

# Getting Jamulus to work for string players

online string rehearsal with imperceptible latency

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## Abstract

Online rehearsal is perceived to be technically impossible for orchestral musicians and of poor quality. This paper challenges this notion by describing solutions to problems experienced during field tests of the Jamulus software designed for real-time online rehearsal in the summer of 2020. Motivated initially as a response to restrictions placed on music rehearsal during the pandemic, but also to determine if a working online rehearsal model could be established, whether to overcome long distances traveling to meet other players or to counter diminished support for arts practice in general. The article identifies the key issues which cause many musicians to dismiss online rehearsal as unworkable. Each element in a 'series configured' chain of criteria necessary for the system to work, is clarified, explained and justified. Invariably, the popular consensus that online rehearsals are unrealistic for string players is reinforced by the absence of one of nine criteria described in the article. Field tests have shown that when these criteria are adhered to without exception, then, online rehearsal becomes a realistic proposition and a powerful tool in the musicians studio, which can complement and support conventional teaching and rehearsal methods.

## Keywords

*Ethernet, Interface, Jamulus, Jitter, Latency, Ping*

## Overview

Jamulus as described by Fischer (2015) is an open source software package which allows musicians to rehearse together in real-time with near zero latency (50/1000 parts of 1 second is barely perceptible). This is achieved by streaming the live rehearsal to a central server located geographically between the musicians using User Datagram Protocol UDP over low bandwidth networks. Jamulus is an audio only platform. The server located between the players (ideally inside a 300km radius), redistributes the audio back to each client in real-time. It is a relatively simple concept but relies on the data packets being sent to be both small in size and consistent in nature. It does not work on mobile devices as they are reliant on wireless communication topology which uses larger data buffer sizes.

Sources of latency of which there are several, and configurations which rely on large data packet exchange must be eliminated for the system to work. This is more difficult to achieve without care and is the main reason why string players are quick to dismiss the concept as unworkable. The article focuses on oversights and interrogates each omission as a singularity. It does this using non-technical language and lists each issue in a logical manner as omission of any single component will result in the system not working.

The article 'Jamulus got us out of a jam' Early (2020), came ahead of field testing of the system and some items which were flagged as recommendations transpired to be mandatory. Having worked through many of the difficulties and setbacks configuring and running the software for young and adult musicians, the present article flags the impediments which were encountered by string players, and shines a light on aspects of the setup which prevented some players from realising the potential of the system and in other cases, rejecting it altogether. In order to make Jamulus part of an everyday practice routine where it can be relied upon by practicing ensembles and working musicians at the click of a mouse, it must be set up properly with a

reasonable level of understanding about what can go wrong and why, aside from the ability to work objectively at rehearsal.

The article will firstly address an aspect which is outside of the control of the users, as if this aspect cannot be resolved, there is little point in continuing. It then examines everyday elements which are within the control of the average musician.

## **Theory**

Sound travels at 1.125 ft per second in 20°C. This is just over one millisecond for every foot of distance travelled. A 30ms delay would therefore equate to being about 33ft from the person you are playing music with. Latency over the internet produces the same type of sound effect (a rapid echo) and can become a distracting influence when playing online if it increases more than 50-100ms. We are trying to minimise this effect therefore at every stage of the process from the audio data leaving your computer, arriving at the server which is hosting the rehearsal, and returning to your computer, – the equivalent to being as close to the player as is acoustically possible. There will always be miniscule latency present in the sound coming back to you during rehearsal which is about 30 parts of 1000 parts of one second with ideal conditions but this is barely perceptible.

## **First considerations**

The starting point in preparing your setup for the application is to look at your internet provision. A common mistake is to survey the upload or download speed for guidance using an online speed test service. It has become apparent that this is the wrong approach to take. When downloading the Jamulus app it is stated that you require less than 300kb of connection speed for up and downstream transfer. So speed is not the issue. What is a critical consideration however using the UDP data transfer protocol mentioned earlier is the degree of 'Jitter' present as this aspect will determine to a large extent the sound quality and your experience with Jamulus. Stephen O'Reilly who has brought choirs in Europe together on the Jamulus platform explains jitter as follows.

'Jitter is defined as variations in the trip time of a stream of data, audio data in this case, which means that portions of that data stream arrive with bursts and gaps and sometimes in a different sequence than which it was sent. Combining this back into a smooth stream is done by the jitter buffer. Jitter can be caused by busy or overloaded routers, route balancing and redirected packets along the route. Jamulus will cope with a small amount of jitter which is to be expected on the internet, but higher levels of jitter will degrade the audio stream and it will sound warbled, watery, with clicks and pops. A test for a clean low jitter route can be done with **ping**, a command line utility available in Mac Windows and Unix. You can ping your chosen server or a well-known server on the internet to see what the variation in reply time is.' O'Reilly (2020)

The audio signal which you generate is traveling from your computer to the nearby server and directly back to your computer. Jamulus uses small packets of audio data and transfers them to and from the server at regular intervals). The flow of this data will be interrupted if there is a *variation* in the travel time of the individual packets of data. This variation is the most troublesome issue experienced in the field tests and is the hardest to resolve as it is for the most part out of your control. You must therefore examine the ping variation on your machine to rule in or out the possibility of the platform working on your internet line before you go any further. If the ping variation is too great (more than 2ms) you will have to look for another internet source. Remember, this does not require huge bandwidth but rather quality in relation to ping variation.

Mandatory requirements are summarised as follows -

- 1 Ethernet connection**
- 2 Low ping variation internet**
- 3 Jamulus software**
- 4 Instrument microphone**
- 5 Audio interface**
- 6 Regular headphones**

## 1 Ping variation inside

In order to check the ping variation outside your home, you must firstly eliminate ping variation inside your home. Impediments to ping stability begin with Wi-Fi signals on which home computers communicate with the internet today. When using Wi-Fi as has become the norm, data transmission is sent to the router in large bursts with gaps between each packet. In addition, Wi-Fi uses buffers which are far too large to allow for a short round trip time for the data to follow. (A buffer is a memory storage capability used to temporarily store data while it is being moved from one place to another). In order for Jamulus to deliver a steady stream of audio as UDP protocol requires, small and consistent packets of data must be sent and received with minimal gaps between them.

By connecting an Ethernet cable from the router to your computer, variation of ping can be overcome and to achieve this a Cat5 Ethernet cable is used. The Wi-Fi connection on your computer should also be disabled to ensure that the signal is following the Ethernet cable path. Powerline Ethernet extenders over long distances are not satisfactory as they add another layer of latency which is caused by encoding delay issues. The shortest distance to the router will produce the best results.

Power saving features and automatic updating should also be disabled as these features cause the processor to lose power or be intermittently unavailable for maximum operation which should be exclusively given over to the Jamulus app during the rehearsal.

Another factor to consider is when your router is being shared by other computer users or similarly when mobile phones are making online calls over in the same router network during the rehearsal. These factors will result in internal data transmission time variation from your computer to the router/ internal ping variation which will translate into disturbance in the audio quality in the virtual space.

## 2 Ping Variation Outside

The data usage in Jamulus is measured in kilobytes rather than megabytes, so bandwidth and internet 'speed' is not the issue here and should not be confused with ping variation which is the issue. If there is variation of more than 2ms in the ping transmission time between your computer the server and back, (either outside because of substandard internet provision or inside because of Wi-Fi connection to the internet and other items mentioned) this will also result in disturbing interference in the sound quality. Both sources of ping variation must be scrutinised as the other criteria will not be capable of delivering trouble free online rehearsal without it. All elements in the chain are equally important without exception and Ethernet cable and a minimal ping variation are the first two links in that chain.

Having connected the Ethernet cable conducting the ping variation test for outside is achieved on mac computers by doing a Network Utility search and then running the ping test. The ping speeds on the right-hand column of the readouts indicates the degree to which the ping signal is varying in milliseconds. Ping tests are available as a command prompt in Windows; Start-Programs-Accessories-Command Prompt, and with Mac operating systems it is available through the Network Utility search. However, another way to examine this as stated earlier is from within the jamulus settings window itself.

Accepting that you have a steady ping time with little variation (in the region of 10ms or less but varying at most 1ms above or below a constant) it is then possible to proceed to the next item.

```
time=6.676 ms
time=6.608 ms
time=6.715 ms
time=6.473 ms
time=6.713 ms
time=6.731 ms
time=6.535 ms
time=6.800 ms
time=6.639 ms
time=6.785 ms
```

```
time=14.552 ms
time=26.163 ms
time=13.026 ms
time=11.041 ms
time=26.496 ms
time=14.079 ms
time=16.013 ms
time=21.589 ms
time=13.262 ms
```

*Minimal ping variation is suitable*

*Erratic ping variation is unsuitable*

### **3 Download the app**

The Jamulus app version 3.6.0 is available from sourceforge.net. It is only necessary to download and activate the Jamulus app and not the Jamulus server app, in order to link to an existing rehearsal session. If you intend to create your own server at a later stage to host your own private rehearsals you will need to set up a separate hosting platform discussed later. Load the app and make the necessary security setting adjustments on your computer to allow the app to run.

Having loaded the app, connect to an available low latency public server from the Jamulus window to test your equipment. You can tell if a host server is vacant, as participants taking part in active public sessions are listed under a host name. The first test to run is available within the Jamulus settings window. The settings panel accessed from a button in the main Jamulus window contains features which will help you navigate the virtual rehearsal space. The first ones to be aware of are on the bottom right hand corner of the settings window relating ping time and overall delay. This is an indication of your current ping variation described earlier only now from within the Jamulus application, and indicates the round-trip time of your audio data to the server hosting the session and back to your computer in real-time – the overall delay and the ping time. This gives the clearest indication of the audio quality you can expect during the rehearsal. The longer the overall delay, the more you are going to perceive the presence of an echo and the smaller the ping variation taking place, the smoother the audio sound can be expected without interruptions, cracks or pops.

### **4 External Microphone**

The quality of the sound you produce in the virtual space for others to hear is firstly determined by your microphone. Many possibilities exist for getting your sound to the computer and on to the virtual rehearsal space. Obvious ones include: the internal microphone on the computer; an external USB microphone; a mini adaptor; a headset with built in microphone; a set of Wi-Fi buds with a microphone. All of these options however are unsuitable for use with Jamulus and are guaranteed to prevent the system from working properly. The sound from your instrument, when it arrives at the rehearsal space (which remember is in another location entirely) will need to be of the highest sound quality possible. All of the options outlined above have produced unfavourable results and much frustration and have been ruled out for the following reasons.

Firstly, an internal microphone on your computer will also pick up the sound of the fan in the computer if it switches on and off, and also necessitates you playing in front of it. Several players doing this alone already creates audio limitations. USB microphones are not suitable for use with Jamulus as they don't usually have ASIO compatible drivers. Low cost mini adaptors which allow an external microphone to be accessed by your computer sound card have sub-standard preamps built into them or none at all and also introduce low quality sound and noise.

Headsets with built in microphones again have mixed quality sound processing capability and in addition, run the risk of their speaker sound being picked up by the microphone component. causing a feedback loop in the virtual rehearsal space. Wi-Fi- earphones or buds add another layer of latency and also cause feedback issues with varying sound reproduction.

A microphone custom built for a stringed instrument can be purchased for less than €50 such as the t.bone Ovid System CC100. An additional clip for a violin/cello is a separate purchase. The advantage of this in addition to solving the above problems is that the sound heard in the virtual space is of consistent volume, timbre and quality as the microphone is clipped directly onto the instrument. If you consider a virtual space where 10 participants may have varying quality microphones you can appreciate how the overall experience for the players will deteriorate greatly given this is just one component of six aspects which must be satisfied, if all links in the chain mentioned earlier are to be undertaken by each participant. The quality of your microphone will not affect you, it will greatly affect your sound as experienced by the other players however.

### **5 Audio Interface**

The audio interface fulfils several important functions. Firstly, it provides the hardware connection between your microphone (usually a 3pin XLR or a TRS 6.5mm jack) and the computer. Even a good quality condenser

microphone will have very little signal output and the interface provides 48v of phantom power to boost the signal and increase the sound/noise ratio. Furthermore, an audio interface converts the analog signal to a digital signal and visa versa and further enhances sound quality with additional signal processing circuitry. Again, overlooking this requirement will result in failure as this configuration equates to the next link in the chain to be undertaken.

The interface also provides gain controls for one or two microphones depending on the model. A second microphone can be helpful as in the virtual rehearsal space, a single microphone connected to the instrument, particularly a cello will not sufficiently pick up the player's voice which will make it difficult for the cellist to engage with the players during rehearsal. Violin players can more easily talk directly into the microphone on their instrument when conversing with the other players. There is also a headphone volume control on the interface which is essential for adjusting the sound level in the earphones independently of the mixer on the Jamulus session window.

Jamulus works for Mac, Windows and Linux operating systems. However, there are differences which should be noted in relation to the interface. The Mac operating system does not require a separate audio driver to be installed whereas the windows operating system does. The added driver adds about 10 ms to the mix. A low cost interface such as the Behringer U-Phoria UMC22 is recommended. The driver for this is available at <http://recordingstudio9.com/about/download/> The driver BEHRINGER\_2902\_X64\_2.8.40 must be loaded firstly on a windows operating system before connecting the interface as directed during the installation process.

*'Using Jamulus without a reasonable audio interface will introduce low quality sound and increase low level noise in the virtual room. It also increases the complexity as the ASIOFORALL driver is tricky to set up and keep working.'*  
(O'Reilly,2020)

More expensive interfaces with Thunder bolt connection to the computer shave about 5ms off the overall latency and are not considered to be essential.

## **6 Wired Headphones**

It is essential to use conventional wired headphones during the rehearsal and not allow the sound of the rehearsal to be played on external speakers or piped into your sound system. As stated earlier, you don't want the sound of your instrument coming back to you after it has been picked up by the microphone of one or more other players. This will firstly be out of sync with the audio of the rehearsal and will also setup a feedback loop which will bring the rehearsal to a halt as players try to establish which of the offending faders will need to be muted. Wireless headphones are unsuitable because of they can add latency and may generate sound quality issues.

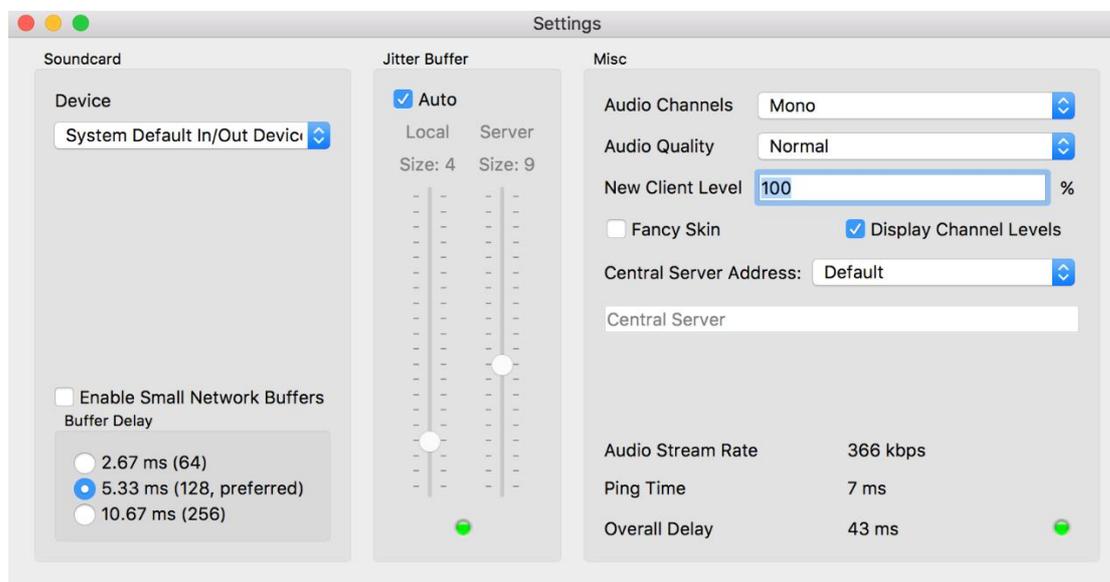
## **The Process**

Jamulus works when all of the participants connect to the nearest or lowest latency server available in the Jamulus window. Alternatively the participant can join a private server set up by one of the group in the vicinity of the players to receive and redistribute the players audio. The sound of the rehearsal is sent to each player at the same time from the central server which each player connects to when joining the session. The easily obtainable ideal of 50ms of overall delay (50/1000 of 1 second) is a near latency free environment to work in in real time. When players are immersed in the work of the rehearsal, this tiny delay is no longer perceptible.

Field tests have show that the number of players who can join a session is limited more by the level of musicianship and their ability to address the technical issues rather than the capacity of the software to accommodate the participants. The latest software can handle as many as fifty participants and more in some cases. It would be prudent however to limit the number of participants for the following reasons. Consider that each link in this six component chain of criteria: low variability of outside ping signal; low variability of internal ping signal/Ethernet cable; quality microphone; audio interface; cabled headphones and a reliable computer, quickly becomes twenty-four components in the chain for a modest string quartet to have a successful rehearsal. With ten players this number runs to sixty links all of which must be addressed. It becomes apparent that 4, 8 or 12 players would really be ideal as each section can be doubled or tripled with ease ensuring the support and balance of parts.

Orchestras intending to hold larger rehearsals would be advised to employ the services of a sound engineer or IT professional to configuring each computer remotely and ensure that all criteria are adhered to without shortcuts. Testing internet suitability, compatibility of devices and consistency in sound production during rehearsals in addition to mentoring players who are new to the system should be undertaken at a professional level as the complexity increases with larger numbers of players.

## Adjusting the Settings



Jamulus settings window

‘Device’ should be set to your pre-connected interface for both input and output. ‘Enable network buffers’ allows support for very small network audio packets. ‘These are only used if the sound card buffer delay is smaller than 128 samples. The smaller the network buffers, the lower the audio latency. But at the same time the network load increases and the probability of audio dropouts also increases.’ (GitHub, 2020)

Jitter is the variation in time between data packets from your computer arriving at their destination, caused by network congestion or route changes and is measured in milliseconds. ‘The overall delay is the sum of the internet and audio interface latencies, the complete time it is taking for each bit of sound to reach your headset from your mic. The jitter is the differences in the overall delay.’ (O’Reilly, 2020)

‘Jitter Buffer’ in settings is a temporary storage buffer used to capture incoming data packets. It is used to ensure the continuity of audio streams by smoothing out packet arrival times during periods of network congestion. Crackling sound is due to lost packets. ‘What we’ve done in choir to reduce this is to switch the auto-buffer off and manually increase it a bit from the auto-set setting.’ (O’Reilly, 2020). In order to strike a balance between the latency and audio quality, Amsden (2020) concurs ‘Reduce the jitter buffer size (latency) until dropouts become unacceptable, then increase the buffer size a little to account for network timing variation.’ (Amsden, 2020)

The remaining items in the settings window; ‘Audio Channels’ should be configured so that you have sound in both ears. If using two microphones - stereo in and mono out, if using one microphone - mono in and mono out; ‘Audio Quality’ should be set at normal or high; ‘New Client Level’ when set at about 20% will let you know at least that someone has entered the session without their volume or settings disrupting the rehearsal. This is helpful to mitigate against late arrival interruptions; ‘Fancy Skin’ option displays in white on black; ‘Display Channel Levels’ should be turned on and the ‘Central Server Address’ should be set at default. The green lights indicate that your system is working properly.

## Private Server

It is not necessary to set up your own private server to start rehearsing on Jamulus. Most of the public hosts sites are unused and vacant. You may want to establish your own private server in order excluded others from joining. This however can already be achieved by clicking the solo button on your Jamulus window fader, to select players whom you wish to exclusively play with. A private server is a more long term solution but it is not a substitute for individual participant requirements already covered. A private server whether at home or on the cloud will not mitigate individual players' internet ping variation issues, or any of the other mandatory set up requirements which each participant must fulfil. Setting up a server may require some technical help as it is outside the scope of the average person's computer skills. A basic overview of the process is outlined here with some points worth noting.

You can host your own server either at home or on a cloud host such as Amazon. It is recommended that you don't run the server hosting the session and the client from the same machine (Mountford, 2020). Running any other programs on the same computer as Jamulus is likely to affect the ping variation, which is the most critical element to maintain quality audio data transfer over the internet using the UDP protocol.

The server will require an average of 250Kbps per player, so if you have only 1Mbps upload and download available, you will run out of bandwidth after 4 players. Also, servers should have at least 1.6GHZ CPU frequency and 1GB of RAM. In setting up home servers you need to be familiar with port forwarding procedures, the local IP address of your Computer, the local IP address of your Router and your Public IP address. These are found on Windows- /Settings/Network and Internet/Ethernet, and on Mac – System preferences/Network. The public IP address can be found in Google by doing a search for your IP address. These three IP addresses are required in the process and should be copied to the clipboard.

A hosted server on a Google or Amazon cloud platform is a more reliable option than a residential server. The basic steps include creating a Google cloud platform GCP account. On this you then create a virtual machine VM instance. The network interface details and port forwarding details are then configured. The Jamulus server application is then installed and firewall rules established to allow Jamulus traffic through the server. The UDP 22124 protocol is specified and Jamulus configurations are compiled on the cloud server. The external IP address of the server is the one that musicians will use when joining the session. There are also adjustments depending on whether you wish the server to be public or private. The procedure is described in detail (Mountford, 2020) and online postings by *Sourceforge* and the *C4 Ensemble*. For a detailed explanation of the process followed setting up a private server on Amazon Lightsail see (Crean, 2020).

## Avoiding Shortcuts

Some players may overlook the need to adhere to the set-up criteria and run into difficulty or causing problems for the others. For even a modest rehearsal project such as a string quartet or something similar to take place successfully, if just one player omits just one of the criteria described, it is likely that whole group will be disappointed. A single item which is left out by one player alone, affects the other players rather than the one who has left it out, making the solution more difficult to isolate and rectify.

For example, let's say the 1<sup>st</sup> violin completes each stage of the chain meticulously but omits to use a set of headphones with a cable and instead uses Wi-Fi earbuds. The second violinist completes each stage but omits to use a microphone that is attached to the instrument. The viola player fulfils each criteria but overlooks the Ethernet cable and instead uses Wi-Fi and the cello decides to use a USB microphone without an interface or worse still the computer microphone because of difficulties getting a USB microphone to communicate with a driver.

All players will experience fan noise from the cellists computer signal feed, a crackling sound from the viola players feed caused by pops from large bursts of data being generated by the viola players Wi-Fi signal. In addition he or she will experience variations in volume from the 2<sup>nd</sup> violin as their proximity to a free standing microphone alters throughout the rehearsal. Furthermore the viola player will have generated a different order of latency to the other players without the Ethernet cable and therefore will appear to the other players to be unable to stay in time.

Each of the 4 players will have similar types of unsatisfactory experience caused by the combined effects of each player's omissions. This is unfortunate given the fact that the rehearsal is quite capable of being conducted in real time without a latency issue. Subsequently, the limitless potential of this approach to online rehearsal is prematurely dismissed.

Conversely, four musicians who have checked each box in terms of the criteria chain set out for them, are familiar with working from the score, and who test their own equipment fairly regularly prior to rehearsal with others, will have a much more gratifying experience and share in the benefits of being truly 'in' a rehearsal zone, much more frequently. This approach does not set out to replace conventional rehearsal, but when its reliability is better understood, it can become a powerful low cost tool in a musician's armoury and help regularise and future proof preparations for live music making.

### **The Virtual Space**

Musicianship is an important aspect of online rehearsal and cannot be substituted with anything less than full preparation as would be expected in a conventional rehearsal. Because so many variables will determine the success of the rehearsal, it is important to minimise obvious oversights and to proceed with the same level of attention (if not more), as would be given a conventional rehearsal. There is no visual component with the Jamulus software. To introduce another platform like Zoom to work alongside Jamulus for visual backup would interfere with the audio quality as the processor grapples with the extra load putting ping stability in jeopardy. It is therefore essential that the players come adequately prepared and learn to listen carefully to the flow of the rehearsal.

### **Conclusion**

A working model for string players to participate in online rehearsal without perceptible latency has been described. Field tests have shown the parameters in which the system must operate and conditions which cause it to fail have been explained. In a short space of time, players can become accustomed to working in the newly created virtual real-time audio space, challenging the popular narrative that online rehearsal is not possible. In fact, Jamulus software demonstrates quite the opposite. String players working initially from a score can become quickly immersed in rehearsal work, online. It's a reliable low cost addition to the tools at the musician's disposal. It bridges the gap caused by restrictions on rehearsals and creates potential for continued self-improvement at the click of a mouse. It has the potential to become an important enhancement to face-to-face rehearsal.

## 9 Point Checklist for a string quartet

All 36 boxes must be checked

Player	Ping Stability Inside/Ethernet	Ping Stability Outside	Instrument Microphone Attached	Interface Driver Installed/Windows	Audio Interface Connected	Headphones with Cable from interface	Jamulus Version 3.6	Exclusive Internet Access	Music Score and parts
Violin I									
Violin II									
Viola									
Cello									

Write your first name and instrument into your profile in the Jamulus window ----  
Top left /View /My Profile so that other players can recognise your fader on their mixer.

### Check List for the Jamulus Settings Window

Set Device to interface that you are using for both in/out in dropdown menu.

Set Preferred buffer delay to 5.33ms.

Tweak jitter buffer settings to obtain best sound quality vs. latency

Set Audio Channels to Mono in/Stereo-out

Set Audio Quality to High

Click ON Display Channel Levels

Set new client level in settings to 0 to minimise being distracted by latecomers

Set Central Server Address to Default

Observe Ping time for large jumps (this will indicate a ruffled or crackly sound that might need to be addressed before rehearsal begins)

Keep overall delay to below 50ms

### **Things to observe when running the test**

Switch off other applications on your computer

Connect to a public server with lowest latency - at the top of the connect options

Run the test beforehand by listening to and tweaking your own return sound unmuted.

Large variations in ping time, predicts a poor quality sound experience more so than your internet speed

Look for exclusive use of internet during rehearsal to avoid demands on data flow and computer processing disruptions from phone calls using data etc.

Power saving options on the computer should be disabled

Keep your overall delay to less than 50ms

Obtain private server address from session organisers for rehearsal if available

### **Checklist for getting the most from the rehearsal**

Treat the online rehearsal with the same level of preparation as a regular rehearsal if not more.

Follow all 6 points for getting it to work without omitting any of the criteria.

Conduct a sound test in advance of the rehearsal to iron out any difficulties you haven't anticipated.

Set all of the players balances for your listening during a sound check before rehearsal commences.

Cultivate the ability to maintain a steady meter without a metronome.

Train yourself to play slightly ahead of a 30ms delay rather than waiting to hear it before playing.

Work with the music score in sections initially to get a sense of which voice is leading or carrying the meter at any given time.

Use a metronome at times to help synchronise parts, particularly at the early stages of learning a piece.

Allow spontaneous counting by a player in problem areas when required.

Finally, try playing the entire work together from your part with the ensemble.

## References

- Amsden, J (2020) *Remote jamming with helix and Jamulus*  
Available from  
<https://jimamsden.wordpress.com/2020/04/04/remote-jamming-with-helix-and-jamulus/>
- Crean, E. (2020) *How to set up a Jamulus server on amazon lightsail*  
Available from  
<https://www.dropbox.com/s/yh766tzvqz6yuti/How%20to%20setup%20a%20Jamulus%20Server%20on%20Amazon.docx?dl=0>
- C4 Ensemble *Jamulus server on GCP quick start video*  
Available from  
<https://www.youtube.com/watch?v=9anNmobd5aY>
- Early, P. (2020) *Jamulus got us out of a jam.*  
Available from  
<http://www.iayo.ie/news/jamulus-article-patrick-early/>
- GitHub (2020) *Jamulus instruction manual.*  
Available form  
<https://github.com/corrados/jamulus/blob/master/src/res/homepage/manual.md>
- Fischer, V. (2015) *Case study: performing band rehearsals on the internet with jamulus.*  
Available from  
<https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwjwgpDBmfnsAhUSXRUIHd4EAFs4ChAWMAF6BAgBEAI&url=https%3A%2F%2Fjamulus.io%2FPerformingBandRehearsalsontheInternetWithJamulus.pdf&usg=AOvVaw2GxJTx7OOHzxV0pHnbuVQg>
- Mountford, B. (2020) *Running a Jamulus server.*  
Available from  
<http://www.c4ensemble.org/remote-live-server.html>
- O'Reilly, S. (2020) *Jamulus introduction and pre-requisites.* Available from  
<https://www.singireland.ie/content/files/Jamulus-intro-and-pre-requisites-Updated-161120.pdf>
- Sourceforge *Running a server*  
Available from  
<https://jamulus.io/wiki/Running-a-Server>

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