition during the same time over three days (example: Zoom audio-video 9:00 Monday, Tuesday, Wednesday) from a fixed location. Assistant A was based in Sea Point, Cape Town, whereas Assistant B was based in Parklands, Cape Town. Due to time constraints, we repeated group calls two times in one afternoon.

3.3.5 Data Analysis

After each video call the PCAPdroid files were saved. We agreed to a common naming convention for saving the CSV files. Each CSV file adhered to the following format:

<App_name>_<Call_configuration>_<Name_of_the_participant>_<Date>.csv

Once the assistants completed all the calls, the data files were combined into a single file using Pandas, a Python data analysis library [*]. The combined data set consisted of the columns shown

[*]https://pandas.pydata.org/

in table 3.4.

Column	Description
App Name	Video calling apps under consideration
Configuration	One of the different configurations listed in Table 3.1
Participant	Chosen to be the same 2 users for both one-on-one and group calls
Source IP address	The source IP address of packets in a single session
Destination IP address	The destination IP address of packets in a single session
Sent MB	Data sent within a single session
Received MB	Data received within a single session
Packets Sent	Number of packets sent within the session
Packets Received	Number of packets received within the session
First Seen	Start time of the session
Last Seen	End time of the session
Iteration number	A maximum of 3 for one-on-one calls and 2 for group calls

Table 3.4: A table showing different columns of our data-set and their meanings.

After combining the data, we calculated the total data usage by adding the sent and received bytes across all configurations. The aggregated data set was then used to identify data usage patterns and perform further statistical analysis. We performed the following statistical tests:

- Correlation coefficient between internet upload speed and data sent
- Correlation coefficient between internet download speed and data received

We calculated the correlation coefficient of the internet upload and data sent to determine how much the internet upload speed impacts data sent. The same goes for calculating the correlation coefficient between internet download speed and data received.

3.3.6 Limitations

As we conducted these experiments in real-time over mobile networks, measurement data might vary. We had limited control over upload and download speed and the variation thereof over the network. We found variance in of our measurements data. We acknowledge that doing a network measurement focused study with more repetitions of the video calls is an area for future research. This section of the study aims to give us an overview of the data usage of these tools to get a holistic understanding of how data usage could influence the usage and usability of the different apps.

3.4 Part 2: Interviews to understand usage, usability and QoE

The below section gives an overview of the methods used for the interview section of the study [†].

3.4.1 Participant Recruitment

To determine the number of participants for the interviews and usability study, we took an adaptive approach as proposed by Sim *et al.* [74]. They state that defining sample size a priori is problematic when doing exploratory research as by definition, exploratory research looks to explore phenomena in relation to themes that can not be identified in advance [74]. An adaptive

[†] All research was conducted during the Covid-19 lockdowns in South Africa. We had to social distance; thus, we conducted all of our research remotely.

approach enabled us to iteratively decide how many participants we should interview as we developed a picture of the themes and the relationship between the themes during the data analysis.

Using the adaptive approach, we recruited ten participants with bandwidth caps and/or a poor internet connection. As this study aims to report on the phenomenon around video-conferencing and how it impacts bandwidth-constrained users, we recruited participants until we felt that saturation around themes was reached. We believe that a larger sample set would not change our underlying findings.

We did convenience sampling to recruit participants by reaching out to organisations that utilise video conferencing tools and asking them to refer participants for the study. We removed participants' identities and assigned an abbreviation for each participant to ensure anonymity. The local university research ethics committee reviewed the protocol. We gave each participant 1GB of mobile data from their service provider to compensate them for the data used during the video-call interviews. Table 3.5 gives an overview of the participant demographics.

Participant	**Age**	**Gender**	**Native Language**	**APP 1 (familiarity)**	**APP 2 (familiarity)**
TS	22	M	Zulu	Google Meet (4)	Zoom (3)
PR	21	M	Zulu	Zoom (4)	Google Meet (5)
LC	34	F	Shona	WhatsApp (5)	Google Meet (1)
ST	39	F	Afrikaans	MS Teams (3)	Zoom (5)
BP	35	M	Zulu	WhatsApp (5)	MS Teams (1)
JJ	31	M	Kirundi	WhatsApp (5)	Google Meet (1)
KS	20	F	Sepedi	MS Teams (3)	WhatsApp (5)
BO	42	M	Ga	WhatsApp (3)	Zoom (1)
MC	37	F	Chichewa	Google Meet (1)	MS Teams (1)
TM	37	F	Xhosa	Zoom (1)	Zoom (1)

Table 3.5: Participant demographics for the usability testing and interviews. The table also indicates which application they assessed and their self-assessed familiarity with the application. Familiarity of 1 = not familiar at all and 5 = very familiar.

Although none of the participants listed English as their native language, they were all comfortable conversing in English.

3.4.2 Interview Structure

To better understand usability and quality of experience, we conducted semi-structured remote interviews and usability testing with the recruited participants. Semi-structured interviews are semi-standardised using an interview questionnaire consisting of predetermined or scheduled primary questions, followed by sub-questions or "probes" [57].

Each participant was assigned two apps from the apps we are analysing in this study to test. The researchers randomly selected which applications each user would test to evaluate each application five times. Before the interview, participants were sent the informed consent form (See Appendix A) over WhatsApp. They had to either sign it and send it back or send a voice note giving verbal consent to participate in the study. As we conducted this study remotely, the interview questionnaire consisted of eight parts done in a single session of two video calls. Each section had predetermined open-ended questions, which enabled us to diverge slightly from the script to probe deeper when needed. Each participant had to join the interview remotely by downloading the specified apps and then joining the video call using meeting links provided. Participants used their mobile devices and mobile data to connect to a video call using applications 1 (APP 1) and 2 (APP 2). Due to time constraints and the technicality of measuring data usage, we did not measure the bandwidth usage of each of the interview video calls. The below gives an overview of how the interview structure worked. First, participants used their mobile devices and mobile data to join a call using APP 1.

On APP 1, we then conducted the following:

- Introductory interview questions
- Usability testing of APP 1
- QoE assessment of APP 1
- SUS assessment of APP 1

Users then used their mobile devices and mobile data to connect to a call using APP 2. On APP 2, we then did the following:

- Usability testing of APP 2
- QoE assessment of APP 2
- SUS assessment of APP 2
- Closing questions

We conducted all of the interviews and the assessments in English. The interviewer made notes during the semi-structured interview by adding data to the LimeSurvey questionnaire (See Appendix B for the full interview script). The interviews were also screen recorded using Screencastify. The data collected was then transcribed for data analysis purposes. The below section gives an overview of the methodology for each part of the semi-structured interview process.

3.4.2.1 Introductory Interview Questions

When participants joined the first video call, we introduced the study and explained how the session would work. Once we completed the introduction, we asked participants introductory questions to better understand their access to the internet, their constraints, how often they use video-conferencing apps, and their preferred applications. Questions included:

- Please tell me about how you access the internet? Do you have any limitations or bandwidth caps?
- Do you have a capped or uncapped connection? What is the speed of your connection? What is the cap?
- Do you ever hesitate to join a call or turn on video due to constraints or to save data?
- What video-conferencing application do you prefer to use? Why?
- Thinking back to your online video calls, what are the most common technical issues you face?
- What video-conferencing application do you use the most? Why?

See Appendix B for the complete list of questions.

3.4.2.2 Usability: Task evaluation and SUS

In the second part of each call, we conducted usability testing. One of the benefits of task evaluation is not just finding out whether usability requirements have been met but also why those requirements have or have not been met. With SUS, despite being one of the most popular methods for assessing perceived usability, Lewis *et al.* [51] and Peres *et al.* [63] highlight that SUS is a non-dimensional measure, and one can only report whether the system was easy to use. SUS does not indicate usability issues users had and what influenced their perceived usability. To get a more holistic understanding of usability constraints, our methods include task evaluation to understand if usability requirements have been met.

For the task evaluation section of the interview, we first asked participants to rate how familiar they are with the application they are currently testing (table 3.5. A rating of 1 on the 5-point rating scale indicated not being familiar, whereas 5 indicated that the user was very familiar with the app. Each participant was then required to perform a series of tasks that led them through the app's main functionalities. These tasks included:

- Switching video on/off
- Switching the microphone on/off
- Switching incoming video off (Microsoft Teams only)
- Sending an in-call message
- Screen sharing (where applicable)

We asked participants to use the "think-aloud" method throughout the testing. They had to explain their thoughts and the step-by-step process of completing the task using sentences like "I am looking at my screen", "I am seeing this", "I am pressing" etc. We observed the process closely and subsequently asked the participant to rate how difficult or easy it was to complete the task where 1 = very difficult and 5 = very easy.

Assessing the limitations of SUS (2.4.2), previous research indicates that non-native English speakers have trouble understanding the word "cumbersome" and "system", which might have implications for the reliability of SUS. As none of the participants in our study was native English speaking, we adjusted the SUS questions replacing "cumbersome" with "awkward" and "system" with “application” [40, 52, 28]. Table 3.6 gives an overview of the SUS questions asked in our interviews.

Number	Question
1	I think that I would like to use this application frequently.
2	I found the application unnecessarily complex.
3	I thought the application was easy to use.
4	I think that I would need the support of a technical person to be able to use this application.
5	I found the various functions in this application were well integrated.
6	I thought there was too much inconsistency in this application.
7	I would imagine that most people would learn to use this application very quickly.
8	I found the application very awkward to use.
9	I felt very confident using the application.
10	I needed to learn a lot of things before I could get going with this application.

Table 3.6: System Usability Scale (SUS) questionnaire with the adjusted questions. Users had to rate each question on a 5-point scale (1 = strongly disagree, 5 = strongly agree).

3.4.2.3 Quality of Experience

To determine the subjective QoE for each application, we asked participants to give a MOS of the overall experience of the call. We obtained the MOS score at the end of the task evaluation of each application. The rating scale was based on 1 = bad and 5 = excellent. Due to the limitations of MOS identified in our literature review (sec 2.4.1), this study adopts dual methods for measuring QoE, utilising MOS during subjective assessments and combining the MOS rating with a descriptive quality assessment. During the descriptive quality evaluation, we asked participants to expand on the cognitive constructs of which QoE consists of according to Wu *et al.* [82] namely; perceived ease of use, concentration, telepresence, perceived usefulness and enjoyment. The aim of combining these two approaches was to identify the underlying individual quality factors influencing MOS.

3.4.3 Data Analysis

Qualitative data collected during the interview section of the research builds on the participant's attitude, opinions, and comments. We transcribed the interview recordings and then imported the transcriptions into NVivo, a Qualitative Data Analysis (QDA) computer software package [‡]. Using Nvivo, we analysed the data for codes and themes using the thematic data analysis method. Thematic data analysis is a method for identifying, analysing, and interpreting patterns/themes within qualitative data [25]. We repeated the coding process until we could not identify new patterns and themes. Once we completed the coding process, we interpreted the coded data to find patterns and trends. Data obtained from the SUS questionnaires were extracted from the transcripts and stored in Google Sheets. We then calculated the SUS score per participant per platform.For the odd number questions, we took the user rating and subtracted 1. For even number questions, we took 5 minus the user rating To obtain the overall SUS score, one must

[‡]https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home

multiply the sum of the item score by 2.5

We calculated the final SUS score as per the formula presented in other our literature view (sec 2.4.2.

3.5 Limitations

Even though the participants involved in interviews were all bandwidth-constrained, this study does not represent a representative sample for understanding usability and QoE. We also note that the limitations faced by these users might not be unique to bandwidth constrained users; however, working with them we are able to surface issues faced by users and future research should be conducted to determine if being bandwidth constrained impacts your behaviour. This study does not provide data and insights for statistical significance. Instead, it presents information on the varying perspectives around usability and the QoE by bandwidth-constrained users. Although we recognise the benefits of increased sample size, recruiting bandwidth-constrained users during a pandemic was challenging. We also note that conducting usability testing in person would have been better, but due to Covid-19 lockdowns and social distancing rules, we had to perform these tests remotely, which meant we had to experience the limitations and frustrations with these users. We acknowledge that it would have been useful to analyse the relationship between bandwidth (internet speed) and the participant's reported QoE. However, at the time of the study it would have been complicated to explain to participants how to capture their internet speed as this study was conducted remotely, during the Covid-19 pandemic. Additionally, it would have prolonged an already lengthy interview and usability testing session. This could be an area of future research.

4

Findings: Bandwidth Usage Measurements

This chapter gives an overview of our findings from our bandwidth measurement experiments. The aim of this chapter is to address research question 4; how does bandwidth usage differ between the Android video-conferencing mobile applications? We unpack the impact of internet speed on our experiments, summarise the consumption for the different call configurations and then present the findings per configuration.

We organised this chapter as follows:

4.1 Impact of internet speed

4.2 Bandwidth usage measurement findings

4.2.1 Audio-video calls over mobile data

4.2.2 Audio-video calls over Wi-Fi

4.2.3 Audio-only calls over mobile data

4.2.4 Group calls over mobile data

4.1 Impact of internet speed

As we conducted the bandwidth measurement experiments over real-time networks, we wanted to understand what the impact of internet speed was on the experiments. As per table 3.2 we saw that Assistant A had a superior internet speed for both their mobile connection and over Wi-Fi.

When measuring the average upload speed over mobile data for all the different calls, Assistant A had an average upload speed of 14.34 Mbps (Std. dev 5.24 Mbps) and an average download speed of 16.88 Mbps (Std. dev 8.17 Mbps). For Assistant A's connection, we saw that the data for upload speeds were closer dispersed than the data for download speed. In comparison, when measuring the upload speeds over mobile data for all the different call configurations, Assistant B had an average upload speed of 1.019 Mbps (Std. dev 0.76 Mbps) and an average download speed of 6.16 Mbps (Std. dev 4.42 Mpbs). Herewith we can conclude 1) that Assistant A's average upload and download speed was superior to that of Assistant B, 2) Assistant A's of connection was less volatile and more consistent than the connection of Assistant B.

To determine whether there is a correlation between internet speed and data usage, we calculated the correlation coefficient between internet upload speed and data sent ($r(116) = 0.13, p = 0.15$) and between internet download speed and data received ($r(116) = 0.15, p = 0.10$). Although both these correlation coefficients are positive, they indicate a weak positive correlation; thus, in both instances, while both variables tend to go up in response to one another, the relationship is not very strong.

We observed a strong positive correlation between the megabytes sent by one assistant and the megabytes received by another assistant during one-on-one video calls. The coefficients were as high as 0.965 ($r(49) = 0.93, p = 0.00$) for $assistant\ A \rightarrow assistant\ B$ and 0.993 ($r(49) = 0.99, p = 0.00$) for $assistant\ B \rightarrow assistant\ A$. A marginally higher value for $assistant\ B \rightarrow assistant\ A$ can be attributed to A's superior connection speed.

As we were conducting these tests in real-time over an open network, we note that although we saw positive correlations, we are not stating that there is definite causation as network congestion could have impacted the internet speed.

4.2 Bandwidth usage measurement findings

This sub-section showcases the bandwidth consumed (in MB) for Assistant A and Assistant B per call as well as the average total data usage (in MB) per app and configuration. Although the experiments were repeated at the same time every day with the same device over the same network, we know that data usage will differ over time and that other user traffic will impact the results. In this section, we represent the data in graphs and table form. For the graphs, we connect the three different calls with a line to better distinguish between the calls, but it is important to note that the data points are plotted in terms of data consumption. The data points are not plotted in order of call 1, call 2 and call 3. Also note, for the tables, we distinguish between the different calls using Assistant Number (A or B) + Call Number (call 1, 2 or 3). Example A + 1 = *Assistant A* call 1.

4.2.1 Audio-video calls over mobile data

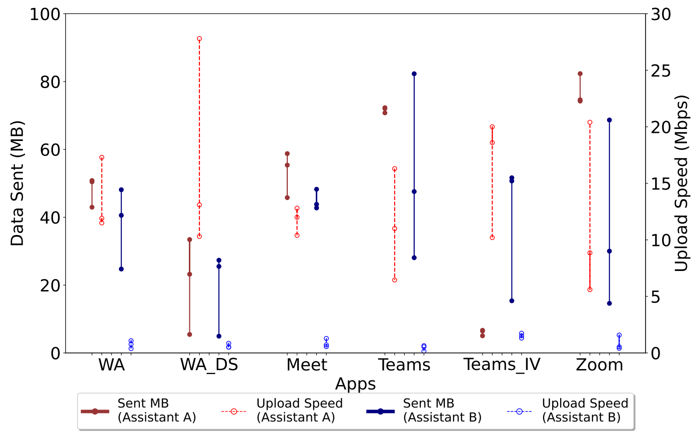

Figure 4.1: All platforms, audio-video over mobile data, data sent: The MB sent (uploaded) for calls 1, 2 and 3 for audio-video calls over mobile data per assistant and platform. Teams_IV indicates the sent data for the configuration where *Assistant B* switched off incoming video. WA_DS indicates the sent data for the configuration where both participants switched data saving mode on.

App	Assistant + Call Nr.	Data Sent (MB)	Upload Speed (Mbps)	Assistant + Call Nr.	Data Sent (MB)	Upload Speed (Mbps)
WA	A + 1	50.81	11.90	B + 1	24.63	0.38
	A + 2	50.43	11.50	B + 2	40.56	1.08
	A + 3	42.95	17.30	B + 3	48.11	0.76
WA DS	A + 1	5.44	10.30	B + 1	4.94	0.51
	A + 2	33.42	13.10	B + 2	25.50	0.85
	A + 3	23.19	27.80	B + 3	27.32	0.51
Meet	A + 1	55.37	10.40	B + 1	42.74	1.28
	A + 2	45.77	12.80	B + 2	48.24	0.71
	A + 3	58.75	12.00	B + 3	43.80	0.56
Teams	A + 1	72.05	16.30	B + 1	82.29	0.16
	A + 2	70.77	11.00	B + 2	28.07	0.54
	A + 3	72.29	6.45	B + 3	47.57	0.64
Teams IV	A + 1	5.04	10.20	B + 1	15.37	1.74
	A + 2	6.44	20.00	B + 2	50.69	1.31
	A + 3	6.67	18.60	B + 3	51.63	1.51
Zoom	A + 1	82.33	8.85	B + 1	14.61	0.54
	A + 2	74.63	5.60	B + 2	30.01	1.58
	A + 3	74.24	20.4	B + 3	68.66	0.41

Table 4.1: All platforms, audio-video over mobile data, data sent: The MB sent (uploaded) and upload speed for call 1, 2 and 3 per assistant and platform. Teams_IV indicates the sent data for the configuration where *Assistant B* switched off incoming video. WA_DS indicates the sent data for the configuration where both participants switched data saving mode on.

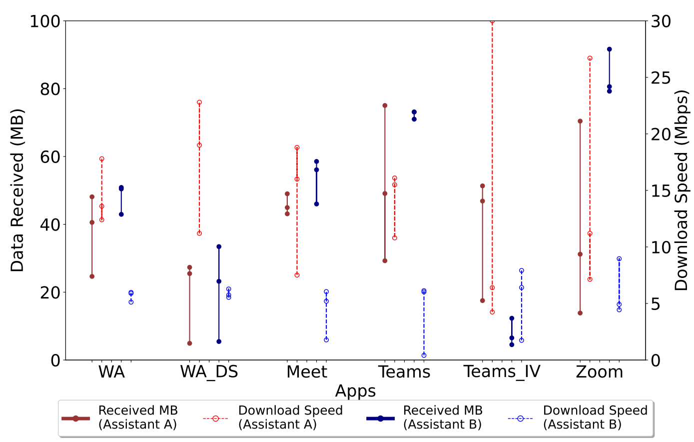

Figure 4.2: All platforms, audio-video over mobile data, data received: The MB received (downloaded) for calls 1,2 and 3 for audio-video calls over mobile data per assistant and platform. Teams_IV indicates the received data for the configuration where *Assistant B* switched off incoming video. WA_DS indicates the received data for the configuration where both participants switched data saving mode on

App	Assistant + Call Nr.	Data Received (MB)	Download Speed (Mbps)	Assistant + Call Nr.	Data Received (MB)	Download Speed (Mbps)
WA	A + 1	24.64	17.80	B + 1	50.86	5.12
	A + 2	40.56	12.40	B + 2	50.43	5.90
	A + 3	48.11	13.60	B + 3	42.94	5.98
WA DS	A + 1	4.92	11.20	B + 1	5.45	5.75
	A + 2	25.47	22.80	B + 2	33.42	6.28
	A + 3	27.32	19.00	B + 3	23.20	5.54
Meet	A + 1	43.09	7.51	B + 1	56.07	1.78
	A + 2	48.99	18.80	B + 2	46.00	6.05
	A + 3	44.94	16.00	B + 3	58.53	5.20
Teams	A + 1	75.03	16.10	B + 1	73.12	0.41
	A + 2	29.26	10.80	B + 2	70.99	6.13
	A + 3	49.09	15.50	B + 3	73.12	6.02
Teams IV	A + 1	17.51	4.24	B + 1	4.52	7.92
	A + 2	46.86	6.40	B + 2	12.30	6.41
	A + 3	51.33	30.00	B + 3	6.51	1.74
Zoom	A + 1	13.84	11.20	B + 1	91.63	4.44
	A + 2	31.19	7.14	B + 2	80.60	8.96
	A + 3	70.42	26.7	B + 3	79.24	4.92

Table 4.2: All platforms, audio-video over mobile data, data received: The MB received (downloaded) and download speed for call 1,2 and 3 per assistant and platform. Teams_IV indicates the received data for the configuration where *Assistant B* switched off incoming video. WA_DS indicates the received data for the configuration where both participants switched data saving mode on

When looking at the cumulative data sent and received (table 4.3) for the audio and video calls over mobile data, Teams and Zoom used the most data for the sum of the sent and received packets between *Assistant A* and *Assistant B*. Teams consumed on average 123.94 MB (Std. dev 23.38) and Zoom 118.57 MB (Std. dev 22.00). Google Meet consumed on average 98.72 MB (Std. dev 3.83). For this configuration, WhatsApp used the least bandwidth, consuming on average 85.86 MB (Std. dev 8.00). Looking at the standard deviation for the different platforms, we found that Meet and WhatsApp's is closer dispersed to the mean and less volatile.

Configuration	Assistant + Call Nr.	WhatsApp	Meet	Teams	Zoom
One-on-one audio-visual call over mobile data	A + 1	75.46	98.46	147.08	96.18
	A + 2	91.00	94.77	100.03	105.83
	A + 3	91.06	103.69	121.39	144.66
	B + 1	75.60	98.82	155.42	106.24
	B + 2	90.99	94.24	99.06	110.61
	B + 3	91.05	102.33	120.69	147.90
	Average	85.86	98.72	123.94	118.57
	Std.dev	8.00	3.83	23.38	22.00
One-on-one audio-visual call over mobile data where one participant switches off incoming video	A + 1	-	-	22.56	-
	A + 2	-	-	53.31	-
	A + 3	-	-	58.00	-
	B + 1	-	-	19.89	-
	B + 2	-	-	62.99	-
	B + 3	-	-	58.15	-
	Average	-	-	45.82	-
	Std.dev			19.31	
One-on-one audio visual call over mobile data with data saving mode	A + 1	10.36	-	-	-
	A + 2	58.90	-	-	-
	A + 3	50.52	-	-	-
	B + 1	10.39	-	-	-
	B + 2	58.93	-	-	-
	B + 3	50.52	-	-	-
	Average	39.94	-	-	-
	Std.dev	23.20			

Table 4.3: All platforms, audio-video over mobile data, Total data usage: Total MB used (upload + download) per Assistant and call for one-on-one audio visual calls over mobile data. We also show the average total MB (upload + download) and std. deviation per platform. Missing values against an app indicates that that particular configuration is not available in the app. The average includes three measurements each from Assistant A and Assistant B.

Comparing the total data consumption of Teams' audio-video configuration over mobile data with Teams_IV (configuration where *Assistant B* switched off incoming video), we note that the total data consumption when switching incoming video off is less. In this configuration, we saw a decrease in the bandwidth consumption for both participants, even if only *Assistant*

B switched their incoming video off. *Assistant A* used a total of 47.01 MB on average, whereas *Assistant B* used 44.62 MB. On average, the total bandwidth consumption of Teams_IV was 63.03% less than when doing an audio-video call over mobile data and 92,62% less when doing an audio-only call.

On fig. 4.1 and fig. 4.2, WA_DS indicates the data consumption for audio-video calls over mobile data where both participants enabled data saving mode. Data saving mode is a feature on WhatsApp that enables users to lower data consumption during chats and calls. Enabling the feature reduces the amount of data consumed by reducing the audio and video fidelity of the calls you make. This configuration was only done on WhatsApp as it is the only application in our study that allows data saving mode. When looking at the bandwidth consumption WA_DS (table 4.3), the average bandwidth consumption for the three iterations was 39.94 MB. For comparison, the audio-video calls over mobile data consumed on average 85.86 MB (114,97% higher than data saving mode), whereas the audio-only calls over mobile data used on average 3.70 MB (90,74% lower than data saving mode). We can thus conclude that using data saving mode had an underlying impact on the data consumption of the WhatsApp audio-video calls.

4.2.2 Audio-video calls over Wi-Fi

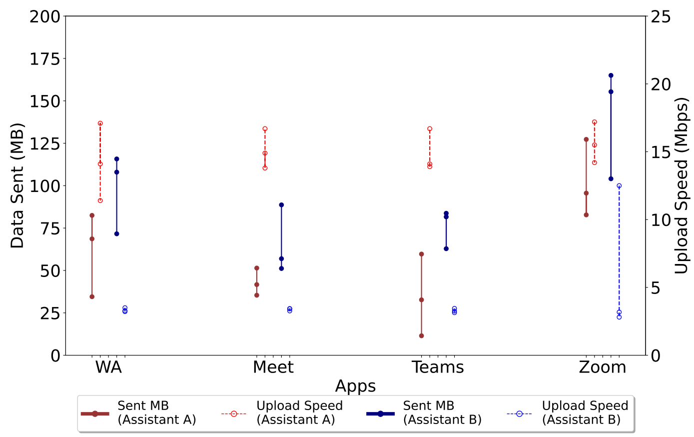

Figure 4.3: All platforms, audio-video over Wi-Fi, data sent: MB sent (uploaded) for call 1, 2 and 3 for audio-video calls over Wi-Fi per assistant and platform.

App	Assistant + Call Nr.	Data Sent (MB)	Upload Speed (Mbps)	Assistant + Call Nr.	Data Sent (MB)	Upload Speed (Mbps)
WA	A + 1	34.52	14.10	B + 1	115.74	3.50
	A + 2	82.46	17.10	B + 2	107.95	3.28
	A + 3	68.63	11.40	B + 3	71.60	3.22
Meet	A + 1	51.41	14.90	B + 1	88.62	3.44
	A + 2	41.66	13.80	B + 2	56.94	3.42
	A + 3	35.38	16.70	B + 3	51.15	3.27
Teams	A + 1	59.66	13.90	B + 1	83.70	3.14
	A + 2	32.68	14.10	B + 2	62.82	3.26
	A + 3	11.48	16.70	B + 3	81.61	3.45
Zoom	A + 1	95.59	17.20	B + 1	155.38	12.5
	A + 2	82.76	15.50	B + 2	104.06	3.18
	A + 3	127.27	14.20	B + 3	165.01	2.81

Table 4.4: All platforms, audio-video over Wi-Fi, data sent: MB sent (uploaded) and upload speed for call 1, 2 and 3 per assistant and platform.

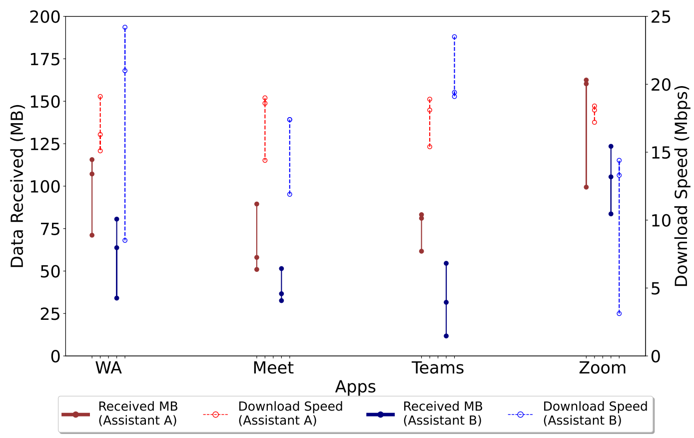

Figure 4.4: All platforms, audio-video Wi-Fi, data received: MB received (downloaded) for call 1, 2 and 3 for audio-video calls over Wi-Fi per assistant and platform.

App	Assistant + Call Nr.	Data Received (MB)	Download Speed (Mbps)	Assistant + Call Nr.	Data Received (MB)	Download Speed (Mbps)
WA	A + 1	107.16	19.10	B + 1	80.58	21.00
	A + 2	115.62	15.10	B + 2	34.06	24.20
	A + 3	71.11	16.30	B + 3	63.75	8.51
Meet	A + 1	89.49	18.60	B + 1	51.46	11.90
	A + 2	58.03	19.00	B + 2	36.64	17.40
	A + 3	50.94	14.40	B + 3	32.58	17.40
Teams	A + 1	61.67	18.90	B + 1	31.59	19.40
	A + 2	83.21	18.10	B + 2	54.55	19.10
	A + 3	81.07	15.40	B + 3	11.76	23.50
Zoom	A + 1	160.27	18.40	B + 1	105.48	3.12
	A + 2	99.41	18.10	B + 2	83.66	14.40
	A + 3	162.49	17.20	B + 3	123.45	13.30

Table 4.5: All platforms, audio-video Wi-Fi, data received: MB received (downloaded) and upload speed assistant and platform.

For the audio-video calls over Wi-Fi, both participants connected to Wi-Fi using the same devices as for the previous calls (table 3.2). When comparing audio-video calls over Wi-Fi, we

Configuration	Assistant + Call Nr.	WhatsApp	Meet	Teams	Zoom
One-on-one audio-visual calls over Wi-Fi	A + 1	141.68	140.90	121.33	255.87
	A + 2	198.08	99.70	115.89	182.17
	A + 3	139.75	86.33	92.56	289.77
	B + 1	196.33	140.13	115.29	260.87
	B + 2	142.02	93.58	117.37	187.72
	B + 3	135.35	83.73	93.37	288.47
	Average	158.87	107.39	109.30	244.14
	Std.dev	29.79	26.25	12.83	47.93

Table 4.6: All platforms, audio-video Wi-Fi, Total bandwidth consumption: Total MB used (upload + download) per assistant (A1 and A2) call (C1 and C2) for one-on-one audio visual calls over Wi-Fi. We also show the average total MB (upload + download) and std. deviation per platform.

found that the average data sent (fig. 4.3) and received (fig. 4.4) to be the highest for Zoom with an average of 121.68 MB sent and 122.46 MB received - consuming in total 244.15 MB. WhatsApp followed with average total consumption of 158.87 MB, 34,91% lower than Zoom. Google Meet used the least amount of data on average, consuming 107.39MB, which is 56.01% less data when compared to Zoom. To determine if bandwidth consumption was significantly lower over mobile data than over Wi-Fi, we performed a one-tailed t-test. We performed the test on a sample of 24 video calls for both Audio-video calls over mobile data and Audio-video calls over Wi-Fi across the four video calling apps. We formulated the following two hypotheses:

1. Null Hypothesis (H_0): The total bandwidth usage for audio-video calls over Wi-Fi was less than or equal to that of audio-video calls over mobile data.

2. Alternative Hypothesis (H_a): Audio-video calls over Wi-Fi consumed more bandwidth than audio-video calls over mobile data.

The calculated t statistic for our test was -3.487 with a p-value of 0.0005, less than the accepted value of 0.05. Based on our p-value, we thus reject the null hypothesis. We conclude that the data consumption for audio-video calls (sent fig. 4.1 and received (fig. 4.2) over mobile data is significantly lower than audio-video calls over Wi-Fi. The total data usage for sent and received is higher over Wi-Fi for Meet (8.79%), Zoom (105.9%) and WhatsApp (85.03%), but not for Teams (-11.81%).

4.2.3 Audio-only calls over mobile data

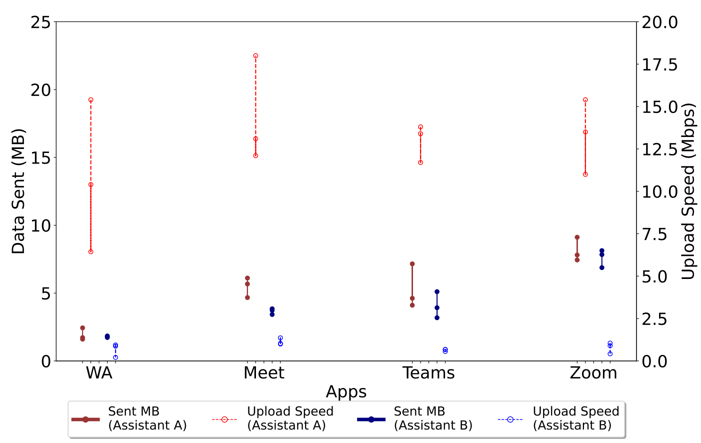

Figure 4.5: All platforms, audio-only over mobile data, data sent: MB sent (uploaded) for call 1, 2 and 3 for audio-only calls over mobile data per assistant and platform.

App	Assistant + Call Nr.	Data Sent (MB)	Upload Speed (Mbps)	Assistant + Call Nr.	Data Sent (MB)	Upload Speed (Mbps)
WA	A + 1	1.71	15.40	B + 1	1.72	0.87
	A + 2	1.60	6.44	B + 2	1.78	0.94
	A + 3	2.43	10.40	B + 3	1.84	0.21
Meet	A + 1	5.67	13.10	B + 1	3.42	1.03
	A + 2	4.67	12.10	B + 2	3.84	1.36
	A + 3	6.10	18.00	B + 3	3.72	1.00
Teams	A + 1	4.61	13.40	B + 1	3.92	0.67
	A + 2	7.15	11.70	B + 2	3.18	0.68
	A + 3	4.10	13.80	B + 3	5.10	0.56
Zoom	A + 1	7.80	13.50	B + 1	6.87	0.42
	A + 2	9.11	11.00	B + 2	8.13	1.05
	A + 3	7.44	15.40	B + 3	7.83	0.90

Table 4.7: All platforms, audio-only over mobile data, data sent: MB sent (uploaded) and upload speed for call 1, 2 and 3 per assistant and platform.

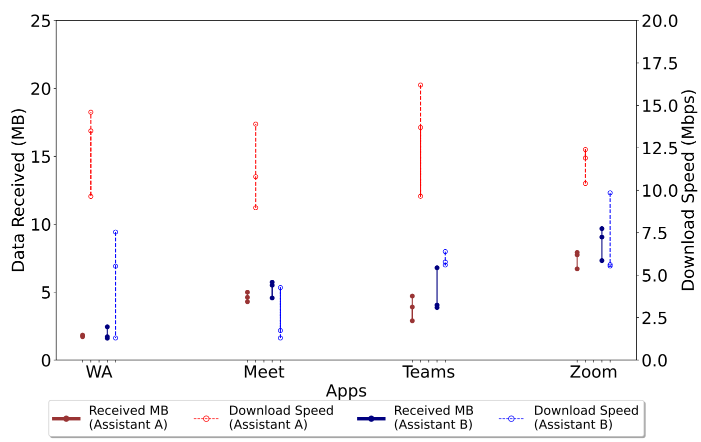

Figure 4.6: All platforms, audio-only over mobile data, data received: MB received (downloaded) for call 1, 2 and 3 for audio-only calls over mobile data per assistant and platform.

App	Assistant + Call Nr.	Data Received (MB)	Download Speed (Mbps)	Assistant + Call Nr.	Data Received (MB)	Download Speed (Mbps)
WA	A + 1	1.72	13.5	B + 1	1.71	7.54
	A + 2	1.79	9.64	B + 2	1.60	5.53
	A + 3	1.83	14.6	B + 3	2.44	1.30
Meet	A + 1	4.29	8.97	B + 1	5.73	1.30
	A + 2	4.62	10.8	B + 2	4.57	4.27
	A + 3	4.99	13.9	B + 3	5.50	1.74
Teams	A + 1	3.90	16.2	B + 1	4.05	6.39
	A + 2	2.89	9.65	B + 2	6.79	5.6
	A + 3	4.71	13.7	B + 3	3.86	5.78
Zoom	A + 1	6.71	10.40	B + 1	9.67	9.85
	A + 2	7.92	12.40	B + 2	9.05	5.62
	A + 3	7.74	11.90	B + 3	7.32	5.54

Table 4.8: All platforms, audio-only over mobile data, data received: MB received (downloaded) and download speed for call 1, 2 and 3 per assistant and platform.

Configuration	Assistant + Call Nr.	WhatsApp	Meet	Teams	Zoom
One-on-one audio calls over mobile data	A + 1	3.44	9.97	8.52	14.52
	A + 2	3.39	9.29	10.04	17.03
	A + 3	4.27	11.10	8.81	15.19
	B + 1	3.44	9.15	7.97	16.55
	B + 2	3.39	8.41	9.97	17.18
	B + 3	4.28	9.23	8.97	15.16
	Average	3.70	9.52	9.05	15.94
	Std.dev	0.44	0.91	0.81	0.98

Table 4.9: All platforms, audio-only over mobile data, Total bandwidth consumption: Total MB used (upload + download) per assistant (A1 and A2) call (C1, C2 and C3) for one-on-one audio only calls over mobile data. We also show the average total MB (upload + download) and std. deviation per platform.

We performed a one-tailed t-test on a sample of 24 video calls for both Audio-video with mobile data and Audio-only configurations across all four video calling apps. We formulated the following two hypotheses:

1. Null Hypothesis (H_0): The total bandwidth usage for audio-video calls was less than or equal to that of audio-only calls.

2. Alternative Hypothesis (H_a): Audio-video calls consume more bandwidth than audio-only calls.

The calculated t statistic for our test was 21.17 with a p-value of 1.16×10^{-25}, which is much less than the widely accepted value of 0.05. It is, therefore, reasonable to reject the null hypothesis and state that the data consumption for audio-only calls (fig. 4.5 and fig. 4.6) was found to be significantly lower as compared to audio-video calls. WhatsApp used on average 95.68% less data. Microsoft Teams used 92.61% less, Google Meet used 90.35% less, and Zoom used 87.40% less.

4.2.4 Group calls over mobile data

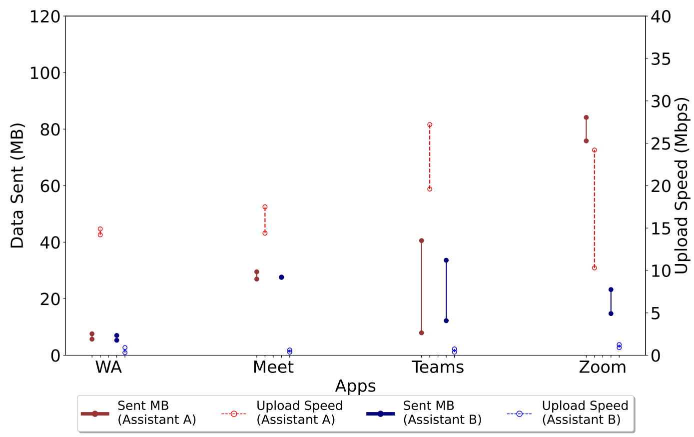

Figure 4.7: All platforms, audio-video group calls over mobile data, data sent: MB sent (uploaded) for call 1 and 2 for group calls over mobile data per platform.

App	Assistant + Call Nr.	Data Sent (MB)	Upload Speed (Mbps)	Assistant + Call Nr.	Data Sent (MB)	Upload Speed (Mbps)
WA	A + 1	7.58	14.20	B + 1	5.30	0.31
	A + 2	5.69	14.90	B + 2	7.00	0.90
Meet	A + 1	26.95	14.40	B + 1	27.53	0.37
	A + 2	29.52	17.50	B + 2	27.66	0.62
Teams	A + 1	40.56	27.20	B + 1	12.22	0.37
	A + 2	7.93	19.60	B + 2	33.61	0.74
Zoom	A + 1	84.13	10.30	B + 1	23.23	1.25
	A + 2	75.83	24.20	B + 2	14.73	0.90

Table 4.10: All platforms, audio-video group calls over mobile data, data sent: MB sent (uploaded) and upload speed for call 1 and 2 per assistant and platform.

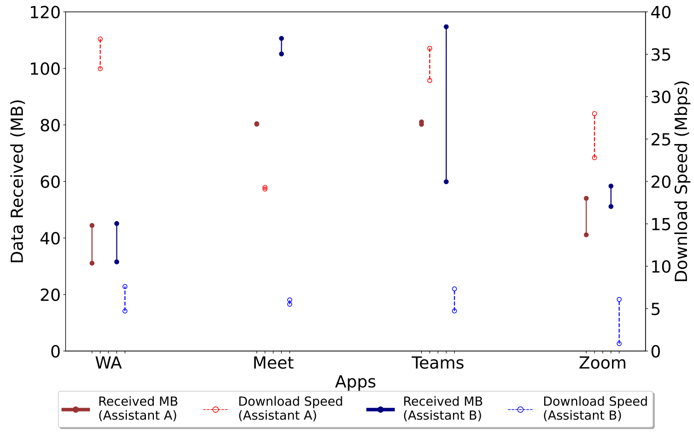

Figure 4.8: All platforms, audio-video group calls over mobile data, data received: MB received (downloaded) for call 1 and 2 for group calls over mobile data per platform.

App	Assistant + Call Nr.	Data Received (MB)	Download Speed (Mbps)	Assistant + Call Nr.	Data Received (MB)	Download Speed (Mbps)
WA	A + 1	44.43	36.8	B + 1	31.54	4.72
	A + 2	31.07	33.30	B + 2	45.11	7.61
Meet	A + 1	80.25	19.30	B + 1	105.10	5.52
	A + 2	80.42	19.1	B + 2	110.60	6.03
Teams	A + 1	80.18	35.70	B + 1	114.72	4.73
	A + 2	81.07	31.90	B + 2	59.88	7.33
Zoom	A + 1	41.10	22.8	B + 1	58.35	0.87
	A + 2	54.02	28.0	B + 2	51.13	6.09

Table 4.11: All platforms, audio-video group calls over mobile data, data received: MB received (downloaded) + download speed for call 1 and 2 per assistant and per platform.

For group calls over mobile data (table 4.12), we only looked at the bandwidth usage of Assistant A and Assistant B. We found that WhatsApp used the least amount of data, consuming on average 44.43 MB (Std. dev 8.81). Zoom consumed on average 100.63 MB (Std. dev 100.63). The data usage for Zoom was the second most competitive following WhatsApp, even though

Configuration	Assistant + Call Nr.	WhatsApp	Meet	Teams	Zoom
Group call over mobile data	A + 1	52.02	107.21	120.75	125.24
	A + 2	36.76	109.94	89.01	129.85
	B + 1	36.85	132.63	126.94	81.59
	B + 2	52.11	138.26	93.50	65.86
	Average	44.43	122.01	107.55	100.63
	Std.dev	8.81	15.72	19.07	31.78

Table 4.12: All platforms, audio-video group calls over mobile data, Total bandwidth consumption: Total MB used (upload + download) per assistant (A1 and A2) and call (C1,C2 and C3) for group calls over mobile data. We also show the average total MB (upload + download) and std. deviation per platform.

one of the lab assistants joined using a computer instead of a mobile device. On both Teams calls, one of the assistants had connection issues, and one assistant got kicked out of the call; despite not having 6 participants for the entire call duration, Teams used on average 107.55 MB (Std. dev 19.07). On Google Meet, one assistant's mobile phone restarted during the call. Google Meet used the most data, on average consuming 122.01 MB (Std. dev 15.72).

4.3 Summary of findings

Looking at our findings documented in this chapter, we can conclude that bandwidth usages over a mobile network varied among the apps and that the apps responded differently to different call configurations. Table 4.13 gives a summary of the data usage for the different call configurations per application.

Call Configuration	Zoom	Teams	Meet	WhatsApp
One-on-one audio-video call over mobile data	118.57	123.94	98.72	85.86
One-on-one audio call over mobile data	14.94	9.15	9.52	3.7
One-on-one audio-video call over mobile data where one assistant switches off incoming video	-	45.82	-	-
One-on-one audio-video call over mobile data with data saving mode on	-	-	-	39.94
Group call over mobile data	100.63	107.55	122.01	44.43
One-on-one audio-video call over Wi-Fi	244.14	109.3	107.39	158.87

Table 4.13: Average total MB used per configuration per platform. Missing values against an app indicates that that particular configuration is not available in the app.

From our findings, we also saw that assistant A had a faster internet connection, and overall higher data usage. We, however, also saw that it had an impact on assistant b who was downloading the data sent from Assistant A. This is aligned with what we know about resource utilisation and performance of video conferencing apps [53]. This can also be explored more in future studies.

Not surprisingly, we found that bandwidth usage of audio-only calls was less than the bandwidth usage of audio-video calls and that optimising settings such as 'switching incoming video off' had an impact on data consumption. These findings align with findings published by Bieringa *et al.* [30] and Greenspector [37].

Comparing the bandwidth usage between the different apps, we found that Teams and Zoom's bandwidth usage had higher variability over mobile networks and that their bandwidth usage was higher than that of WhatsApp and Meet. We saw that WhatsApp's data usage was most optimised for calls over mobile networks. Our measurements indicated that WhatsApp used the least amount of data for audio-video calls, audio-only calls, and group calls. We will discuss the implications of our findings in the chapter 6.

5

Findings: Interviews, QoE and Usability Studies

This chapter presents the findings obtained in the second part of our two-prong study. Here we address research questions 2- 4:

- How do users with bandwidth constraints, and poor internet connections utilise video-conferencing apps, and what are their pain points?

- How do users with bandwidth constraints, and poor internet connections perceive the quality of experience of these tools?
- How does usability differ between the different applications for users with bandwidth constraints and poor internet connections?

5.1 Connecting and participating in video-conferencing

At the onset of this paper, we define a bandwidth-constrained user as a consumer limited by their infrastructure and/or finances to partake in the advantages of the internet. To understand the participants' constraints, we asked the following questions:

> **Interview Question:** Please tell me about how you access the internet? Do you have any limitations or bandwidth caps?

> **Interview Question:** What type of connection do you have? Is it capped or uncapped?

When we unpacked the bandwidth constraints of participants, we found that most participants were constrained due to the cost of data and not due to poor network coverage. 8 out the 10 participants indicated that they were limited due to the cost of data and not having unlimited access to Wi-Fi. Only participants ST and BO said they were constrained due to poor network coverage.

"I do have Internet at home, but I live in the last row of civilisation. Even though we have fibre, it is often down. And then what happens, is we also have very poor mobile signal." - ST

When it came to participation in video calls, we found that most of the participants used pre-paid or "pay-as-you-go" data or mobile data provided by institutions (such as universities and companies) to connect to calls. In cases where participants had access to Wi-Fi, the Wi-Fi was offered freely to the community, provided by institutions/companies or was available at work. These users, however, were geographically constrained during lockdown as they could only use the Wi-Fi when they were in a particular location (such as on university campus). We also discovered that when participants were only using mobile data, the cost of data was relatively prohibitive in participation.

To enable us to understand how the pandemic influenced participants' usage of video-conferencing apps, we asked the participants the following questions:

> **Interview Question:** Before Covid-19, how often did you use video-conferencing applications? Daily, weekly, monthly or yearly

> **Interview Question:** How often do you currently use video-conferencing applications? Daily, weekly, monthly or yearly

In line with global trends, we saw the participants' usage increase due to Covid-19, with 8 out of 10 participants indicating that their usage increased after the onset of the Covid-19 pandemic. Before the pandemic, most participants indicated that they used video-conferencing applications weekly in comparison to daily during/after the pandemic. Participant BO and TM indicated that they never made video calls prior to the pandemic. While recall bias is a potential issue here since we asked them to reflect on "Before COVID-19", we note that there is clearly a perception that use of video-conferencing increased following the start of the pandemic. These interviews were conducted in August 2021, about 18 months after the initial lockdown in South Africa commenced.

"Before Covid, I was not [in South Africa], so I was not using video calls. I was in Ghana and I was not making [video calls] because I was with family." - BO -

We expanded the question around app usage and asked the participants what they primarily used video-conferencing for prior to the pandemic vs. during the pandemic. We found that the 8 participants who used video-conferencing apps prior to the Covid-19 pandemic, mainly used video-conferencing apps to connect with family and friends. Participant ST indicated she used it for work, whereas participant TS only used it for specific purposes (specifically mentioning an interview he had over video call). When asked what they primarily use video-conferencing for during the Coronavirus pandemic, there is a clear shift in the usage trends. The majority of participants indicate they used it for multiple purposes, including work, school, church, and to stay connected to family and friends.

To get an idea of what video-conferencing apps the participants have, we asked them at the beginning of the interview which video-conferencing apps they have installed on their mobile phones. We noted that all participants had WhatsApp installed, whereas 5 out of 10 participants had Zoom installed, and three had Google Meet and Microsoft Teams respectively installed.

5.2 Impact of data consumption and features on use of video-conferencing apps

Despite the increase in usage, all participants indicated that data consumption of these applications is a concern for them. To understand their constraints, we asked participants if they were hesitant to join video calls using their mobile data; all of the participants indicated that they were reluctant to participate due to the data consumption of the tools.

"When it comes to video calls, I have to think twice because I know the cost. Sometimes when I use maybe an hour – it sometimes takes 1 GB and sometimes 800 Mb." - JJ -

"At my university residence, it is fine, but when I'm at home, it is challenging. I hardly attend online [university] meetings." - KS -

We also found that participants cannot freely participate in conference or social calls due to bandwidth constraints and are thus limited in when and how they use the applications.

"When I make a normal call, it uses a lot of airtime, so it's easier for me just to make a video call with Wi-Fi. If I'm not at the Wi-Fi, I do not do the video call." - TM -

"There are times where I save/conserve my data for [video calls]. When I was using the data back home, I used to save it specifically for a certain time of the day or buy those hourly data bundles to do my video calls." - TS -

When we asked participants about what actions they perform to improve the quality of calls and/or reduce the data consumption of video calls, 6 of the participants indicated that they tend to switch their video off to enhance the quality of their call or to reduce data usage.

"The first time connection drops or, if I am having issues connecting, I will switch my video off. If it does not improve and becomes a problem, I will ask other participants to switch their video off to lessen the strain on my mobile connection." - TS -

"The only way to reduce data consumption is to reduce the call duration." - BO -

Although WhatsApp has a data-saving mode, none of the participants who assessed WhatsApp listed it as an option to reduce data consumption. Likewise, with Microsoft Team's functionality to switch incoming video off. Despite this, all of the participants had strategies to reduce data usage ranging from switching their video off to reducing to the length of the call.

5.3 Lack of visibility and understanding of app data consumption

To understand users' comprehension of data consumption, we asked the bandwidth-constrained users to tell us how much data a 20-minute one-on-one audio-video call would use. The answer varied between 100 MB to 250 MB. One participant indicated that she uses between 500 MB to 1 GB for an hour call and calculates the consumption. 3 out of the 10 participants answered 'they do not know' or 'a lot'.

Additionally, we asked participants how they monitor their data usage. We found that none of the participants used bandwidth monitoring applications to monitor their data usage. Participants LC, PR and MC indicated that they check their data balance before and after the call to see how much data the call consumed, whereas participant TC said they would predict how much data she would need to make a call.

"Normally, I just check before and after the call. I do not have an app to monitor it. However, WhatsApp says [how much data a call used]. When you click on the call you had in your call log, it says how long and how many MB you used." - LC -

"I would dial the SSD code to check the data. I would check before joining." - PR

"It is more of a hinge than anything. I would guess how much data I would need for the call based on the amount and how long the call will take. I will buy the data and use it during the call. If my prediction were far too low, I would receive an SMS from my mobile provider to tell me my data was running out. I would need to buy more data or wrap up what we are talking about before I get disconnected." - TC -

We found that participants had little understanding of how much data the different applications used and there was limited visibility over the bandwidth the different apps use. We found that only WhatsApp showed data usage after a call has been completed.

5.4 WhatsApp is the preferred app of choice

To understand what app the participants use the most and which app they preferred to use, we asked the participants the following questions:

Interview Question: What video-conferencing application do you use the most? Why?

Interview Question: What video-conferencing application do you prefer to use? Why?

Participant	**Most used App**	**Preferred App**
TS	Meet	WhatsApp
PR	Meet	Meet
LC	Teams and Zoom	Zoom
ST	Teams	Meet
BP	Zoom	Zoom
JJ	WhatsApp	Zoom
KS	WhatsApp	Teams
BO	WhatsApp	WhatsApp
MC	WhatsApp	WhatsApp
TM	WhatsApp	WhatsApp

Table 5.1: The most used app per participant as well as their preferred app.

When it comes to application preferences, we found that participants in white-collar environments (office/university) mostly used Meet, Zoom and Teams as they were mandated to use these apps. We could also see that the participants in white-collar environments preferred different apps for different purposes. This could be due to them adopting a broader selection of apps for video-conferencing purposes.

"When I was in university, we use to use Zoom and then when I started working, we use Google Meet. I found Google Meet to be easier." - PR -

"I would say for professional use, I would probably, use Teams. And for social/personal, I will probably use WhatsApp. " - BP -

"I think for social calls, I very much prefer WhatsApp. For work calls, I don't want it to interfere with my personal space, then I will go for Google Meet. " - TS -

In comparison, participants who did not function in white-collar environments mostly used and preferred WhatsApp as this was the app used the most by them.

"Easier to connect with my family. When I just want to connect with my family, I just use WhatsApp and the video call." - TM -

It is possible that this could be connected to education level and/or occupation; however, we did not specifically ask participants what their highest level of education or job is. This is an area for future research.

In terms of preference, we also found that when users made a self-motivated decision regarding which application to use, WhatsApp was the preferred tool of choice.

"If I have to use Microsoft Teams, then great, however, if I have the option to use WhatsApp, then I'll rather use WhatsApp." - BP

"[To call] friends and family you only need their cellphone number [to be able to] call them. Where with Teams, I think, you would need an email which means you have to ask an extra question 'what's your email?' before you can make it happen. Hence, I am more likely to stay with WhatsApp." - BP -

"I'm going to always use WhatsApp - to save the most data." - TM -

Participants preferred WhatsApp because it was convenient and cost-effective.

5.4.1 Freedom of platform choice

When we asked participants how frequently they can choose the platform to use for video calls, we found that users do not really have a choice regarding which applications they can use. We discovered that employers or institutions to which they belong (such as universities, churches and non-profit organisations) mandate the adoption and use of specific video-conferencing applications. For instance, participant MC indicated that she could only attend church online using Zoom. Participant TS stated that his university was using Teams, and his work was using Google Meet.

"I use WhatsApp for everything. I send messages, Whatsapp calls and Whatsapp video calls. We were using Zoom for church. The church closed during lockdown last year so we were meeting on Zoom. The church decided that we have to use Zoom." - MC -

"I do not have a choice." - LC -

"For social calls, I think that is the most freedom I get to choose the platform. For work or school – that seemed to be set on using a specific tool. For school, they were set on using MS Teams and for work Google Meet." - TS -

5 out of the 10 participants indicated that they can only choose which platform to use to video call family and friends. We, however, also discovered that ineffectively their decision is heavily impacted by the convenience of the platform and data constraints of the other participants in the call.

5.5 Convenience of use

Convenience includes 1) how many people have the application installed, 2) do they need to download the application before they can join a call, and 3) do they need an email address to join a meeting. Participant JJ noted that WhatsApp was more convenient because most people have it installed, whereas participant BO preferred Zoom as the people he conversed with prefer to use Zoom.

"Mostly, I always choose WhatsApp. Because that is what many people are using, with Zoom, you need to ask the other person to download the app. WhatsApp is convenient." - JJ -

"I prefer Zoom as most people I have conversed with over video tend to gravitate towards that. To fit their sort of preference, I have ended up using Zoom as well." - BP -

When it comes to data constraints, bandwidth limitations and the bandwidth constraints of the connecting users are limitations to participation. We found that if the other users they want to video call with are bandwidth-constrained, they will gravitate towards the more cost-effective platform for all participants joining the call.

"I do not have a choice. If it is family because of data issues on their side, we strictly use WhatsApp. If it is a call with people who have Wi-Fi access, then we use Zoom because it is clearer and easier." -LC -

"I prefer WhatsApp because it is much cheaper in a way – with WhatsApp, if you buy WhatsApp data, you can use it for not just calls but chats as well. So it is like, you do not have to go out of your way or spend more money to buy data." - TS -

5.5.1 Quality of Experience

Interview Question: How would you rate the quality of this call on a scale of 1 to 5 where is 1 bad and 5 is excellent?

Participant	WhatsApp	Meet	Teams	Zoom
TS	-	4	-	3
PR	-	4	-	4
LC	5	4	-	-
ST	-	-	1	3
BP	2	-	4	-
JJ	4	5	-	-
KS	5	-	3	-
BO	4	-	-	1
MC	-	4	1	-
TM	-	-	1	3
Average	4	4.2	2	2.8
Std. dev	1.22	0.45	1.41	1.10

Table 5.2: The MOS rating given per application for APP 1 and APP 2 they tested. Missing values against an app indicates that that particular application was not tested by the participant

Participant BO and MC could not connect to APP 2. Participant BO could not get the audio for Zoom to connect whereas participant MC could not get the Teams to work. Due to these technical issues, we asked them to rejoin the interview using APP 1. We then asked them to give a MOS rating for APP 2.

Based on these MOS ratings, Google Meet had the best QoE, followed by WhatsApp, Zoom and Teams (table 5.2). Key factors influencing MOS rating were audio lags and inconsistent video streams. Taking a human-centric approach to QoE, we further explored the cognitive constructs influencing QoE as per Wu *et al.*'s framework [82]. These constructs include concentration, presence, perceived ease of use, perceived usefulness and enjoyment (sec 2.4.1).

5.5.2 Concentration and Presence

Interview Question: What influenced your concentration during the video call?

Interview Question: How would you describe your sense of presence in this call and what do you think influenced it?

Our findings indicate that connectivity issues and video streams were the key aspects that influenced users' concentration and presence. As per our usage findings, we found that bandwidth-constrained users tend to switch their video off. Expanding on this, we explored how video-off influences their presence. We asked participants to rate their presence on a Likert scale when the video is on vs. when the video is off. 1 = not present at all to 5 = very present.

Interview Question: If your presence is a 5 (very present) in an in-person meeting, how present do you feel when participating in the video call when everybody's video is on? 1 = not present at all to 5 = very present

Interview Question: If your presence is a 5 (very present) in an in-person meeting, how present do you feel when participating in the video call when all video is off? 1 = not present at all to 5 = very present

Participant	Presence rating when video is off	Presence rating when video is on
TS	3	5
PR	4	5
LC	4	5
ST	1	1
BP	2	4
JJ	3	4
KS	2	3
BO	2	5
MC	1	5
TM	1	5

Table 5.3: The Likert-scale rating given per application rating how present they felt with video on vs. video off. 1 = Not present at all 5 = Very present

Table 5.3 gives an overview of the rating per participant. Based on these ratings we found that participants felt more present with video on in comparison to video off and that for the majority of the participants a video meeting was the same as talking to someone in person.

5.5.3 Perceived ease of use

Interview Question: What influences your perception of how easy it is to use this application?

Interview Question: On a scale of 1 -5, how would you rate the ease of use of this application? 1 = It is difficult to use 5 = It is easy to use

During the quality of experience section of the interview, we asked participants what influences their perception of how easy it is to use a platform during the video calls. We found that the key factors influencing perceived ease of use related to the ease of joining a call and the interface layout. We will now discuss each of these factors.

1) The ease of joining a call

A key theme that emerged during our data analysis was around how easy it is to join a call. Having to create meeting links using an email address and adding meeting pins and passwords were some of the key constraints identified.

"With video-conferencing platforms I value the most basic features more than the added extras. How quickly it is to join the call and what are some of the alternatives in case you cannot join the call on like your mobile internet. Just like being able to join very quickly." - TS -

"If I can hear the sound and if it is easy to connect. You can just go to the WhatsApp number of someone and press the video icon. It is much easier than other apps like Zoom. You have to create the meeting, you have to invite someone, and send a link. With [WhatsApp] there is no sending link. You just go to the phone." - JJ -

2) The interface layout

Another key theme that emerged during our data analysis was around how the interface layout influenced users' perception of how easy the app is to use. We found that using clear iconography with description labels improved users' perceived ease of use.

"If the icons that are explanatory and they use captions for the extra settings. That makes it a good experience." - LC -

"The icons are pretty much clear – they are there in front of you. You would see a camera icon and then in your mind, you would know this one is for whether I see or not see. And also the microphone and the earphones. In your mind you will be, earphones are for me to hear. So if there is a line, it means I am not hearing anything." - KS -

When we asked participants to rate their perceived ease of use of the apps they were testing, we found that WhatsApp was perceived as the easiest app to use, followed by Google Meet, Zoom, and Teams. Their perception, however, could be influenced by their familiarity with WhatsApp - as it is a popular messaging app in South Africa and all participants had it installed on their mobile phones. We, however, did not ask participants to rate their familiarity with all the applications in the study, only the ones they were testing.

5.5.4 Enjoyment

> **Interview Question:** What influences your levels of enjoyment when participating in a video call using this application?

When it comes to factors influencing enjoyment of the different apps, our findings indicate that connection related issues outweighed app usability and that the most significant factor influencing enjoyment related to connectivity.

"The connection part is the most important part when having a meeting. I have to be able to hear what you are saying." - PR -

"What influences my enjoyment is the audio and the video. I could hear your audio; I could hear you clearly. The video was not too bad. I could see you and I think you could see me." - TS -

We furthermore noted participant BO saying that [audio and video] breakages in the call would impact his enjoyment. Participant JJ saying stated that connection issues make him feel distressed.

"If I have a steady stream and if there are no breakages, I really enjoy it. If there were breaks in the connection, I would not even enjoy the call." - BO -

"A poor connection makes me feel distressed. When you're distressed, you don't know what to do. You might even get angry, and people in the meeting might ask you something and won't get a response from you. And then they think, why aren't you saying anything? It is very stressful." - JJ -

Other factors influencing enjoyment included familiarity with the application and the features available on the application.

5.5.5 Perceived usefulness

During the interviews, we asked participants to rate the usefulness of APP 1 and APP 2 and tell us what influenced their perceived usefulness of each of the applications they tested.

Although all participants agreed that video-conferencing applications are useful, we found that convenience and affordability influence the perceived usefulness of each app the most. We found that the participants found WhatsApp the most useful.

"With WhatsApp, 98% of the people I know have it, so and because many people have it, I can access those people via the application. Whereas with Teams, 90% of my contacts do not have the application. If I suggest that we use it, nobody will agree to use it." - KS -
"WhatsApp is very useful because so many people can afford it, and so many people have it." - LC -

"The challenge is how many people are using it. So, when you're using it, and other people aren't using it, the impact won't be there. Everyone would need it on their device for you to enjoy that."- JJ -

"What influences my perceived ease of use is how convenient it is. My family has it so that we can get in contact with each other." - JJ -

"What makes me think if [an app] is useful or not is how quickly I can get on a call. How easy it is to get on a call. Does everybody else that I need on the call, can they get on the call? Or can they figure out how to use it?" - ST -

Other factors attributing to WhatsApp having the best-perceived usefulness is related to the apps data consumption. Participant LC noted that you can specifically buy WhatsApp data bundles which is more cost-effective than normal data bundles.

5.6 Application Usability Assessments

5.6.1 System Usability Scale (SUS)

To determine the usability for each app, we asked participants to complete the system usability scale questionnaire. Table 3.6 gives an overview of the questions asked during the usability questionnaire. Table 5.4 gives an over of the final SUS score for APP 1 and APP 2 assessed per participant. We will discuss the SUS scores of each of the applications in conjunction with the task evaluation findings in section 5.5.2.

Participant	**WhatsApp**	**Meet**	**Teams**	**Zoom**
TS	-	87.5	-	55
PR	-	95	-	80
LC	95	85	-	-
ST	-	-	90	90
BP	100	-	87.5	-
JJ	80	62.5	-	-
KS	100	-	82.5	-
BO	80	-	-	Could not connect
MC	-	80	Could not connect	-
TM	-	-	20	30
Average Std. Dev	91 9.46	82 12.17	70 33.48	63.75 26.89

Table 5.4: The SUS rating calculated for each platform assessed per participant. The final score was calculated by taking the odd number questions' rating and subtracted 1 from the rating. For even number questions, we took 5 minus the user rating. To obtain the overall SUS score, we multiplied the sum of the item scores by 2.5

The final score was calculated by taking the odd number questions' rating and subtracting 1 from the rating. For even number questions, we took 5 minus the user rating. To obtain the overall SUS score, we multiplied the sum of the item scores by 2.5 As participant BO and MC could not join the video call on APP 2. We continued the second part of the interview using APP 1. We did not ask participants BO and MC to complete the SUS questions as they could not connect using APP 2.

As part of the SUS findings, we wanted to determine the reliability of the SUS answers. Reliability is the extent to which an instrument will give the same results if the measurement is to be retaken under the same conditions [62]. To determine reliability, we calculated Cronbach's alpha as $\alpha = 0.84$. Research shows that for the questionnaire to be reliable, the Cronbach's alpha values should be at least 0.70 [44]. Cronbach's alpha is calculated using the following formula:

$$\alpha = \frac{N\bar{c}}{\bar{v} + (N-1)\bar{c}}$$

In the formula N is equal to the number of items, $\bar{c}$ is the average inter-item covariance among the items and $\bar{v}$ equals the average variance.

5.6.2 Task Evaluation

For the task evaluation, we asked participants to complete a number of tasks. After completing the task they had to rate on a Likert scale between 1 - 5 how easy or difficult it was to complete the task. 1 = difficult and 5 = easy. Tasks included:

- Switching video on/off
- Switching the microphone on/off
- Sending an in-call message
- Screen sharing (where applicable)

- Switching incoming video off (Microsoft Teams only)

Table 5.5 gives an overview of the ratings given per task per application. Due to the technical issues participant BO and MC faced, they did not do the task evaluation for APP 2.

Participant	App	Video on/off	Mic on/off	In-App Messaging	Screen-sharing	Incoming video off
LC	WhatsApp	5	5	4	-	-
BP	WhatsApp	5	5	5	-	-
JJ	WhatsApp	5	5	5	-	-
KS	WhatsApp	5	5	5	-	-
BO	WhatsApp	4	4	1	-	-
	Average	4.80	4.80	4.00	-	-
TS	Meet	5	5	3	2	-
PR	Meet	5	5	5	5	-
LC	Meet	4	5	3	3	-
JJ	Meet	5	5	3	3	-
MC	Meet	5	5	5	3	-
	Average	4.80	5.00	3.80	3.20	-
ST	Teams	5	5	3	4	4
BP	Teams	5	5	1	2	2
KS	Teams	5	5	4	1	2
TM	Teams	1	5	1	1	1
	Average	4.00	5.00	2.25	2.00	2.25
TS	Zoom	5	5	4	4	-
PR	Zoom	5	5	5	5	-
ST	Zoom	4	4	5	5	-
TM	Zoom	2	5	1	1	-
	Average	4.0	4.75	3.75	3.75	-

Table 5.5: Likert rating per app per participant for each of the tasks evaluated during the task assessment (1 = difficult and 5 = easy). - against an task indicates that the functionality was not available in the app.

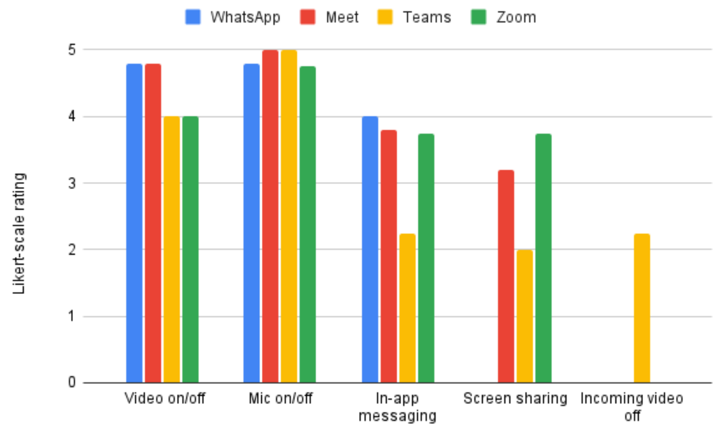

Figure 5.1: Average Likert rating per app per for each of the tasks evaluated during the task assessment (1 = difficult and 5 = easy).

From the data presented in table 5.5 and figure 5.1, we observed that most participants had no issues with switching video on/off. Only participant TM had difficulty doing the task which could be related to her unfamiliarity with both the applications as she only uses WhatsApp. Furthermore, participants had no trouble switching their microphones on and off. In the subsections below we expand on the usability of each of the apps as well as on the usability issues observed for in-app messaging, screen sharing and switching incoming video off.

5.6.2.1 Usability: Microsoft Teams

According to our SUS evaluation Teams had an average SUS score of 70 (table 5.4) which indicates C usability grade rating (table 2.4). The calculated standard deviation of 33.48 (table 5.4) indicated that usability varied among the participants.The usability rating is also validated by the qualitative feedback we got from users.

"Teams has a little bit more technicalities that someone might take a long time to manoeuvre around." - BP -

From the task evaluation, we found that 2 of the 4 participants found sending in-call messages and screen sharing difficult. Participants indicated that the most significant usability issues around sending in-call messages related to the positioning of the feature. Both participant ST and BP expected the functionality to sit at the bottom of the screen within the expanded context menu.

"Just the chat thing that is in the wrong place. I would have wanted it in the same row. Why is it up there? Why is it not with everything else at the bottom? " - ST -

"I'm thinking of clicking on [the three dots]. Perhaps it will give me an option to send a message, but I am clicking on the three dots that are on the bottom [of the screen]. On the options, there is none that says send a message. So I don't know where to go to next. " - BP -

"I just wish all the people will put the share screen in the same place. It's also a context menu [item]. There is a little up arrow that says share. It doesn't always say share, which is frustrating." - ST -

"[I gave it a 2 rating], because I had to search for it a little bit. It wasn't straightforward." - BP -

For Microsoft Teams, we also explored if users knew what 'switch incoming video off' meant. We posed this question to all participants to determine if the feature labelling within the app was self-explanatory. Only 1 out of the 10 participants knew what 'switch incoming video' meant. Both participants BO and TS thought it meant rejecting an incoming call.

"So what you're size saying is while we are on this call, and calls are incoming, you must stop it. I don't know." - BO -

"I think it means, rejecting a call. I am not sure." - TS -

We also found that none of the participants who evaluated Microsoft Teams knew that functionality is available on the Teams app. When we asked participants evaluating Teams to switch their incoming video off, they rated the difficulty 2 out of 5. Indicating that it was relatively difficult.

"I've previously never thought of it, but now that you said it I could find it. I previously never thought that I could switch off your video, the incoming video." - KS -

Participant KS found it difficult because she expected the functionality to be integrated as part of the meeting participants section.

5.6.2.2 Usability: Zoom

Although Zoom was the second most installed app among the participants, Zoom had the lowest average SUS score (table5.4) among the apps. A score between 62.7 - 64.9 indicates a C- usability grade (table2.4). The calculated standard deviation also indicated that usability varied among participants. Key usability issues and constraints observed during the interviews related to meeting passwords, frustration with connecting audio and video, and not being able to use the mobile website to join a call. We will now expand on each of these usability issues.

1) Meeting pins and passwords

When it comes to meeting pins and passwords, we found that it adds cognitive load for users and that it makes the application seem more difficult to use. Participant TS was noted saying that adding meeting pins and passwords makes it more intimidating to use, whereas participant BO stated it makes the application seem more challenging to use.

"I think Zoom looks a bit more intimidating from the minute you join with all the meeting ids and passwords." - TS -

"WhatsApp is so easy to use, but Zoom is somehow technical. It was challenging connecting the picture and the audio at the same time." - BO -

"I have always been sceptical about how we join Zoom video calls. I know it is a safety feature, but it is annoying to remember passwords and meeting ids - TS -.

2) Connecting audio and video

With Zoom we also found that participants got frustrated at the beginning of the call when trying to connect the audio and the video. For participant BO, this was especially challenging as he ended up aborting Zoom and continuing the interview on WhatsApp.

“WhatsApp is so easy to use. Zoom is somehow technical, especially connecting the picture and the audio at the same time. It is difficult.” - BO -

3) Having to download the app before being able to join a call

Another frustration we observed related to having to download the app before one can participate in a call. User expectation was that once they click on the call link they will be able to join a video call without constraints.

”The initial impression I had was that I would be able to click on the link, straight and then get connected. But after several tries, I decided to download the app. Download wasn’t a problem, but initially, I thought, the phone I’m using does not have enough space to download the app. So I had to delete a number of my files in order to make space for the Zoom.” - BO -

5.6.2.3 Usability: Google Meet

Based on our SUS evaluation WhatsApp had an average SUS score of 83 (table 5.4) which indicates A usability grade rating (table 2.4). The calculated standard deviation of 12.17 (table 5.4); the second lowest variability among the app SUS scores.

Despite the high usability score, we found during the task evaluations, usability issues around screen-sharing. Feedback from users indicated that there was no visual indicator to highlight that the screen was sharing. Despite this, our other qualitative data obtained through the interviews supports the higher SUS score as we noted positive feedback from participants.

"It's just easy. It doesn't give grief. It is like bare-bones. It doesn't have too many features. It is just a nice thing for a call. I feel like [the other apps] are quite heavy. " - ST -

"Google Meet is for me the ideal tool to use. It is much quicker to join, much smoother in doing the basic tasks like hearing someone on video or voice call. It also has the option to dial in if you cannot join with your internet. It is quite good." - TS -

5.6.2.4 Usability: WhatsApp

During our interviews, we found that all of the participants had positive sentiments towards the usability of WhatsApp and it was often bought up by participants, even if they were not evaluating the applications. According to our SUS evaluation WhatsApp had an average SUS score of 91 (table 5.4) which indicates A+ usability grade rating (table 2.4). The calculated standard deviation of 9.46 (table 5.4); the lowest variability among the app SUS scores.

Participant LC and JJ noted that WhatsApp is easy to use for new users. Participant LC stated that although the experience between Google Meet and WhatsApp was the same, her familiarity with WhatsApp influenced how she felt about using the application.

"For the beginner, I think WhatsApp is easier as there are fewer options/settings. Google Meet is not useful for the beginner as you have to wait for an invitation, and you need to create a room. All those processes." - JJ -

"I would say WhatsApp felt better because I am used to it. It is the same; the experience is almost the same as the one on Google Meet." - LC -

5.7 Summary of findings

In this chapter, we presented findings of how bandwidth-constrained users utilise video-conferencing apps. We saw the participants' usage increased due to Covid-19. Most participants indicated that they used video-conferencing apps weekly in comparison to daily during the pandemic. Despite this, all participants indicated that data consumption of these apps is a concern and as such it causes reluctance to use the tools. We also found that participants cannot freely participate in conference or social calls due to bandwidth constraints and are limited in when and how they use the applications.

In this part of the research, we found that participants had little understanding of how much data different applications used and there was limited visibility over the bandwidth the different apps use. We found that only WhatsApp showed data usage after a call has been completed.

We concluded that participants in white-collar environments (office/university) mostly used Meet, Zoom and Teams as they were required to use these apps. Also, these participants preferred different apps for different purposes. This could be due to them adopting a broader selection of apps for video-conferencing purposes. In comparison, participants who did not function in these environments mostly used and preferred WhatsApp as this was the app used the most by them. This can be possibly connected to education level and/or occupation; however, we did not specifically ask participants what their highest level of education or job is. When users made a self-motivated decision regarding which application to use, WhatsApp was the preferred tool of choice. Participants preferred WhatsApp because it was convenient and cost-effective. WhatsApp has specific features to support lower data costs, but lacks support for screen sharing, and has limits on group call size - which increased from four participants to eight in April 2020. Understanding this in more depth is an area for future exploration.

During this section of the research, we also discovered that users do not really have a choice regarding which applications they can use. We found that their institutions mandate the adoption and use of specific video-conferencing apps. Five (5) out of the 10 participants indicated that they can only choose which platform to use to video call family and friends. We also found that when they do have a choice their decision is heavily impacted by the convenience of the platform and data constraints of the other participants in the call. Convenience related to 1) how many people have the application installed, 2) do they need to download the application before they can join a call, and 3) do they need an email address to join a meeting.

To measure QoE, participants rated the quality of each call using a MOS of 1 to 5, where 1 is bad and 5 is excellent. Expanding on participants' rating (table 5.2 we found that key factors influencing MOS rating were audio lags and inconsistent video streams.

When it comes to usability, 5.6 gives an overview of the different evaluations. For the task evaluation, we present the average rating across the tasks of switching video on and off, switching their microphone on and off and sending in call messages. We only included these three tasks, as they were constant across all four platforms.

Measurement	**WhatsApp**	**Meet**	**Teams**	**Zoom**
QoE (std.dev)	4 (1.22)	4.2 (0.44)	2 (1.41)	2.8 (1.09)
SUS (std.dev)	91 (9.46)	82 (12.17)	70 (33.48)	64.75 (26.89)
Task evaluation (std.dev)	4.53 (0.46)	4.53 (0.64)	3.75 (1.39)	4.17 (0.52)

Table 5.6: QoE, SUS and task evaluation ratings per application.

During our task evaluation, we were able to identify usability issues with the different applications. In general, most participants had no issues with switching video on/off on the different applications. Using the average rating each user gave for the different tasks and the standard deviation, we saw that WhatsApp and Google Meet had the best usability followed by Zoom and then Teams. During this evaluation, we were also able to identify some usability constraints which can be addressed by the developers of these applications.

6.

6

Discussion

In this study, we measured the data usage of different Android video-conferencing apps, and we embarked on a journey to better understand bandwidth-constrained users' perceptions of mobile video-conferencing apps. Our findings contribute to the body of knowledge around 1) implications for measuring bandwidth, QoE and usability, 2) implications for designs regarding video-conferencing, and, 3) implications for organisations utilising video-conferencing apps.

In this chapter, we will first look at the methodologies applied in this study and the implications of the different methods. We will then discuss the implications of our findings for design by looking at the cost of participation; the price bandwidth-constrained users pay to partake in video calls. We will lastly discuss the implications of our research for organisations that utilise video-conferencing tools and how they can ensure equal participation and inclusion.

6.1 Comparing Assessment Methods

For this study, we use a human-centric approach to better understand the factors influencing QoE, rather than calculating technical performance data (chapter 3). We asked bandwidth-constrained users to self-report their QoE by giving a MOS rating and then to describe the cognitive perceptions which influence their experience (sec 5.5.1). Although we explored each of the constructs (perceived ease of use, concentration, presence, perceived usability, enjoyment) which influence QoE as proposed by Wu *et al.* [82], the feedback from our interviewees reinforces that the key aspect influencing QoE was the quality of the network. We found that many QoS and QoE aspects correspond and that technical performance is a user property residing in user perception. This aligns with findings published by Shin *et al.* [73]. It is, however, necessary to re-iterate that we did not measure usability to see if one application is good or bad, but to see how they perform relatively against each other. Hoßfeld *et al.*'s [45] stated that having users give a MOS rating as an experience rating is a practical way to convey QoE. We, however, found that if we only used MOS, we would not have received additional insights into the factors influencing QoE and user experience. Utilising QoE constructs identified in Wu *et al.*'s [82] framework was a worthwhile extension on MOS and allowed the effective unpacking of human factors influencing the perceived QoE. We urge HCI and networking researchers to extend the framework and do more research into the human factors influencing QoE.

Looking at SUS, we firstly found SUS to have high levels of reliability when calculating Cronbach's alpha. We saw that through SUS that both Zoom and Teams had lower usability ratings than WhatsApp and Meet. This aligned with the qualitative data and task evaluation data obtained during our interviews. Collating our findings from our SUS evaluation of Microsoft Teams with Pal *et al.*'s [62] findings, our rating align closely with their study. In our research, Zoom's usability score, however, differs from findings published by Sauro and Lewis [69]. Their results indicated better usability. Future research should be done around how SUS is perceived by different user groups, i.e. bandwidth-constrained users vs users who have no internet constraints. When looking at the effectiveness of SUS, we note that only utilising SUS scores would not have provided us with insights into usability issues per application and if usability has been met or not. Utilising task evaluation in combination with SUS enabled us to understand the usability constraints of each of the apps and validate our SUS scores with qualitative data.

Measurement	WhatsApp	Meet	Teams	Zoom
Bandwidth usage (15 min call)	85. 86 MB	98.72 MB	123.94MB	118.57MB
QoE (out of 5)	4	4.2	2	2.8
SUS (out of 100)	91	82	70	64.75
Task evaluation (out of 5)	4.53	4.53	3.75	4.17

Table 6.1: Comparison table of the findings per measurement metric and platform. For the bandwidth usage we only showcase the average consumption for audio-video calls over mobile data (table 4.3). Whereas for the task evaluation, we present the average rating across the tasks of switching video on and off, switching their microphone on and off and sending in call messages. We only included these three tasks, as they were constant across all four platforms.

Table 6.1 gives an overview of the findings per measurement tool. For the data usage we only showcase the average consumption for audio-video calls over mobile data. Whereas for the task evaluation, we present the average rating across the tasks of switching video on and off, switching their microphone on and off and sending in call messages. We only included these three tasks, as they were constant across all four platforms. Comparing the methods, we saw that the different ratings closely aligned. We also found that both MOS and SUS provides a good indication of QoE and usability, respectively. As noted in our methodology (chapter 3), limitations faced by these users might not be unique to bandwidth constrained users and future research should be conducted to determine if bandwidth constraints have an impact on behaviour and usability of these applications.

6.2 Implications for design

In the introduction of this study, we defined a bandwidth-constrained user as a consumer limited by their infrastructure and/or finances to partake in the advantages of the internet. Our participants described the challenges around finances and infrastructure that created a barrier to participation in video-conference calls. However, we also found that bandwidth caps and poor internet connections are not the only hurdles these users need to overcome.

One of the first hurdles is often presented before participating in a call. Compelling users to download the app before participating in a video call presents a barrier to participation and adds to the cost of participation. Installing and updating the app requires more bandwidth, which is already a constraint for users. This was explicitly the case with Zoom and WhatsApp, where users cannot join a video call on the mobile website and need to download the app to participate (sec 5.6.2). Phokeer *et al.* [65] found that in South African township communities, a considerable amount of data gets used over cellular networks to do app installations and updates. They proposed finding a solution that enables people to update their mobile phones without consuming internet traffic. Expanding their idea, they stated that if phone updates can be predicted, we can provide updates in a "localised" fashion to enable faster and less costly updates. Alternatively, we recommend that these platforms be designed in such a way to allow mobile-only users to participate without being forced to download the app. Google Meet and Teams are examples of apps allowing users to connect using the mobile website. However, future research should be conducted to understand the difference in performance between the apps and mobile websites for each platform.

The second hurdle users face relates to the emotional cost of participation. When users are able to join a call, either using the mobile website or app, they often need to consider when to participate. We found that due to bandwidth constraints, users cannot freely and unlimitedly join in a conference or social calls and, as such, are restricted in terms of when and how they use these apps (sec 5.2). This is in line with research published by Donner[39] stating that constrained users tend to "dip and sip" instead of "surf the internet". As per Donner's [39] research, we also found that these users try to conserve their airtime and data bundles to enable them to participate in calls when needed. And as such, the users' metered mindset has a drag on effective and engaging use of the internet. We also observed that users tend to limit when and how they do video calls and that they tend to switch their video off or reduce call duration to conserve data (sec 5.2). This links with research by Chetty *et al.* [34] which highlighted that bandwidth caps shape how, when, and for how long people browse. Wyche *et al.*'s [83] findings also confirmed that bandwidth constraints affect users' interactions, and these users plan their behaviours and are deliberate with their actions. To ensure users can freely participate without a metered mindset, we need to continue to advocate for bandwidth-constrained users and call on practitioners, policymakers, and technologists to push downwards on data prices and make applications even more data-efficient. This is also in line with Donner's [39] research.

The next hurdle users face to the usability of the different applications. Based on SUS, WhatsApp and Meet had good usability. WhatsApp and Meet consistently had better SUS and task evaluation ratings, which correlate with our qualitative data and users' positive sentiment towards those apps. Based on our SUS scores and our task evaluation, Teams and Zoom had more usability problems. The poor usability of Zoom was surprising as it was the second most downloaded app among the participants. Improving these apps by addressing the usability issues presented in sec 5.6 ultimately has implications for design.

Our research found that one of the key usability issues across all the apps related to the lack of visibility of data consumption. During our research, we found that users did not know how much data the different apps consume and that they had little visibility of the data usage of the apps (sec 5.3). This prevents users from understanding what is depleting their data and limits them in managing data usage. In line with Donner's [39] recommendations on improving usability for bandwidth-constrained users, one way to enhance the usability of video-conferencing apps is to create greater visibility and control around data usage of these apps. Chetty *et al.* [34] also advocates for creating better visibility of app data consumption. They argue that creating better visibility and control will help users understand the cost associated with their behaviours and the cost of participating in video calls [34].

The next hurdle users face is the monetary cost of participation. Looking at Chetty *et al.* [34]'s research on bandwidth caps, they state that bandwidth caps force people to put a monetary price on their internet use. Our bandwidth measurement findings in chapter 4 shed light on the bandwidth usage of the different call configurations and platforms; and, when mapped back to cost per MB, gives an overview of how much a call would cost. It highlights that data saving features such as 'data saving mode' and a feature to 'switch incoming video off' reduced data consumption. Despite this, users had little knowledge or understanding of these features and that it could reduce the monetary cost of participation (sec 5.3). Based on these findings, we recommend developing features to notify users when connecting using mobile data and asking them if they want to switch to data saving mobile or if they want to disable incoming video. User on-boarding and education around these features within the app would also create better awareness of how to reduce the cost of participation. Jitsi (not measured) also allows the end-user to control the quality of the incoming video.

There are, however, two sides to how these apps can save data. The recommendations mentioned above are client-side features that will give the user control. The other side is server-side solutions that can reduce the amount of data consumed. This is visible in an automatic reduction in data usage for slower connections (as can be seen in table 4.3), but also in platforms such as Google AMP or FreeBasics, which offer a lower-bandwidth or 'closer' placement of content' to improve the performance of the applications. While some bandwidth-constrained users see FreeBasics as undesirable due to the compromised experience, this approach bears further thought on ways to deliver better performance without using more data.

6.3 Implications for Organisations and Institutions

During our research, we found that users often do not have a choice or voice when it comes to which applications get used (sec 5.4.1). These findings are similar to findings published by Phokeer *et al.* [65] about resourced-constrained communities not having a choice of connection type to access the internet. Organisations and institutions should therefore recognise that they are in a position of power and might impose a higher burden on participants when mandating the use of a specific video-conferencing application. We, therefore, urge organisations and institutions to holistically look at the data consumption, usability, QoE and functionality of the different apps before mandating their use.

Although organisations and institutions cannot address the implications of design, their responsibility is to strive to be inclusive and ensure equal participation. We also posit the following implications for organisations and institutions:

Firstly, when mandating the use of video conferencing, ensure you provide means for users to connect by providing them with data or a Wi-Fi dongle. Additionally, also note that the call configurations impact data usage for participants. From our bandwidth measurement experiments (chapter 4) we saw that call configuration differed between the configurations. If possible, utilise audio-only calls or encourage users to only switch video on when talking.

Secondly, we also recommend that organisations and institutions educate their users on how to reduce data consumption when using mandated apps, regardless of which application they choose to use. Educating users about features and behaviours around data consumption would enable them to control their consumption and make informed choices.

Lastly, we want to emphasise the importance of organisations and institutions shifting towards mobile-centric consumers and continuing to support initiatives to lower data costs. Advocating for bandwidth-constrained users and putting pressure on telecommunication companies to reduce data costs should be a continuous endeavour to ensure inclusion and equal participation.

7 Conclusion

At the onset of the Covid-19 pandemic lockdowns, everything from education to work to socialising shifted to "online-only". Due to these lockdowns, video-conferencing applications were swiftly adopted and used to enable people to stay connected. In this study, we took the first step to understand the data usage, usability and QoE of mobile video-conferencing apps among bandwidth-constrained users in South Africa. To understand and measure usability and QoE, we reached out to organisations that utilise video conferencing apps and recruited bandwidth-constrained users. We conducted interviews with these participants. To understand the bandwidth usage of the different apps, we conducted experiments to measure the data usage of different Android apps. Our findings contribute to the body of knowledge around implications for measuring bandwidth, QoE and usability. We found that utilising MOS (for QoE) and SUS (for usability) is sufficient. However, if you want a deeper understanding of factors influencing QoE and usability, researchers must expand their measurement methods to include qualitative assessments (for QoE) and task evaluations (for usability). Our findings help the research community understand the advantages and disadvantages of using the different techniques and provide guidance on combining them for broader insights. During this study, we also highlight implications for design by shedding light on the day-to-day struggles of bandwidth-constrained users and the different barriers to participation they face. These hurdles include: having to download the applications, the emotional and monetary cost of participation, and lastly, usability. Based on these findings, we posit implications for design and give practical recommendations on how companies developing video-conferencing apps should develop these applications to accommodate bandwidth-constrained and 'pay-as-you-go' users. Lastly, we suggest that organisations and institutions using video-conferencing apps to connect to bandwidth-constrained users should be conscious of user constraints and limitations to ensure inclusion and equal participation. We conclude that we all need to be the voice for bandwidth-constrained users and continuously advocate for them so that they are not excluded, especially in a locked-down society.

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A
Appendix

DEPARTMENT OF COMPUTER SCIENCE

UNIVERSITY OF CAPE TOWN
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RESEARCHER/S: Dominique Oosthuizen
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Informed Voluntary Consent to Participate in Research Study

Project Title: **Comparing Android video conferencing applications' bandwidth usage and understanding the effect of bandwidth caps on video conferencing tools' usability and adoption**

Invitation to participate, and benefits: You are invited to participate in a research study conducted with users who are required to use video conferencing tools but has bandwidth caps. The study aim is to inform organisations and the broader research community about the relative usability of video conferencing tools and to highlight how these tools can be designed, developed and built to be more inclusive for users with poor/limited internet connections.

Procedures: During this study, you will be asked to participate in a video call and partake in a usability study and a interview. For the usability study, you will be asked to perform a set of task related to video conferencing (turning video on/off, audio on/off, sharing your screen). After the usability study, we will conduct an interview about your usage and adoption of video conferencing tools.

Recording: We may take photographs and/or record video as part of the study. Photographs will be used as visuals for the dissertation while video recordings will only be used for data analysis. If you object to this, please indicate below.

Risks: The only possible risk is usability tests and interview data is leaked. Despite this, the potential harm will be minimal as you will not be required to share personal information during the usability testing or interviews.

Feedback: You will receive feedback about the results of this research via a white paper. This is a paper explaining the findings in a non-scientific manner.

Disclaimer/Withdrawal: Your participation is completely voluntary; you may refuse to participate, and you may withdraw at any time without having to state a reason and without any prejudice or penalty against you. Should you choose to withdraw, the researcher commits not to use any of the information you have provided without your signed consent. Note that the researcher may also withdraw you from the study at any time.

Confidentiality: All information collected in this study will be kept private in that you will not be identified by name or by affiliation to an institution. Confidentiality and anonymity will be maintained as pseudonyms will be used.

What signing this form means: By signing this consent form, you agree to participate in this research study. The aim, procedures to be used, as well as the potential risks and benefits of your participation have been explained verbally to you in detail, using this form. Refusal to participate in or withdrawal from this study at any time will have no effect on you in any way. You are free to contact me, to ask questions or request further information, at any time during this research.

I agree to participate in this research (tick one box)	☐ Yes	☐ No	_________ (Initials)
I agree to be photographed	☐ Yes	☐ No	_________ (Initials)
I agree to be video-recorded	☐ Yes	☐ No	_________ (Initials)
I agree to the use of properly anonymized photographs as part of the final dissertation	☐ Yes	☐ No	_________ (Initials)
I agree to the use of properly anonymized video recordings for data analysis purposes	☐ Yes	☐ No	_________ (Initials)

Type text here

Name of Participant	Signature of Participant	Date

Dominique Oosthuizen	Dominique Oosthuizen	16/07/2021
Name of Researcher	Signature of Researcher	Date

B
Appendix

Hi. I'm Dominique

I am currently a Masters of IT student at UCT, doing my research on the user experience of mobile video-conferencing tools for bandwidth-constrained users.

For my research, I'm doing data usage comparisons of WhatsApp, MS Teams, Zoom, and Google Meet.

Today, we are specifically going to look at your experience of [APPLICATION A] and [APPLICATION B].

This session will be run in 2 parts. In the first part, I'll ask you some questions relating to how you use video conferencing applications. In the second part, I'll ask you to perform a few tasks while we are participating in the video call. During this, I'd like for you to think out loud just so I know what's happening in your head.

I'd like to stress that I'm really excited to find out more about your experience using video conferencing applications - there are no right or wrong answers here.

Would you mind if I record this session? We won't publish anything you say publicly. All findings from your interview will be published as part of my dissertation but your identity will be protected. Additionally, I also would like to find out if I can take a screenshot of our call - your face will be blurred out, but I might use the screenshot as an example of a call in my dissertation.

Incentive: After we've completed this session, I'll send you the 500MB data bundle to the mobile phone number you provided.

Before we start, I just want to stress that a few questions might be repetitive as we are using a combination of methodologies for this research.

Section A: DEMOGRAPHICS

Participant demograpics

A1. NAME

A2. **AGE**

A3. **GENDER**

MALE ☐

FEMALE ☐

A4. **NATIVE LANGUAGE**

A5. **What type of device are you using to connect to these calls?**

A6. **What apps do you have installed on your phone?**

Section B: CONNECTION AND DEVICE DETAILS

B1. **Please tell me about how you access the internet? Do you have any limitations or bandwidth caps?**

B2. **What type of connection do you have?**

B3. **Do you have a capped or uncapped connection? What is the speed of your connection? What is the cap?**

Capped ☐

Uncapped ☐

B4. **Do you ever hesitate to join a call or turn on video due to constraints or to save data?**

Yes ☐

Comment

No ☐

Comment

B5. **What cell phone do you primarily use?**

B6. **Are you ever concerned that your device limits the quality of your video-conferencing?**

B7. **How much data do you think a video call of 20 minutes uses if everyone's video and sound is on? (if there are 2 participants)**

B8. **What video conferencing application do you prefer to use? Why**

ZOOM

Comment

MICROSOFT TEAMS

Comment

GOOGLE MEET

Comment

WHATSAPP VIDEO

Comment

Other

Other

Section C: INTERVIEW QUESTIONS

C1. Thinking back to your online video calls, what are the most common technical issues you face?

C2. What are some of the things you worry about when using video-conferencing applications? (e.g. data usage, connecting successfully, security, kids interrupting)

C3. Do you think video conferencing tools are useful? If yes, why and if no, why not?

C4. **What video conferencing application do you use the most? Why?**

- ZOOM ☐
- MICROSOFT TEAMS ☐
- GOOGLE MEET ☐
- WHATSAPP VIDEO ☐
- OTHER ☐

C5. **How often do you currently use video conferencing applications - daily, weekly, monthly quarterly or yearly?**

- DAILY ☐
- WEEKLY ☐
- MONTHLY ☐
- QUARTERLY ☐
- YEARLY ☐

C6. **What did you primarily use it for?**

C7. **Before covid-19, how often did you use video conferencing applications - daily, weekly, monthly quarterly or yearly?**

DAILY ☐

WEEKLY ☐

MONTHLY ☐

QUARTERLY ☐

YEARLY ☐

NEVER ☐

C8. **What video conferencing tools did you primarily use before Covid?**

C9. **When participating in video conferencing calls, what type of device do you prefer to use? Computer / Tablet / Phone?**

COMPUTER ☐

TABLET ☐

CELLPHONE ☐

A COMBINATION (SEE COMMENTS) ☐

C10. **During a video call, when will you switch your video on? And when do you prefer to switch it off?**

C11. **Do you ever turn video off to improve the quality of your connection?**

C12. **What are your concerns about the security of the application you prefer to use?**

C13. **What do you think it means when an application says it is end-to-end encrypted?**

C14. **When participating in video conferencing calls, are you ever concerned about the amount of data the call will use? If yes, how do you monitor/manage the data usage? Include: why or why not.**

C15. **Does your company/institution etc. give you data when using these tools for study/work purposes?**

YES ☐

NO ☐

C16. **When you make calls, how frequently do you get to choose the platform?**

C17. **If you know [preferred application] uses more data, will you switch to an application that uses less data?**

YES ☐

NO ☐

Section D: USABILITY TESTING APPLICATION A

We are now going to do a usability study of [APPLICATION A]

When you perform the tasks, please talk me through what you are doing and say what you think.

Scenario: You are currently in an important meeting, there is a crisis in the background and you quickly need to mute your mic and switch your video off.

Remember to explain to me what you do.

D1. FACILITATOR: What platform are we using for this study?

- ZOOM ☐
- MS TEAMS ☐
- GOOGLE MEET ☐
- WHATSAPP VIDEO ☐

D2. On a scale of 1 - 5, how familiar are you with this platform? 1 - Not at all 5 - Very familiar

- 1 ☐
- 2 ☐
- 3 ☐
- 4 ☐
- 5 ☐

D3. CAMERA: Let's say you firstly want to switch your camera off. How would you go about doing so?

D4. Did the participant pass this task?

- Yes, easily ☐
- Took a little time but succeeded without prompting ☐
- Needed a prompt ☐
- Failed - couldn't complete the task ☐
- Connection error ☐

D5. **How would you rate how easy this task was for you on a scale of 1 to 5 where 1 is very difficult and 5 is very easy?**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

D6. **MIC: You now want to switch your microphone off. How would you do it? (Remember: after switching it off - switch it back on after a few seconds as I need to get your feedback)**

D7. **Did the participant pass this task?**

Yes, easily ☐
Took a little time but succeeded without prompting ☐
Needed a prompt ☐
Failed - couldn't complete the task ☐
N/A - connection error ☐

D8. **How would you rate how easy this task was for you on a scale of 1 to 5 where 1 is very difficult and 5 is very easy?**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

D9. **MESSAGING: How would you go about messaging the participants in the call?**

D10. **Did the participant pass this task?**

EXTEND: If the functionality isn't available - do you think it is needed?

- Yes, easily ☐
- Took a little time but succeeded without prompting ☐
- Needed a prompt ☐
- Failed - couldn’t complete the task ☐
- N/A - Connection error ☐
- N/A - Functionality not available ☐

D11. **How would you rate how easy this task was for you on a scale of 1 to 5 where 1 is very difficult and 5 is very easy.**

- 1 ☐
- 2 ☐
- 3 ☐
- 4 ☐
- 5 ☐

D12. **INCOMING VIDEO: What can you do to reduce data usage of this call?**

D13. **Do you know what I mean when I say "switch incoming video off?"**

D14. **Did you know switching off incoming video improves your data usage? Can you check if you can switch incoming video off for [application a]**

D15. **Did the participant pass this task?**

- Yes, easily ☐
- Took a little time but succeeded without prompting ☐
- Needed a prompt ☐
- Failed - couldn't complete the task ☐
- N/A - Connection error ☐
- N/A - Functionality not available. ☐

D16. **How would you rate how easy this task was for you on a scale of 1 to 5 where 1 is very difficult and 5 is very easy? [MS Teams only]**

1 ☐

2 ☐

3 ☐

4 ☐

5 ☐

D17. **CONNECTION ISSUE: During our call now, have you seen any indicators that your connection is giving you issues? What were they?**

D18. **SCREEN SHARING: Please share your screen and show me how you would go about installing[application b]. (if not yet installed)**

D19. Did the participant pass this task?

- Yes, easily ☐
- Took a little time but succeeded without prompting ☐
- Needed a prompt ☐
- Failed - couldn't complete the task ☐
- N/A - Connection error ☐
- Functionality not available ☐
- Already installed ☐

D20. How would you rate how easy this task was for you on a scale of 1 to 5 where 1 is very difficult and 5 is very easy?

- 1 ☐
- 2 ☐
- 3 ☐
- 4 ☐
- 5 ☐

D21. How was the download process for you?

D22. Did you ever consider the size of the application before you downloaded it?

Section E: QOE APPLICATION A (2)

E1. **How would you rate the quality of this video conferencing call? Taking everything into account audio/visual/experience (1 - bad and 5 - excellent)**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

E2. **Why did you give that rating?**

E3. **On a scale of 1 - 5, how easy do you think it is to use this application? 1 (very difficult) to 5 (very easy)**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

E4. **TELEPRESENCE: How would you describe your sense of presence in this call and what do you think influenced it?**

E5. If your presence is a 5 (very present) in an in-person meeting, how present do you feel when participating in the video call when everybody's video is on? 1 (not present at all) to 5 (very present)

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

E6. If your presence is a 5 (very present) in an in-person meeting, how present do you feel when participating in the video call when all video is off? 1 (not present at all) to 5 (very present)

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

E7. PERCEIVED EASE OF USE: What influences your perception of how easy it is to use this application?

E8. CONCENTRATION: What influenced your concentration during the video call?

E9. **How would you rate your concentration in the video call? 1 (bad) to 5 (excellent)**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

E10. **ENJOYMENT: What influences your levels of enjoyment when participating in a video call using this application?**

E11. **When participating in the video call, how would you rate your sense of enjoyment of this application? 1 (bad) to 5 (excellent)**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

E12. **PERCEIVED USEFULNESS? How useful do you think this application is and what influences how useful it is to you?**

E13. **On a scale of 1 - 5, how would you rate the usefulness of this application? 1 - not useful at all 5 - extremely useful**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

Section F: SUS APPLICATION A

Scale: 1 (strongly disagree) to 5 (strongly agree)

F1. **I think that I would like to use this application frequently**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

F2. **I found the application unnecessarily complex**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

F3. **I thought the application was easy to use**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

F4. **I think that I need the support of a technical person to be able to use this application**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

F5. **I found the various functions in the application were well-integrated**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

F6. **I thought there was too much inconsistency in this application**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

F7. **I would imagine that most people would learn to use this application very quickly**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

F8. **I found the application very awkward to use**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

F9. **I felt very confident using the application**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

F10. **I needed to learn a lot of things before I could get going with this application.**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

Section G: USABILITY TESTING APPLICATION B

Okay - we are now going to jump off this call and look at the usability of [application b]. Please join the call via the link I sent you.

G1. **FACILITATOR: What platform are we using for this study?**

ZOOM ☐
MS TEAMS ☐
GOOGLE MEET ☐
WHATSAPP VIDEO ☐

G2. **On a scale of 1 - 5, how familiar are you with this platform? 1 - Not familiar at all 5 - Very familiar**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

G3. **CAMERA: Let’s say you firstly want to switch your camera off. How would you go about doing so?**

G4. **Did the participant pass this task?**

- Yes, easily ☐
- Took a little time but succeeded without prompting ☐
- Needed a prompt ☐
- Failed - couldn’t complete the task ☐
- Failed - couldn’t complete the task N/A - Connection error ☐

G5. **How would you rate how easy this task was for you on a scale of 1 to 5 where 1 is very difficult and 5 is very easy?**

- 1 ☐
- 2 ☐
- 3 ☐
- 4 ☐
- 5 ☐

G6. **MIC: You now want to switch your microphone off. How would you do it? (Remember: after switching it off - switch it back on after a few seconds as I need to get your feedback)**

G7. **How would you rate how easy this task was for you on a scale of 1 to 5 where 1 is very difficult and 5 is very easy?**

1 ☐

2 ☐

3 ☐

4 ☐

5 ☐

G8. **Did the participant pass this task?**

Yes, easily ☐

Took a little time but succeeded without prompting ☐

Needed a prompt ☐

Failed - couldn't complete the task ☐

N/A - Connection error ☐

G9. **MESSAGING: How would you go about messaging the participants in the call?**

G10. **Did the participant pass this task?**

Yes, easily ☐

Took a little time but succeeded without prompting ☐

Needed a prompt ☐

Failed - couldn't complete the task ☐

G11. **How would you rate how easy this task was for you on a scale of 1 to 5 where 1 is very difficult and 5 is very easy.**

- 1 ☐
- 2 ☐
- 3 ☐
- 4 ☐
- 5 ☐

G12. **INCOMING VIDEO: You want to switch incoming video off. Do you know what I mean when I say "switch incoming video off?"**

G13. **How would you go about switching incoming video off? (MS Teams only)**

G14. **Did the participant pass this task?**

- Yes, easily ☐
- Took a little time but succeeded without prompting ☐
- Needed a prompt ☐
- Failed - couldn't complete the task ☐
- N/A - Connection error ☐

G15. **How would you rate how easy this task was for you on a scale of 1 to 5 where 1 is very difficult and 5 is very easy? [MS Teams only]**

- 1 ☐
- 2 ☐
- 3 ☐
- 4 ☐
- 5 ☐

G16. **Do you think this is a feature that will be useful for all the VC applications?**

G17. **CONNECTION: What are ways you can tell if your connection is causing issues?**

G18. **Please tell me how you would go about in sharing your screen?**

G19. **Did the participant pass this task?**

- Yes, easily ☐
- Took a little time but succeeded without prompting ☐
- Needed a prompt ☐
- Failed - couldn’t complete the task ☐
- N/A - Connection error ☐
- Functionality not available ☐

G20. **How would you rate how easy this task was for you on a scale of 1 to 5 where 1 is very difficult and 5 is very easy?**

- 1 ☐
- 2 ☐
- 3 ☐
- 4 ☐
- 5 ☐

Section H: QOE APPLICATION B (2)

H1. **How would you rate the quality of this video conferencing call? (1 - bad and 5 - excellent)**

- 1 ☐
- 2 ☐
- 3 ☐
- 4 ☐
- 5 ☐

H2. **Why did you give that rating?**

H3. **On a scale of 1 - 5, how easy do you think it is to use this application? 1 (very difficult) to 5 (very easy)**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

H4. **PERCEIVED EASE OF USE: What influences your perception of how easy it is to use this application?**

H5. **TELEPRESENCE: How would you describe your sense of presence in this call and what do you think influenced it?**

H6. **CONCENTRATION: What influenced your concentration during the video call?**

H7. **How would you rate your concentration in the video call? 1 (bad) to 5 (excellent)**

H8. **ENJOYMENT: What influences your levels of enjoyment when participating in a video call using this application?**

H9. **When participating in the video call, how would you rate your sense of enjoyment of this application? 1 (bad) to 5 (excellent)**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

H10. **PERCEIVED USEFULNESS? How useful do you think this application is and what influences how useful it is to you?**

H11. **On a scale of 1 - 5, how would you rate the usefulness of this application? 1 - not useful at all 5 - extremely useful**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

Section I: SUS APPLICATION B

Scale: 1 (strongly disagree) to 5 (strongly agree)

I1. I think that I would like to use this application frequently

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

I2. I found the application unnecessarily complex

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

I3. I thought the application was easy to use

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

I4. I think that I need the support of a technical person to be able to use this application

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

I5. **I found the various functions in the application were well-integrated**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

I6. **I thought there was too much inconsistency in this application**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

I7. **I would imagine that most people would learn to use this application very quickly**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

I8. **I found the application very awkward to use**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

I9. **I felt very confident using the application**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

I10. **I needed to learn a lot of things before I could get going with this application**

1 ☐
2 ☐
3 ☐
4 ☐
5 ☐

Section J: CLOSING QUESTIONS

Closing questions for comparison

J1. **How would you compare your experience with [application a] in comparison with [application bl]?**

J2. **Which application did you most enjoy using? And why?**

J3. **Describe how a bad connection influences your perceived ease of use of video conferencing applications**

J4. **Describe how a bad connection influences your sense of enjoyment**

J5. **Which application do you think is most easy to use?**

Application A ☐

Application B ☐

Equal ☐

J6. **Do you have any other comments you want to make about the applications?**

J7. **Which application do you think you will continue using in the future?**

Thanks for participating.