A FRAMEWORK FOR REAL-TIME ONLINE COLLABORATION IN MUSIC PRODUCTION

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ABSTRACT

This paper presents a potential hybrid framework that addresses the limitations of established approaches to online collaboration. The framework seeks to unify the benefits and efficiency of real-time interactions with multiple concurrent collaborators while preserving the high definition and integrity of the undertaking's audio.

The degree of collaborative online interactions between musicians and producers from around the world has become progressively more sophisticated with increasing needs in bandwidth and computing processing power. However, a prevailing general dichotomy exists in collaboration architectures: synchronous one-to-one or one-to-few, or asynchronous one-to-many or many-to-many, frameworks.

An examination of existing collaboration platforms and practices notes that high-definition audio streaming over the Internet limits the number of simultaneous participants. Accessing bespoke cloud storage for distributing audio content, however, can avoid the need for data-intensive transmission in real-time, and synchronous streaming of remote control data and rudimentary videoconferencing can facilitate real-time music production collaboration.

1. BACKGROUND

While the concept of music producers collaborating in an online environment is not a new one, developments in the ubiquitous Internet-connected environment has been the catalyst for recent advances in collaborative platforms for music-based activities. Instrumental music teachers, for instance, have adopted videoconferencing applications, such as Microsoft's Skype, to facilitate long-distance instruction (Ajero 2010; Callinan 2005; Dammers 2009; Pike and Shoemaker 2013), and telematic performances (Iorwerth, Moore, and Knox 2015; Rofe, Murray, and Parker 2017). Online communities of musicians have taken advantage of software specifically designed for real-time 'jamming', such as MusicianLink's jamLink and Syneme's Artsmesh to overcome geographical distances and collaborate on a truly global scale. Common to these synchronous approaches is the streaming of high-definition audio, which is intrinsically bandwidth- and processor-intensive. The transmission of audio from a local network to the Internet can subject the data to latency and loss that adversely affect the sound quality. Synchronous collaboration typically limits the total concurrent connections to one, or a very small number, accordingly minimising the effect of these limitations. Additionally, the inherent advantages of a synchronous approach support remote high-definition audio recording and monitoring, instantaneous decision making and time-efficiency.

Audio streaming capabilities have also found their way into widely-available Digital Audio Workstation (DAW) software applications, either through the integration of third-party platforms such as Source Elements' Source-Connect Pro, or, in the case of Steinberg's VST Connect Pro and VST Connect Performer, as extensions of Steinberg's DAW platform, Cubase Pro. Such approaches provide for synchronous collaboration but are typically restricted to a limited number of participants, due to the data- and bandwidth-intensive nature of high-definition audio streaming. Direct integration of an audio streaming mechanism with a DAW affords the facility to compensate for networking latency, and undertake post-session file restoration or replacement with locally-stored lossless audio. (Source Elements 2016b; Steinberg Media Technologies GmbH. 2014).

In asynchronous, multilateral frameworks, various collaborators upload/download audio data from a central cloud repository and collaborate off-line. Sharing newly-recorded or edited audio is performed post factum, resulting in protracted discussions (often text-based), increases in revisions, or indeed abandoning existing work altogether. In this context, the musically creative and time-efficient natures of synchronous approaches no longer exist.

DAW-integrated online file sharing amongst multiple collaborators had its origins in the Rocket Network, introduced in 1998, and integrated a year later into Steinberg's flagship DAW at the time, Cubase VST (Price 2001; Thornton 2006; Walker 2005). This integration features, for example, in the latest versions of Cubase Pro and Avid's Pro Tools DAW platforms, which utilise private cloud storage as a central repository for a project's assets and settings. Known as VST Transit and Cloud Collaboration respectively, collaborators can download and import tracks and parameter settings directly into their local version of a project, make contributions or edits, then upload their latest version back to cloud storage for dissemination to all other group members. This mode of collaboration, however, sacrifices a synchronous workflow in favour of increased participation.

Owing to current Internet-specific networking limitations, the desire of musicians to work with high-definition audio assets in a synchronous collaborative environment necessarily consumes significant bandwidth that limits the number of active connections. Enhancing an online collaborative model's inclusivity to encompass a more significant number of participants, unavoidably shifts its mode of operation to an asynchronous paradigm. What is currently lacking, and what this paper focuses on, is a framework that delivers online music production collaboration in a synchronous, multilateral manner while working with high-definition audio assets.

An important distinction to draw at this point is between the concept of 'real-time'—of performing synchronous interactions—and the reality of streaming data over the Internet. Intrinsic delays in network streaming applications are inevitable. Therefore 'real-time' does not equate to 'instantaneous'. The very nature of a network such as the Internet, with its myriad intervening connections, traffic congestion and distances travelled, dictates that incremental delays will accrue as data travels from server to client. Therefore, the proposed framework seeks to not only minimise delay but also minimise the inevitable effect delay has on the collaboration.

2. RELATED WORK

2.1. Existing Platforms

Current and previous online platforms employed for music-focused collaboration fall into the following categories:

- Videoconferencing with or without an application sharing facility
- Audio streaming via a web browser-based application
- DAW-integrated audio streaming
- DAW-integrated cloud storage and file sharing

Contemporary examples of these categories include:

- Videoconferencing with or without application sharing:
  - Skype (Microsoft Corporation 2018a)
  - TeamViewer (TeamViewer 2018)
  - Microsoft's Skype for Business (Microsoft Corporation 2018b)
  - Cisco's WebEx (Cisco Systems Inc. 2018)
  - Zoom Video Communications' Zoom (Zoom Video Communications Inc. 2018)
- Web browser-based audio streaming:
  - Source Elements' *Source-Connect Now* (Source Elements 2018)
  - *Cleanfeed* (Cleanfeed LLC 2018)
  - *Zencastr* (Zencastr 2018)
- DAW-integrated audio streaming:
  - *Source-Connect Pro* (Source Elements 2016a)
  - VST Connect Pro/VST Connect Performer (VST Connect Pro, 2014)
- DAW-integrated cloud storage and file sharing:
  - *Cloud Collaboration* (Avid Technology Inc. 2018)
  - *VST Transit* (Steinberg Media Technologies GmbH. 2018)

2.2. Previous Work

A recent article submitted to the Journal of Technology in Music Learning written by the authors surveyed the collaboration platforms above, and their associated practices, which consequently informed the framework's design. The survey aimed to answer the questions:

> *What are the characteristics of an online, multi-user, collaborative platform that enables synchronous interactions with a universally-accessible high-definition music production project? Secondly, to what extent do the currently-available platforms meet these characteristics?*

Completing the survey assisted in developing a short list of essential characteristics that a novel and effective synchronous multilateral collaboration framework for music production should possess, specifically:

1. Equal access to, and synchronous control of, a shared music production project amongst all collaborators
2. Capability for engagement with data-intensive, high-definition audio assets

3. Latency compensation for synchronised playback and recording
4. Cost-effective hardware and software resources
5. Audio/Video communication streams

All of the current platforms surveyed fell short of satisfactorily meeting all five essential characteristics for synchronous group collaboration in music production. Table 1 collates the data generated from the survey.

Consequently, what follows is a proposed framework that aims to provide a synchronous, multilateral collaborative platform meeting all the characteristics above. The framework's central premise derives from the decision to not stream high-definition audio in real-time, owing to its restrictive and exclusory nature. Instead, control and note data, generated by the participants and mirrored by the music production software, is streamed across the collaboration to synchronise and align all instances of the DAW project.

3. THE PROPOSED FRAMEWORK

3.1. Introduction

This section provides some background on the key facets of the proposed collaboration framework. It focuses on three integral components (Fig. 1) for online music production collaboration, namely:

1. A multi-user platform for music production activities
2. Data capable of providing control of the music production platform
3. Networking consequences for transporting the control data over the Internet

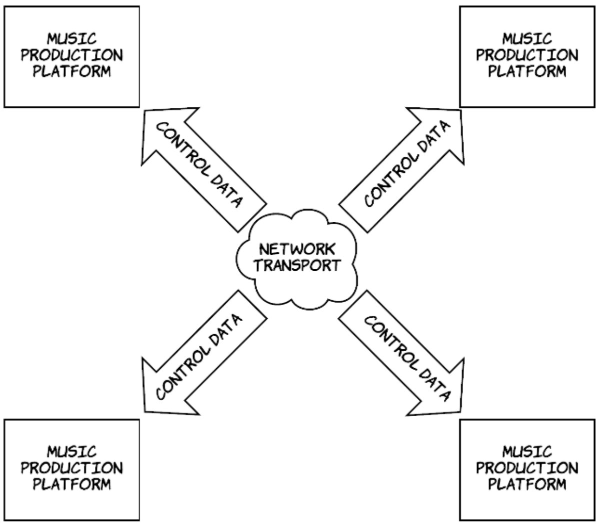

Figure 1. The three integral components for online music production collaboration

It is not unreasonable to begin the process of constructing an online collaborative framework in music production around the most ubiquitous music production tool today, the DAW. The prevalence of DAW software applications in professional, educational and home studios makes it the most obvious choice in conducting music production activities. Just as a mixer console is the hub of studio and live sound purposes, the DAW provides a virtual mixer console for online endeavours around which, traditional and modern production techniques can be accessed and executed.

The framework aims to integrate multiple remote instantiations of the same DAW platform, all with the same open musical project. Facilitating the integration is streamed control data that encompasses the DAWs various operations, including the creation of new material and editing of existing material, using industry-established studio production techniques, performed at one location and synchronously reflected at all others.

The streaming of data in a real-time environment is typically confronted by issues that intrinsically hamper the undertaking's synchronised nature, in particular, latency and reliable delivery of data. Latency is the sum of various delays incurred in the generation, transmission and reception of data packets, and over a Wide-Area Network (WAN) such as the Internet, can be unsteady without the instigation of specific management protocols. Furthermore, data packets can be lost during transmission, or arrive at the receiver out of their intended order, posing critical complications for music performance collaboration where accuracy is an essential character. The Transmission Control Protocol (TCP) does offer reliable delivery of data over the Internet, but also incurs higher latencies due to the establishment of network connections, and the retransmission of lost and out-of-order packets. Alternatively, the User Datagram Protocol (UDP) forgoes such reliability in favour of lower latencies but has no facility to deal with lost data. Hence delivery is not guaranteed. However, the Real-Time Protocol (RTP), which typically travels over UDP, can provide a degree of reliability, error correction and strategies for lost data that make real-time streaming via UDP a viable option. Together with the Real-Time Control Protocol (RTCP), the delivery of multimedia packets is monitored for any transport issues and initiates action to mitigate their effect.

3.2. The Framework

Figure 2 provides an overview of the proposed collaboration framework, as deployed at a single node, purely regarding data generation and transmission. The success of the framework is dependent on the efficient transfer of the control data:

- From a local controller, and the other collaborators over the Internet, to a local DAW project
- From the local DAW project to the other collaborators over the Internet

	Synchronous	Multilateral	Equal Access	High-definition Audio	Latency Compensation	Cost Effective	Communication Mode
Videoconferencing (e.g. Skype, Zoom, Cisco WebEx)	✓ Online real-time interactions	✓ Up to ~100 participants	✘ Only session host	✘ Lossy Opus codec, up to 510 kbps only	✘	✓ Free	Audio/Visual
Videoconferencing & Application Sharing (e.g. Skype for Business, TeamViewer, Cisco WebEx Training Centre)	✓ Online real-time interactions	✓ Up to ~1000 participants	**Limited** Only one user at a time, and only during the session	✘ Lossy Opus codec, up to 510 kbps only	✘	✓ Modest annual subscription fees	Audio/Visual
Videoconference, Application Sharing & Audio Streaming via Internet Browser (e.g. Source-Connect Now, CleanFeed, Zencastr)	✓ Online real-time interactions	✓ Up to ~1000 participants	**Limited** Only one user at a time, and only during the session	✘ Lossy Opus codec, up to 510 kbps only	✘	✓ Modest annual subscription fees	Audio/Visual
Source-Connect Pro & Source-Sync Rewire Solution	✓ Online real-time interactions	**Limited** Up to 4 discrete users using Multi-Connect option	**Limited** Access to DAW at recording end only	✓ AAC-ELDv2, Asynchronous audio repair or PCM WAV replacement	✓	✘ Over AUD$2000 just for Source-Connect Pro	Audio Only
Source-Connect Pro & Source-Connect Link DAW Integration	✓ Online real-time interactions	**Limited** Up to 4 discrete users using Multi-Connect option	**Limited** Access to DAW at recording end only	✓ AAC-ELDv2, Asynchronous audio repair or PCM WAV replacement	✓	✘ Over AUD$2000 just for Source-Connect Pro	Audio Only
VST Connect Pro DAW Integration for Cubase Pro 7 onwards	✓	✘ Only one discrete connection	**Limited** Access to DAW at recording end only	✓ Lossless Audio PCM WAV replacement	✓	✓	Audio/Visual
VST Transit for Cubase Pro 8.5 onwards/Cloud Collaboration for Pro Tools 12.5 onwards	✘	✓	✓ Each user can update the DAW project from cloud storage	✓ FLAC or WavPack Lossless Audio	N/A	✓ Included with the cost of the DAW, with modest storage upgrade fees	Text Only

Table 1: Comparison of select existing online collaboration platforms against the essential characteristics

A discrete mode of communication is an essential feature of the framework to coordinate the collaboration, and exploiting a combination of audio and visual components has been found to be an effectual means of conducting online interactions, providing the integrity of the connection is stable and there is sufficient bandwidth available (Isaacs and Tang 1994; Riley 2013). The inclusion of cloud storage offers an access point to the DAW project's data-intensive audio files for all of the collaborators. A centralised repository of audio assets preserves the collaborators' musical contributions and output and provides a retrieval system to update the DAW project across the collaboration consistently.

The proposed framework addresses all five essential characteristics of a successful synchronous multilateral online collaboration platform, as identified in the survey.

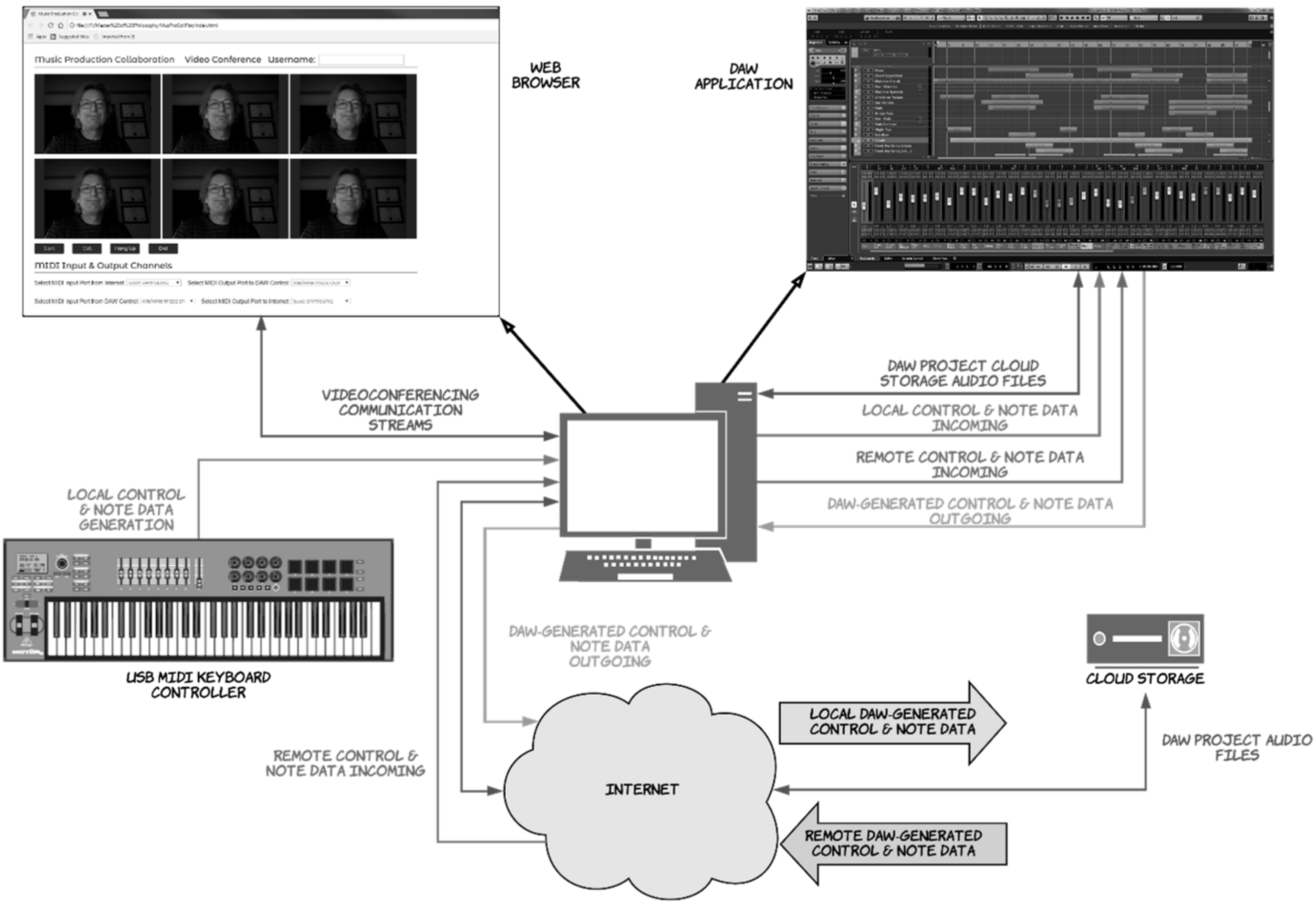

Figure 2. The proposed synchronous multilateral online collaboration framework for music production

A DAW software application, such as Steinberg's Cubase Pro 9.5 (Cubase Pro 2018) among others, can provide the means for creating, recording, modifying, and producing a music project and should, therefore, form the nucleus of a collaboration framework. While a DAW can be operated using traditional mouse clicks and key commands, modern DAWs can also interface with a remote controller device. Such devices transmit note and control data protocols that are mapped to specific events and operational commands, fulfilling the same role as a computer's mouse and keyboard. Control data protocols that are Internet Protocol (IP) compatible have the capacity for streaming over the Internet, and as such, it is these data streams, combined with real-time networking protocols, the proposed framework employs to facilitate synchronous control between all remote instantiations of the DAW project.

The authors found that while the DAW-integrated audio streaming platforms Source-Connect Pro and VST Connect Pro provide synchronous interactions, there is an imbalance in being able to access the DAW project (Stickland, Scott, and Athauda 2018). In both instances, only the host, who instigates the collaboration, can directly interact with the DAW application. Instead, the remote collaborator/s interact with relatively simple software interfaces that assist in the monitoring of audio signal levels and the status of the connection. For the collaboration to be truly equitable, each participant has their instance of the DAW project running on a local computer, and each remote instantiation is interconnected.

The framework employs reliable, multilateral network connections over the Internet to achieve this level of functionality. Establishing a private online group ensures that all other participants receive real-time control data generated from operational commands at any of the collaboration's nodes.

While DAW-integrated audio streaming does indeed provide synchronous collaboration, the survey revealed that such a facility is extremely limited in the number of active participants (Source Elements 2016b; Steinberg Media Technologies GmbH. 2014). Conversely, it also distributes high-definition audio files asynchronously, replacing a project's streamed compressed lossy audio recordings with locally-stored lossless audio via file transfer over the Internet. VST Connect Pro and Performer, in particular, provide Cubase Pro with an integrated A/V communication capability, which enhances the collaborative experience through direct vocal and visual cues. Ultimately, professional music production activities utilise high-definition audio files, however, as the survey demonstrated, working with high-definition audio assets comes at the expense of the synchronous nature of the collaboration, and synchronous audio streaming comes at the expense of the number of collaborators. Therefore, the proposed framework eschews synchronous audio streaming altogether.

The authors' survey showed that DAW-integrated cloud storage and file sharing provides for asynchronous collaboration, avoiding real-time streaming of audio in preference for remotely-stored, lossless audio assets, accessible to any number of collaborators sharing the same DAW project. While the platform does provide direct communication between collaborators, it is text-based in the absence of third-party videoconferencing that could offer a more efficient mode of communication (Steinberg Media Technologies GmbH. 2015; Steinberg 2015b, a). While existing DAW-integrated file sharing solutions lack spontaneity and time-efficiency, they do provide an efficient manner in which to distribute high-definition audio contributions to online collaborators working on a common DAW project, albeit post-factum. For that reason, the proposed framework employs existing DAW-integrated cloud storage and file sharing facility. Requiring every participant to begin a collaboration session by synchronising their local version of the project with the one in cloud storage, all of the project's high-definition audio assets, together with any other track types and initial settings, are imported and available to each collaborator at the outset.

DAW instrument tracks employ the use of virtual software synthesisers and samplers in the form of plug-ins, inserted into the track. Interestingly, Instrument tracks require the input of note and controller data to trigger sounds, yet they output high-definition audio signals. Given that the framework employs the use of streamed control data for synchronous remote DAW operations, the same data channel is used to distribute Instrument track-specific note and controller data generated at one node to all others. The demand on the available bandwidth for such data streaming is markedly lower than that needed to realise efficient audio streaming, yet it yields new audio material at each DAW instance while also maximising the framework's potential synchronicity.

The survey's discussions on the effects of inherent latency over the Internet primarily centred on the resultant delay in audio streams from one host to another. Existing audio streaming solutions demonstrated that synchronising audio streams and a DAW can be achieved by compensating for the delay the Internet imposes, but only over a single connection. Such compensation, however, does not allow for synchronisation over multiple connections. Since the framework does not require audio streaming, but rather localised playback of a DAW project, then the effects of latency on audio playback are minimised. In this case, the synchronous nature of the collaboration encompasses aligned playback, navigation and operational control across the individual instances of the DAW project.

Exploring the utilisation of the Source-Connect Pro audio streaming application identified its price as a possible limiting factor. Currently, a single, enduring licence costs more than AU$2000 making it a likely cost-prohibitive option for large groups, especially considering every collaborator requires a licensed version. This discovery led to the belief that for a collaboration framework to be inclusive, it also needs to be affordable for an average user.

The proposed framework's hardware resources for an end-user include:

- A desktop or laptop computer that satisfies the chosen DAW manufacturer's recommended requirements with access to a webcam and microphone source for videoconferencing
- An external audio interface with additional MIDI input and output ports
- Monitoring headphones to assist with feedback limitation and echo cancellation
- An external controller for note and control data generation

  A modem/router for accessing the Internet and streaming control and note data

Depending on the framework's chosen mode of network data transport and delivery, a centralised server may be required to manage the various control and videoconferencing data streams. Two widely-deployed examples of such servers are a Multipoint Control Unit (MCU), and a Selective Forwarding Unit (SFU). MCUs have typically been a hardware resource, such as Cisco's end-of-life TelePresence MCU 5300 series, and Polycom's RealPresence Collaboration Server (Polycom Inc. 2018; Cisco Systems Inc. n.d.). More recently, however, there has been a shift towards software-based, and subsequently cheaper, MCUs. The RealPresence Collaboration Server, for instance, is offered as either a hardware or software solution. An SFU, such as Frozen Mountain's LiveSwitch server application, is a software-based alternative to MCUs, offering a one-up, many-down collaboration topology, offering a reduction in upload bandwidth requirements, and hence better CPU performance than an MCU (Frozen Mountain 2018).

Standard videoconferencing alone lacks two fundamental capabilities for synchronous, multilateral online collaboration: equal access to the shared project, and working with high-definition audio. However, the proposed framework's implementation of videoconferencing only calls for a simple A/V communication platform since its role is not to provide access to the DAW application, nor be the collaboration's audio source. While meaningful communication is vital in group work, the integrity of the communication stream is not the framework's primary concern, and occasional glitches are tolerable since they have no bearing on the DAW project's audio. Moreover, a rudimental videoconferencing platform places fewer demands on a computer's CPU, reducing the chance of it interfering with the DAW's performance.

4. CONCLUSION AND FURTHER WORK

Effective group collaboration that aims to create and manipulate high-definition audio assets in real-time requires operative multilateral connections that deliver equitable access to a shared music production platform. Today's approaches and solutions, however, fall short of meeting all the established criteria for achieving such a level of functionality. As such, this paper has presented an alternative structure and approach to online group collaboration, with its particular focus on real-time music production. Existing music-specific collaboration frameworks concentrate on one of two methodologies: real-time audio streaming, or asynchronous inclusivity for multiple collaborators.

Audio streaming over the Internet impacts profoundly on interconnectivity, with the number of active participants inversely proportional to the definition of the audio stream; the higher the quality, the more data-intensive the stream becomes, which in turn necessitates a restrictive number of connections. Despite increases in bandwidth over time, the Internet's lack of operative Quality of Service (QoS) is mainly responsible for this restriction. Therefore, the proposed framework seeks to limit its effects by eschewing real-time, high-definition audio streaming. Instead, the framework bases its central premise around real-time streaming of data that is less bandwidth-intensive and remotely controls the functionality of a DAW software application. The music production project's audio assets are, alternatively, downloaded from cloud storage before, or at the outset of, an online collaboration undertaking, via existing DAW-specific file sharing, and imported directly into the project.

Eliminating synchronous high-definition audio streaming from the framework's basis of operation provides the additional benefit of minimising the effect latency has on the collaboration. Rather than obligate each end-user to monitor streamed, latency-prone playout, the source of the framework's audio is from localised DAW playback. While each instance of the DAW across the collaboration is interconnected, thus allowing for remotely-coordinated transport functionality, the monitoring of each instance's audio playback is independent of the others. The collaborators are unaware of the slight differences in timing that inherent latency imposes across the framework since they only hear the playback of their version of the DAW project.

The proposed framework does indeed encompass audio and video streaming over the Internet as a component of its communication means, and further, these streams will inevitably encounter latency and jitter. The anticipation is that the impact such delay and clocking issues have on the framework's operability will be diminished since the communication streams are not critical to the remote operation of the DAW. Furthermore, expectations are that the quality of the framework's communication means will be akin to existing commercial web browser-based videoconferencing platforms.

The next phase of the framework's evolution is an implementation and testing regime that focuses on each of the essential characteristics. It will examine network protocols and architecture, real-time data streaming, interfacing with a DAW project, and videoconferencing.

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