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Open Call Deliverable OCI-DS3.2
Final Report (eMusic)

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Abstract

We conducted several experiments to evaluate usability of the Géant BoD service for remote collaboration in musical education, performing arts and cultural exchange. We can conclude that although the BoD service did not improve communication conditions in our case, the Géant network together with the NRENs involved provides sufficiently stable environment and the transmission quality characteristics for such a delay sensitive application. All experiments have been very positively accepted by the musicians, teachers and sound engineers as novel ways of distance collaboration. It has been shown that the educational and collaboration impact of the activities enabled by the project is significant.

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Executive Summary

The main objective of the project was to demonstrate a novel use of the Géant bandwidth on demand (BoD) service to support remote education and collaboration in music (eLearning) and remote access to cultural performances (eCulture). The project consortium was formed by a group of three performing art academies and three European NRENs.

We established BoD connections between all three pairs of Géant - NREN access points. We extended the high-quality connectivity from Géant – NREN access points all the way to the performing arts academies by semi-dedicated paths based on lambdas and L2 VLANs. Initially we tested the network characteristics with common tools to check delay, packet loss and throughput. Then we conducted several experiments with real musical performances and lectures to evaluate usability of the Géant BoD service for remote collaboration in musical education. We additionally did a remote real-time sound mixing/teaching experiment. We gathered experiences of the musicians using questionnaires.

We can conclude that the Géant network together with the NRENs involved (CESNET, GARR, JANET) provides a sufficiently stable environment and the transmission quality characteristics for such a delay sensitive audio/video application as the real-time collaboration in musical education among all involved musical schools (AMU, CONTS, ENU). We believe that this finding can be generalized to the rest of the Géant network and the connected NRENs. In extreme cases (between distant countries), delay can be limiting even within Europe.

We encountered some instability problems over the BoD paths, probably related to delayed ARP packets, which were not present over the best-effort path. Delay was slightly higher over BoD than over best-effort for one pair of institutions. The user interface was rather complex, which requires network engineers for its use and it could not be used by users outside ICT (such as performing artists). There were occasional outages of the BoD services (connections could not be reserved through the GUI). However, the Géant technical support was always quick and providing as much assistance as possible.

All experiments have been very positively accepted by the musicians, teachers and sound engineers as novel ways of distance collaboration. It has been shown that the educational and collaboration impact of the activities enabled by the project is significant.

1 Network setup

The network setup is shown in Fig. 1. In Prague, we configured two network paths from the Géant PoP in the CESNET premises in Zikova street to the AMU premises over a metropolitan network. For the best-effort tests, a regular routed network path was used. For the Géant BoD tests, an L2 connection was used. The VLAN mapping feature on a Cisco router was used to map a local VLAN number to one of the two BoD VLANs configured. One BoD VLAN goes to Milan, where it is connected to a 1 Gbps lambda connection to CONTS in Trieste. The other BoD VLAN goes to London, where it is connected to a 10 Gbps Lightpath connection to ENU in Edinburgh. Switching between best effort and BoD paths can be done simply by connecting the end host PCs to the corresponding switch ports and configuring IP addresses. In AMU, the same switch port can be used and the best effort or BoD path is used depending on the remote IP address used.

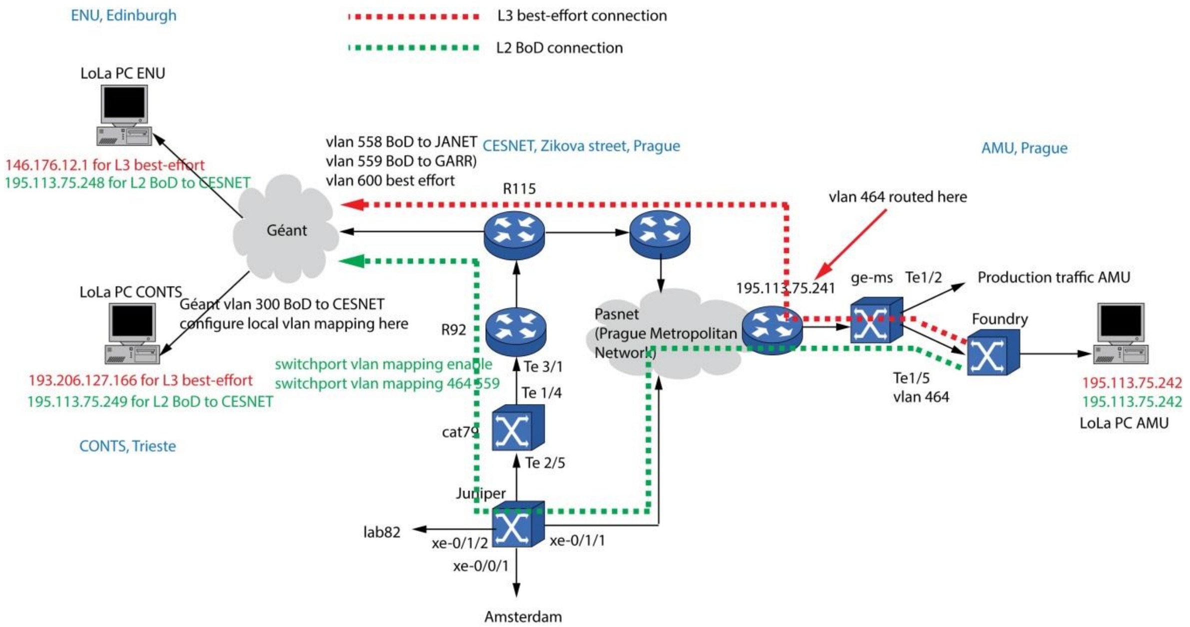

Figure 1.1: Connections between AMU, CONTS and ENU

2 Network tests

Before the experiment with artists, we tested the network with usual network tools and the transmission application LoLa. We wanted to test connectivity, delays, packet loss and the operation of the LoLa software as well as the effect of the BoD service on these network characteristics. The connectivity and operation test using the LoLa software over a best-effort network path between AMU and CONTS is illustrated in Fig. 2.1.

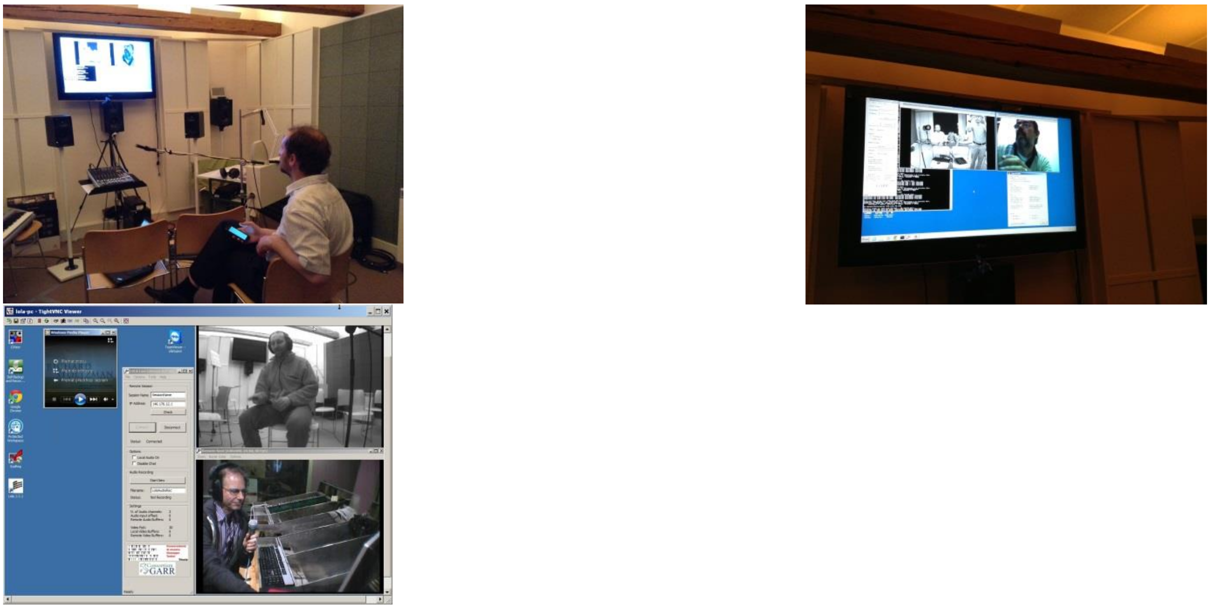

Figure 2.1: LoLa test AMU - CONTS on 4 June, 2014

We then used ping and traceroute to test best-effort and BoD network paths between all three pairs of end points. A screen capture of ping and traceroute tests of the best-effort network path between AMU and ENU is in Fig. 2.2. There were 13 hops between the end stations, no packet loss and stable RTT of 23 to 24 ms.

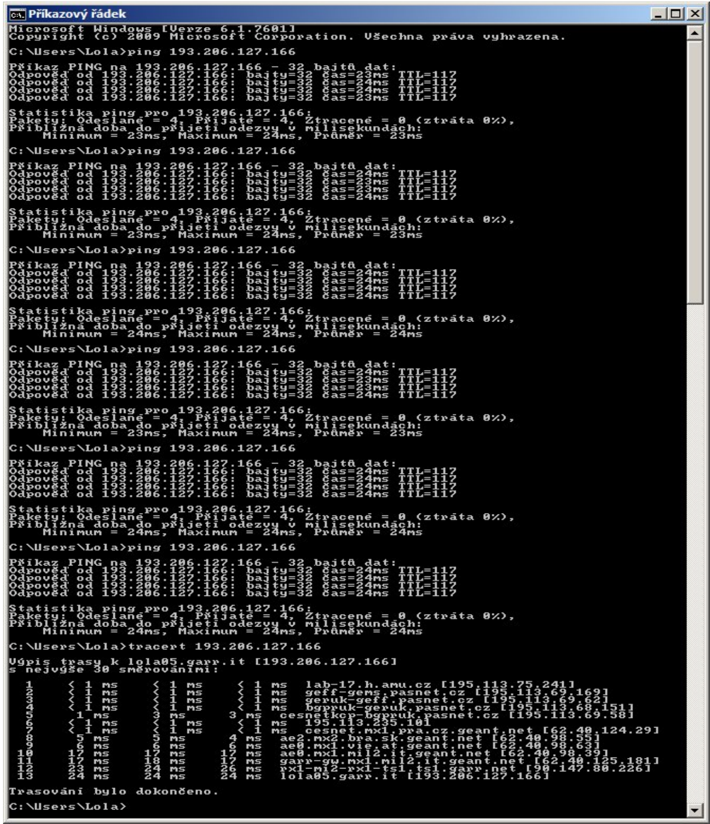

Figure 2.2: Ping and traceroute test the of AMU - ENU best-effort path

The results of the delay measurements are summarized in Table 2.1. After we switched to the BoD path, the average RTT between AMU and CONTS increased slightly to 28 ms (most likely due to a different network path). There were no evident changes in the jitter between best effort and BoD connections among all involved institutions.

	min RTT	avg RTT	max RTT	50% percentile	75% percentile	90% percentile
AMU – CONTS	23.60 ms	23.71 ms	23.90 ms	23.70 ms	23.70 ms	23.90 ms
AMU - ENU	30.00 ms	30.21 ms	61.00 ms	30.00 ms	30.00 ms	30.00 ms
CONTS - ENU	35 ms	35 ms	86 ms	35 ms	36 ms	36 ms

Table 2.1: Tests of best-effort network paths

The current way an end user requests a BoD service between locations does not seem to be very straightforward. When asking end users who were not network experts (e.g., sound engineers, multimedia experts and musicians) to setup a BoD link themselves, their experience was quite negative. Also more network aware people had difficulties in understanding the setup process (booking, requesting, committing, activating, and also the way back to de-commit a service). Our experience shows that the service would benefit from a simpler portal and streamlining the process.

Technically, our tests showed that there are some instabilities when setting up a BoD L2 circuit. In particular, when the circuit is first setup, there are issues (likely because of the ARP protocol) which can make the first packets arrive with a very long delay (seconds in some cases) or be completely lost for a non negligible period (from 100 ms up to 3 or 4 seconds) before the packets flow in a more stable way. These instabilities were affecting heavily for example the initial negotiations of the LoLa application, which does some initial tests also along the network to try to optimise its internal connection parameters. While on the best-effort connections we never had issues, on the BoD links we often had negotiation problems, and completely wrong reports to the end users about the parameters of the connection (jitter, latency), and in some cases the connection required long (many seconds) repeated negotiations before it became usable. As said, this is likely because of the effect of ARP and other L2 parameters along the BoD path setup, and should be investigated. Moreover, the total average delay was sometimes higher over the BoD connection than the best-effort connection.

3 Experiments with musicians

3.1 Playing together AMU - CONTS

The first experiment with artists that we did was playing music together between AMU (Prague) and CONTS (Trieste). The goal was to evaluate the effect of the Géant BoD service on real-time remote collaboration for such a sensitive audio/video application. We created a questionnaire to get feedback from the artists. Questions were devised collaboratively by network technicians, musical teachers and sound engineers from musical schools. The questionnaire consisted of four sets of questions to be asked before the trial, after using the best-effort network, after using the BoD network and the concluding post-trial questions. The questions are in Appendix A. The goal was to have comparative responses, to evaluate experience of artists on both ends and between multiple experiments. There were different network paths with different kinds of music and artistic personalities. In some cases, it was not straightforward to determine a comparable feedback, as the technical and artist people tend to think in their own terms, but it was very fruitful and positive experience. Note that we also played "blind tests" to the musicians involved, in order to evaluate how much they could really distinguish different connection situation/configuration.

In addition to evaluating the effect of the BoD service itself, the goal of the experiment also included:

a) to better understand when a computer network can be used for playing music together over a distance, in what cases can this be used and what are the limitations

b) to determine if there are some technical parameters in sound and picture transmissions that can be tuned to improve usability of remote playing together

Ivan Vokáč played a cello in AMU and Hiromi Arai played a piano in CONTS. The piece of music was Fantasiestücke from Robert Schumann. The recording studio in AMU during the experiment is shown in Fig. 3.1.

Figure 3.1: Playing together experiment between AMU (Prague) and CONTS (Trieste)

The key observations from the experiment are the following:

- In this particular experiment, one musician described himself as well adaptive and quite technically minded, whereas the other felt sensitive to the environment and was not a technical person. They did not play together before neither personally or over the network
- It seems that the order of importance for acceptably playing together is good sound, feeling the environment of other musicians and good vision of other musicians
- Good sound means not only the transmission quality, but very much also the quality of sound capture and reproduction, including volume, dynamics, space and echo
- The musicians did not complain about the delay in both the best-effort and BoD cases. It was approx. 17 ms and 19 ms respectively, one way and including the end host delays.
- The second trial (with BoD) was appreciated as more comfortable. However, both musicians independently said it was probably because they got used to each other.
- The applications where this audio/video technology can be useful, were seen mostly as rehearsals, also for live occasional performances, but probably not for recording.

3.2 Playing together CONTS - ENU

On December 16th, 2014 we performed a second music "playing together" experiment, this time between CONTS and ENU. In CONTS we had again Hiromi Arai playing the piano, and at ENU we had Rik Evans playing viola. They selected some pieces of music that required them to watch each other more often than usual while performing and the need to stick together "a tempo" in a very strict way. Because Hiromi Arai now had experience with remote performances, we also had the chance to evaluate what it means to be somewhat more experienced with the technology. We choose her again because she described herself again as "sensitive to the ambience and not at all a technical person".

The best-effort network connection between CONTS and ENU was very stable, there were no losses, little jitter and 35 ms RTT delay. There was no measurable difference in delay and jitter between best-effort and BoD circuits.

During the experiment, we have setup different environment conditions for the musicians. We first asked them to play together the pieces a number of times in "average setup conditions", to get used to each other (again they never met before and never played together the pieces) and remove the initial bias in their experience.

Then we started with some "blind tests" with them. First with a Standard Definition video, at 30 fps, and we used some data buffers which introduced an additional latency (about 8 ms); then we removed the additional audio buffers and asked them to re-evaluate the experience. Although the latency difference was quite small, they immediately told us they felt much better with the lower latency. And when we increased it again, they recognised the difference. A second test was increasing the video frame rate to 60 fps, while still in SD resolution. The feedback was that it was easier to follow each other at higher frame rate because the movement looked more "natural". At last we switched to HD video transmission on the CONTS to ENU side, both at 30 fps and at 60 fps. Comments from ENU reported a much better feeling of the "presence" of the remote partner in HD and high frame rate, which enabled them to improve further their performance. When we took the back to SD video, the difference was clearly perceived. We also made a test session in HD using JPEG video compression for transmission. Although this does introduce a very small (<2 ms) additional latency which is not detectable, the feeling was worse than with uncompressed HD video; the presence of some small compression-related artefacts in the image also proved to negatively influence the experience. So, we were able to conclude that besides a good low latency sound, the presence of an high quality image is also important, because it makes the feeling of the "presence" of the remote partner much more natural and real, and this affects the overall experience.

3.3 Remote mixing AMU - ENU

The goal of this experiment was to verify if low-latency network transmissions can be used as a tool for remote teaching of real-time music mixing or recording. Such a scenario could provide high-quality experience in mixing sound for live music radio broadcasts. Another example application is to reduce the cost of sound engineering for live broadcasts of concerts and other events, allowing the use of permanent studio sound mixing equipment, rather than using expensive recording vans. The configuration of the experiment is shown in Fig. 3.2 and the recording studio in AMU during the experiment can be seen in Fig. 3.3. A live jazz trio playing in ENU was captured by seven microphones which were transmitted to AMU, along with a 8th channel for communication. An 8-channel sound adapter (Hammerfall Multiface II) was used with the LoLa software. Students in AMU were mixing this music into a two-channel stereo sound, which was sent back to ENU. Teachers on both ends were evaluating the resulting sound. The experiment was successful, the students and teachers found the experience comparable to the local work in one room. We can conclude that the proposed scenario was proved to be practically usable.

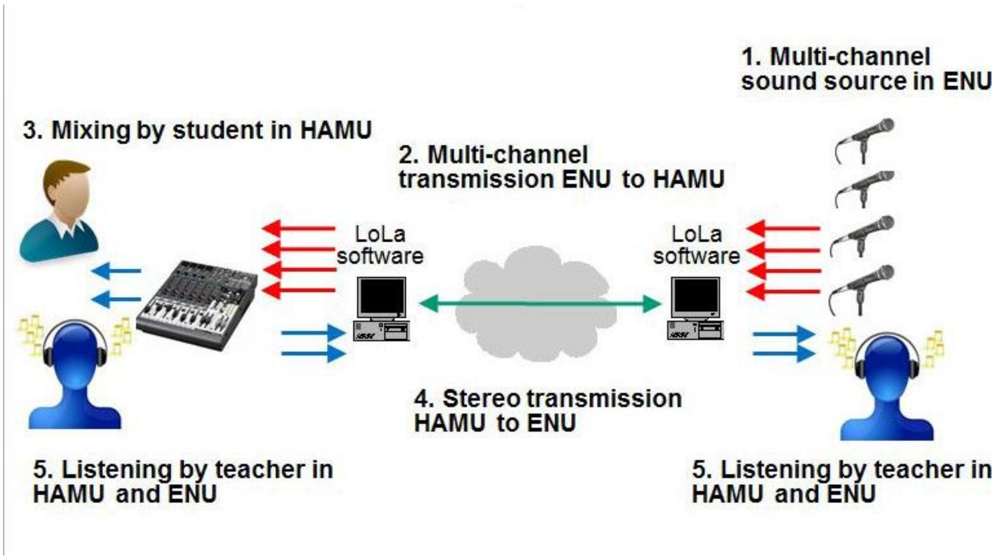

Figure 3.2: The scenario of the remote sound mixing experiment between AMU (Prague) and ENU (Edinburgh)

Figure 3.3: Recording studio in AMU, during the remote sound mixing experiment

4 eCulture performances

An eCulture “cyber performance” has been successfully conducted between Prague and Athens for the Géant symposium. Three musicians and one singer in Prague were performing in real-time together with one musician in Athens. The event was captured on two 4K cameras. As there was a HD projector only and insufficient network connectivity inside the venue building, the picture was transmitted in HD resolution with low-latency JPEG 2000 compression in an FPGA-based 4K Gateway device, along with the LoLa sound and video transmission.

Figure 4.1: eCulture cyber performance between Prague and Athens for the Géant symposium

Video recording with mixed sound from both ends can be seen at:
https://www.youtube.com/watch?v=6121z1AtQZ8

Additionally, we collaborated in organizing a cyber-performance between Prague, Barcelona, Miami and Taiwan for the APAN 38 meeting. Users in Asia at the APAN meeting in Taiwan, demonstrating that real-time collaboration between performing artists in Europe, Asia and America is possible thanks to the latest high-speed networks and transmission hardware and software.

Figure 4.2: eCulture cyber performance between Prague, Barcelona, Miami and Taiwan for the APAN 38 meeting

5 Summary of observations

In this chapter we summarize our observations when talking to performing artists about their experiences and feelings when using the Géant network and the BoD service for their collaboration.

The artists that participated in all our experiments generally felt positive about the technology and scenarios. They missed social contact, but it was compensated by practical benefits of distance collaboration. They considered it useful mostly for rehearsals, both when they play in a group but do not have time to meet physically or with a conductor or a choreographer, who often comes from a different place than the musicians and dancers and remote collaboration allows to get acquainted before the performance. The technology is not intended to be a replacement of the traditional way of rehearsing, teaching and performing, but an additional tool available.

More comments were obtained from musicians than from dancers, probably because musicians need much more precise synchronisation. It seems that the order of importance for comfortable playing music together over distance is good sound, feeling other musicians and good vision of other musicians.

Good sound means not only small delay, but also the quality of sound capture and reproduction, volume, dynamics, space and echo. Feeling of other musicians is related to many complex elements which are not easy to reproduce in a remote setup: musical instruments are objects that create sound in various directions with various spectral characteristics, including reflections from the room - which is different from the remote one. Visual clues like eyes contact are also very important for musicians, even if they use them only at certain points during their performances.

As video can be slightly delayed after audio, due to added delay in cameras and TV screens, which is difficult to remove, it may be needed in some cases to align them, adding some additional delay to the audio if the total latency allows room for this within the comfortable limit.

But in general these problems can be overcome by some anticipation and experience. Indeed professional musicians feel at ease quicker than students because of their experience in performing together in different conditions, including large spaces with noticeable physical delays and constraints. But in any case all reach the comfort level within very few minutes after their first try of these technologies.

6 Conclusions

We can conclude that the Géant network together with the NRENs involved (CESNET, GARR, JANET) provides a sufficiently stable environment and the transmission quality characteristics required for such a delay sensitive audio/video application as the real-time collaboration in musical education among all involved musical schools (AMU, CONTS, ENU). We believe that this finding can be generalized to the rest of the Géant network and the connected NRENs. In extreme cases (between distant countries), delay can be limiting even within Europe.

We encountered some technical issues with the BoD service: These were initial connection instabilities; there is a rather complex user interface, which requires network engineers for its use and it could not be used by users outside ICT (such as performing artists); there were occasional outages of the BoD services (connections could not be reserved through the GUI). However, the Géant technical support was always quick and providing as much assistance as possible.

The BoD service can be potentially useful by providing an end-to-end L2 connection, removing L3 elements in the path, hence potentially reducing packet jitter and latency. However our experiment did not show an evident and measurable advantage in using the BoD service compared to the current overprovisioned best effort services over GÉANT and the NRENs, and in some case the BoD service resulted with worse characteristics than the best effort one. There are definitely applications that can benefit from guaranteed bandwidth, better latency and jitter characteristics, so for the future development, we suggest to focus on examining different network services, implementations, which are simple to deploy and use and which provide information about and ability to request a specific geographical network path. This might be the Géant testbed service being developed.

The impact of the conducted experiments and obtained observations is the following

- We initiated international collaboration among cultural institutions over the Géant network in an European scale, paving the way for a larger scale collaboration among more partners on a more permanent basis in the future.
- Students, teachers and sound engineers in several European performing art academies learned about possibilities of the Géant network for their distance collaboration and have acquired practical experience in this area.
- Géant users have seen how low-latency transmission technologies combined with the Géant network enable real-time collaboration over distance in new fields, such as producing a collaborative cyber performance sharing cultural experiences.

- Enhanced low-latency transmission software LoLa for collaboration in performing arts and specialized graph-based multi-camera transmission software for remote voice analysis for healthcare purposes are available for the community.

- Géant activities in support of distance collaboration in new fields have been presented also to the partner networks and their users in Asia at the APAN meeting in Taiwan, demonstrating that real-time collaboration between performing artists in Europe, Asia and America is possible thanks to the latest high-speed networks and transmission hardware and software.

Appendix A Questionnaire

A.1 Pre-Trial Questions

Which instrument do you play?

For how long have you played your instrument?

Which style of music do you play?

Are you a professional musician?

Do you mainly perform live or are you mainly involved in studio recordings? Or both?

If you take part in studio recordings, do you wear headphones? If not, why?

What aspects do you feel are important to establish a close connection with other musicians while playing/performing?

How sensitive are you to your surroundings while playing? Do you feel you can adapt easily?

What are the factors that you consider important in assessing whether a performance is successful?

Have you played together with a remote musician before? Or have you received a remote masterclass before?

Do you use applications such as Skype or Facetime to connect with people remotely?

Would you describe yourself as being 'technically-minded'?

What music are you going to play?

Why did you choose this music?

How did you prepare for the session with the remote musician?

Did you communicate with the remote musician in advance of the trial?

What are your expectations for performing remotely?

A.2 Post-Best Effort Questions

Could you hear your remote partner well?

How important was is to be able to see your remote partner?

How did you find communicating and interacting with the other musicians? How did this differ from face-to-face situations?

If you felt that you were playing out of time with the remote musician, what did you do to correct this?

How was the quality of music played?

A.3 Post BoD Questions

How did this session compare to the previous session? In what ways was it similar? In what ways was it different?

How was the quality of visual communication with your remote partner in this session? How did it compare with the previous session?

If you felt that you were playing out of time with the remote musician, what did you do to correct this? How did this compare with the previous session?

Did you feel that the quality of music differed from the previous session? If so, in what ways?

Which session was the most effective? Why?

A.4 Post-Trial Questions

If you have previous experience of playing with a remote musician, how did this trial compare to your previous experience?

In what ways are remote sessions similar to co-sited sessions? In what ways are they similar?

Did the quality of music differ from playing with co-sited musician(s)? If so, how?

Did the technology 'disappear' at any point? Did you forget it was there?

Would you be happy to perform in front of an audience where one or more of your fellow musicians was remote?

What are the advantages of remote performances? What are the disadvantages?

For which type of music practice would this technology be most useful?

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