THE ITINERANT ORCHESTRA, A 5G, MULTI-CAMERA, REMOTE AND DISTRIBUTED VIDEO PRODUCTION EXPERIMENT

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ABSTRACT

This paper presents the implementation of the Itinerant Orchestra use case, a technical and artistic challenge, in which musicians located in a main concert hall play together with other itinerant musicians walking in the streets of Turin, Italy, while approaching the concert hall. Audio-Video signals of the itinerant musicians are transmitted via a 5G network to the main editing site where they are properly processed and mixed with the orchestra located in the concert hall. The architecture for the outdoor and indoor 5G network coverage, the integration of the technical solution for the television remote production, and relevant collected measures and KPI analysis from the network and functional perspectives are also described in this paper.

INTRODUCTION

In the context of the 5G-TOURS (1) project and in particular of Turin touristic city set of Use Cases (2,3 and 4), the main objective of the Itinerant Orchestra use case is to exploit the 5G-TOURS network features for remote television production, analyzing how 5G networks could support various scenarios in which high-quality video is generated and transmitted. In a distributed TV video production context, the content needs to be produced by mixing local and remote audio and video contributions in the TV studio. The remote contributions are thus delivered to the main editing site via the 5G network in real time.

As depicted in Figure 1, in the Itinerant Orchestra use case, musicians located in the main concert hall play together with other musicians walking in the streets while approaching the concert hall. Each musician is followed by one (or more) cameraman shooting their performance and providing cues to stay in synch with the main orchestra performance. The generated high-quality AV signal is transmitted via the 5G network to the main editing site where it is properly processed and mixed with the orchestra located in the concert

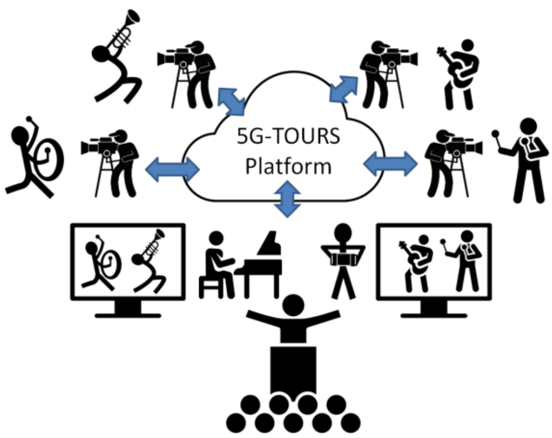

Figure 1 – The Itinerant Orchestra Schema

hall.

The spectators in the concert hall can watch the itinerant musicians playing and walking in the streets towards the Palazzo Madama (5), as real time virtual presence, on one or more LED walls and listen to their performance via an amplification system, mixed to the local orchestra, until they enter the concert hall and join the orchestra. Palazzo Madama is a large historic building that now houses the collections of the Museo Civico d'Arte Antica, Turin's municipal museum of ancient art, and it is the location in which the experiment take place.

According to the literature (6) the delay threshold at which effective real-time musical collaboration is possible is around to 50-70 msec. In this context, the project LOLA (7). (LOw LAtency audio visual streaming system), aims to define a system for distributed performing arts interaction over advanced packet networks with delays closer to that range. The system is intended to operate on high performance networking infrastructures, and it is based on low latency audio/video acquisition hardware and on the integration and optimization of audio/video data acquisition, presentation and transmission. Despite this, it has to be highlighted that the LOLA project is mainly designed for fixed studio records and therefore is not suitable for our use case that foresees itinerant performers, nevertheless LOLA project define the lower bound of latency reachable with fixed cabled solutions, therefore we can use it as a reference point in terms of performances.

IMPLEMENTATION

In this section we analyze the remote TV production environment in terms of signals exchanged from/ to all elements involved in a typical situation of remote production and in particular for the Itinerant Orchestra use case.

The Remote Musician

Each remote performer involved in the experiment is equipped with: radio microphone to transmit the audio to the equipment of the cameraman; this audio signal is strictly a real time high quality signal and one way from the performer to the operator (Up-link) with single stereo channel; the intercom audio, also known as IFB (Interruptible Fold Back) for the real time communication, which typically is the audio signal originated from the Production Control Room (Downlink); the intercom signal could be used as sync signal ("click"), a signal to indicate the right moment of attack on the musician. During the first trial we used a professional controller pad in order to send pre-recorded synch click tracks to the remote performers. In order to maintain the latency on this kind of sync signal as low as possible we used a professional radio intercom system.

The Cameraman

Each cameraman is equipped with: a full HD/ 4K professional camera (and camera rig): this is the source of the video to be transmitted to the Production Control Room; the intercom equipment: to manage the communication to / from the Production Control Room also for the actor/ speaker/ musician, this intercom signal is generally requested by the director to maintain a connection to the cameraman, in order to communicate camera events, movements or information, as best practice, it is strongly recommended to have a two-way intercom communication, even if the cameraman-to-director direction is supposed to be little used; the radio Mic receiver: receiver of radio microphone of the actor/ speaker/

musician; the LiveU's 5G bonded video device: 5G equipment able to connect and exchange audio-video data with the 5G cell.

Signals that are carried out by the 5G network are:

- Low Latency HEVC (High Efficiency Video Coding) coded video Full HD with a TV production level quality of 20Mbps (audio current default is AAC (Advanced Audio Coding) 192 kbps total for both 2 audio channels/single stereo) from the 5G video transmission unit to the Control Room;
- Real time AAC Audio with bitrate 192 Kbps from the performer to the Control Room (orchestra) for the mixing management, embedded into the Full HD video stream from the camera to the 5G video transmission device;
- Real time bi-directional audio provided by IFBv2 of LiveU system for the intercom between remote people (cameraman and musicians) and the Production Control Room.

The Production Control Room

The Production Control Room is equipped with: the bonded video HW & SW server to grant the data receiving / exchange from/ to remote operators, the number of cameramen will be, at this stage, two; the Production Control Room Intercom Management System; the Video Mixer and all equipment for the management (and recording) of different signals (also the distribution of A/V real time content to Auditorium's displays and speakers in case of the Itinerant Orchestra event). On the audio side the main part of the chain is the delay processor in order to align the signals and let the whole system play in synch as described below. In Figure 2 an image of the control room setup in Palazzo Madama is reported.

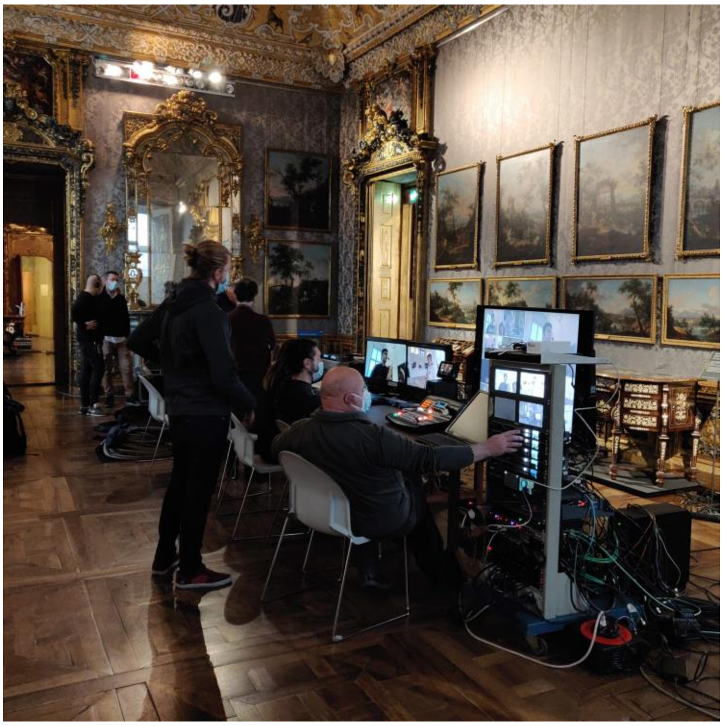

Figure 2 – The Control Room setup in Palazzo Madama

In the context of the Itinerant Orchestra implementation it has to be underlined that, of course, low delays are needed in order to allow the musicians to play together while also getting timely synch cues from the conductor/orchestra, but even a more important remark is that each remote site has to manage the same, fixed, delay. In the following validation results section next in this paper details on this are reported.

The network deployment have been carried out by TIM and Ericsson based on outdoor and indoor coverage analysis of Palazzo Madama area. Rai and LiveU have defined the technical solution for the TV remote production use, in particular in Palazzo Madama and for the Itinerant Orchestra scenario.

OUTDOOR AND INDOOR 5G NETWORK COVERAGE

In order to provide the requested 5G coverage inside the museum, TIM and Ericsson worked on the design and development of an ad-hoc 5G network solution. As described above, the itinerant orchestra scenario also requires an external coverage to provide connectivity to the musicians performing in the surroundings of the museum. On such basis, to satisfy this specific requirement, in addition to the 5G indoor coverage it has been necessary also to deploy a complementary 5G outdoor coverage, since the area around Palazzo Madama was covered only by LTE.

The 5G-TOURS network solution has been designed as an extension of the 5G commercial network. For this reason, the network solution has been deployed based on the NSA (non-standalone) Option 3 architecture in which the radio access network is composed of a LTE layer as “anchor layer” (working at 1800 MHz with 20 MHz bandwidth) and a 5G layer as secondary layer (working at 3.7 GHz with 80 MHz bandwidth) (8); in this architecture LTE provides the control plane function while LTE and NR are used for the data plane. The radio access network is then connected to EPC (Evolved Packet Core) that for this specific implementation was the commercial CN. From the implementation perspective, the radio solution identified for the 5G indoor coverage has been the Ericsson Radio 4422 with the Kathrein 80010922 antenna (9). In order to provide the coverage for the requested rooms, the adopted solution consists of four different radio installations mounted on ad-hoc built pole to ensure the best stability and allow the mounting of all required components in terms of radio, antenna (two antennas for each radio), power supply and cabling (optical fiber and RF). To avoid any impact on the cultural value of the site, the optical fiber needed to reach each indoor radio unit was laid using the available ducts infrastructure of the building that are already used for the electrical, fan coil and LAN provisioning.

Figure 3 shows the installations in Sala Quattro Stagioni and Sala Acaja in Palazzo

Figure 3 – Installation for 5G indoor coverage in Palazzo Madama Sala Quattro Stagioni and Sala Acaja and rooftop antenna for the 5G outdoor coverage

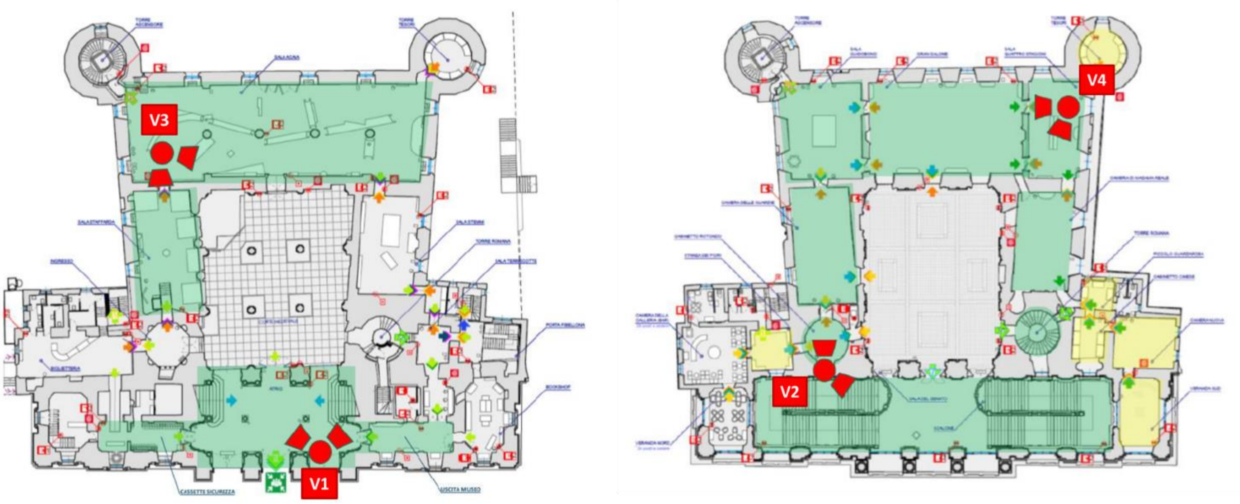

Figure 4 – Location of the installations and 5G indoor coverage area

(ground floor and first floor)

Madama for the 5G indoor coverage and the rooftop antenna that provides the 5G outdoor coverage (camouflaged in a fake chimney). It is worth highlighting that such indoor installations are a prototype solution; the final network setup will aim to reduce the impacts in terms of visibility through the use of more appropriate components that can be integrated with the building architecture and/or museal infrastructure.

Based on the deployment described above, the 5G indoor coverage of Palazzo Madama consists of 4 different cells referred as V1, V2, V3 and V4 (Figure 4 shows the installation locations and the coverage area of the ground floor and the first floor, respectively). The baseband unit for the 5G indoor coverage is the Ericsson Baseband 6630 located in the network exchange point located 2.8 Km far from Palazzo Madama. In order to provide the 5G fronthauling connection (based on Common Public Radio Interface, CPRI) between the radio units inside Palazzo Madama and the baseband in TIM premises, an ad-hoc optical fiber connection has been installed consisting of 8 couples of fibers of which 4 couples has been used to connect the 4 Radio 4422, 1 couple to provide broadband Internet connection for the LiveU server and 3 spare couples as backup and/or future development of the 5G indoor coverage. The LTE anchor layer of the 5G indoor coverage is provided by the two outdoor LTE commercial sites that cover Palazzo Madama; in particular, through a signal measurement campaign, one site was identified as the anchor for the 5G indoor cells V1 and V2 while the other one as the anchor for V3 and V4. For the 5G outdoor coverage, the TIM site has been extended to provide a co-site 5G cell through the installation of an Ericsson Baseband 6630 (10) and an Advanced Antenna System (AAS) Ericsson AIR 6488 (11).

In terms of radio performances, the 5G-TOURS network solution was able to provide throughputs of 900 Mbps in downlink and 75 Mbps in uplink as well as an average end-to-end latency of 15 ms.

APPLICATION COMPONENTS

For the Itinerant Orchestra trial, due to practical reasons related to the number of musicians and cameramen and the requirements to have a complete synch between the audio and the camera feed, it is necessary to transmit the musician audio via the cameramen 5G LiveU bonding device rather than having the musicians using a separate LiveU device. In particular, in addition to the video signal generated by the camera used by the cameraman, there are other audio important signals.

The "main" audio signal is the one generated by the musician's instrument. It must be sent to the director with the highest possible quality and with the minimum possible latency. It was decided to use the LiveU backpack's audio channel, so it is necessary to transmit the signal from the musician to the cameraman via real-time short-range radio link for the connected movements. The main signal is generated by a microphone placed on the instrument according with the standard in live shows. The connection to the director must ensure a very high sound quality and a low latency.

To transmit this signal to the LiveU backpack a short-range real-time radio microphone is used in order not to limit the relative movements between musician and cameraman. This audio stream is fed into the camera as a standard mic, and the camera embeds it into its Audio/Video output (SDI) into the LiveU backpack. Thus, the complete audio-video synch is also achieved.

About the video operator intercom, the intercom that connects the director to the cameraman is a "classic" system. It is provided in the LiveU 5G bonding backpack device, from which it is extracted with a headset or earphones connected with wire. The LiveU solution also includes audio from the cameraman back to the production room.

For the musician Intercom: the connection between director (music assistant) and musician is used for:

- Indications of "cue": it is the hint that the musical consultant can appropriately indicate to the musician the exact instant to start. It has to be considered that the musician has no other information about the piece being played so the accuracy of the sound trigger becomes important. This is a critical signalling; the latency of this connection must be as low as possible.
- Synchronism signal ("click"): even if the professional musician is able to adopt and maintain the right rhythm, it seems appropriate that he can be guided on the current rhythm held by the orchestra, unless the music score is written to minimize the importance of synchronism.
- Directions of "director": considering addition directions concerning the position of the musician, the speed of translation, or other information that the director could give to the moving performers;

The musician Intercom connection, in general, does not require high bit rate capability but very low latency, when the typical TV production approach is not applicable some online-gaming intercom solutions such as Discord (12) and Mumble (13) have been investigated to be used instead of the radio intercom system.

TRIALS AND VALIDATION RESULTS

The Itinerant Orchestra first trial took place in Turin at Palazzo Madama museum, and during this preliminary trial it was possible to measure the glass-to-glass latency of the system and the throughput provided by the LiveU backpacks. Typically, in the TV production context, talking about latency, we're referring to end-to-end latency, also known as "glass-to-glass" latency: the amount of time it takes for a single frame of video to transfer from the camera to the display.

The scenario was based only on two out of four remote musicians foreseen initially and only a part of the orchestra inside Palazzo Madama. Differently from the planned setup the connection between MCR (Master Control Room) and the remote musician was provided by a RF analog commercial intercom system, and the device used for the measurements was a Mixed oscilloscope. The measure setup is shown in Figure 5.

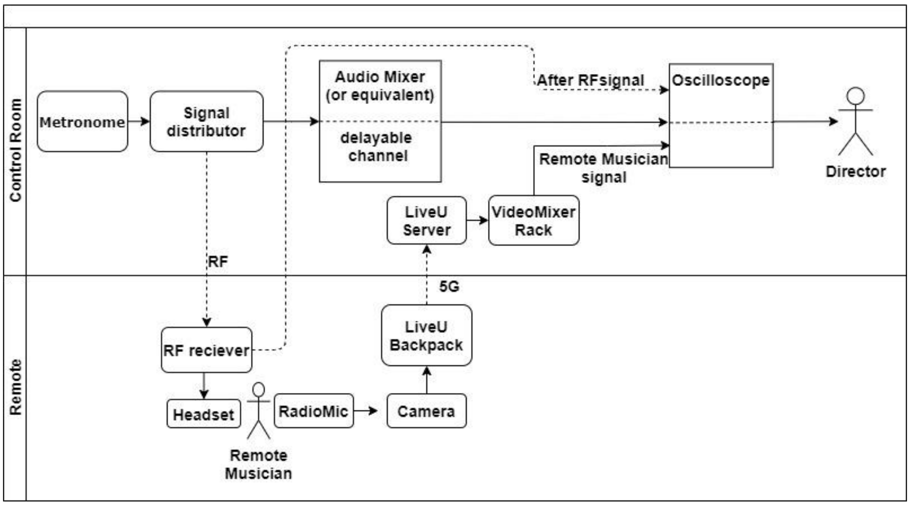

Figure 5 – Glass-to-glass measure setup

In order to measure the glass-to-glass latency we used a metronome click track as the reference signal de-embedded from the video signal in order to calculate the latency introduced by the system. This kind of measurement is not only more reliable but it grants a wide range of measurement probes in the chain. In fact, with audio, we can measure the latency of the overall system, but also the latency introduced, for instance, by the RF intercom system. The two measured signals are presented in Figure 5 set-up. In Figure 6 an example of the measurement process is presented: the peak coming from the signal reference (yellow) and the feedback signal after the 5G system (lower in amplitude in pink).

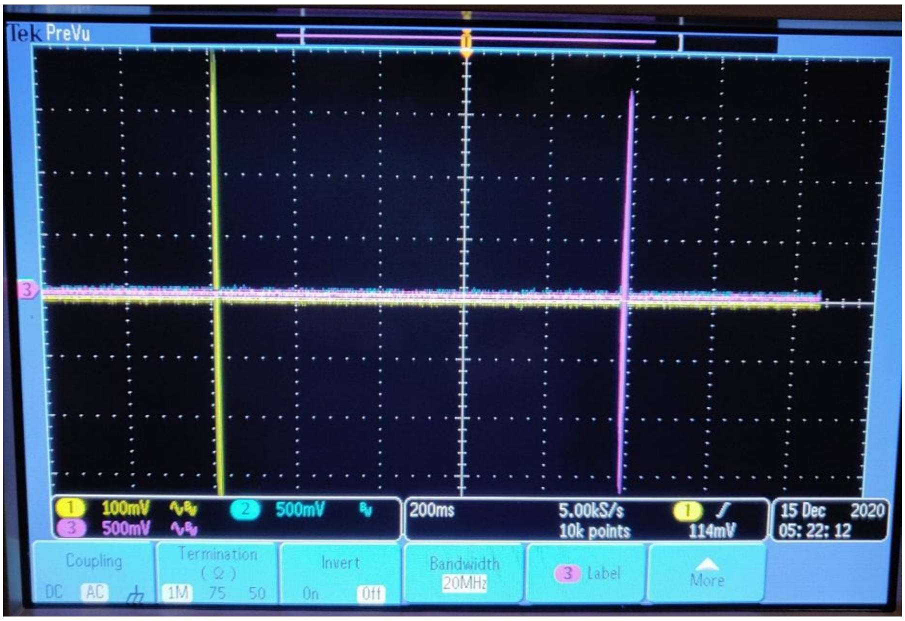

Figure 6 – An example measurement process, oscilloscope measure

During the trial in Palazzo Madama we were able to test the overall latency of the system, the measured delay compared also with the previous test performed in TIM laboratory. The TIM laboratory measurement setup performed in September 2020 involved basically the same measurement setup of the trial except for the 5G coverage, that in case of TIM laboratory setup were offered different cells. The achieved results, as reported in the Table 1**Error! Reference source not found.**, are pretty constant in time with a relatively low deviation and both tests indicate a similar value

Delay measure	AVG (ms)	MIN (ms)	MAX (ms)	STDEV
Tim lab (sep2020)	900	900	900	-
Trial Palazzo Madama (dec2020)	970	960	980	10

Table 1 – Glass-to-glass latency measure

of glass-to-glass latency.

The measure of glass-to-glass latency is fundamental to provide an adequate synchronization of the system. In fact, in order to let the orchestra on the stage play together with the remote musicians we delayed accordingly the start signal for the stage director, since it is impossible to anticipate the start for the remote performers. In Figure 5 you can see the “metronome” signal that goes directly to the stage director and musicians and is ‘delayed’ by the audio mixer with a delay that is equal to the glass-to-glass measure we get during the system evaluation.

To summarize, the start metronome signal is sent to both, remote musicians and fixed stage orchestra, but for the last one is delayed by 960ms in order to let them play in sync with the remote musicians**Error! Reference source not found.**.

By using a multi-camera environment, we performed a second type of test, with multiple backpacks involved. The main objective here is to check if, and how, the latency involves the backpacks, in particular if it is present some kind of difference between the four backpacks. The results of this experiment tell us that we have some offset between backpacks, the reason is partially explained and related to the routing of the UDP streams in the network.

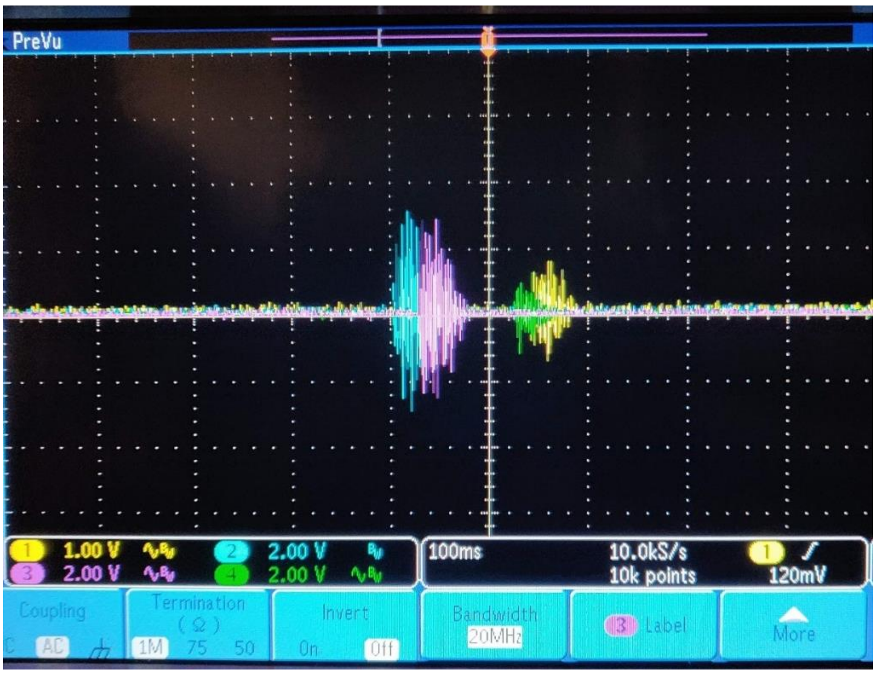

Figure 7 – Delay difference between backpacks

The setup does not involve the same layout presented in Figure 5, but as we have three inputs only in the oscilloscope, we measured the inter-latency between the four feedback audio signals coming back from the units in field, without the reference signal as a comparison. In this way we checked the delay between each backpack signal. Again, with this setup we sent a metronome audio signal reference, and the result is visible in Figure 7.

The difference between the peaks was constant during the tests, the maximum value of this latency recorded between the backpacks was around 150ms. In Figure 7 we can see the four audio metronome signal returns from the units divided into two pairs of signals with a difference of around 150ms. It's important to note that during this test we placed the four backpacks on the control room desk, in order to avoid any possible problem with coverage and connectivity.

Finally, thanks to LiveU logs, it was possible to retrieve information regarding the bandwidth, latency and packet loss rate. In the following chart we have multiple axis: bandwidth [kbps] uses the left, primary Y axis. Latency [msec] and loss rate [%] use the right, secondary Y Axis. Each point on X axis is 5 secs snapshots.

The "extrapolated latency" shown in the graphs is part of the overall 600 (or 800ms in this case "end-to-end") msec latency. It represents what the LiveU application logs as a snapshot at 5 secs intervals, as to what it estimates/ predicts/ believes/ anticipates the network latency is (for example, also including any latency within the 3rd party cellular modem), after that "extrapolation" and other calculations, based on its own packets exchange between unit and server. In Figure 8 we can see the chart related to a field unit during the trial.

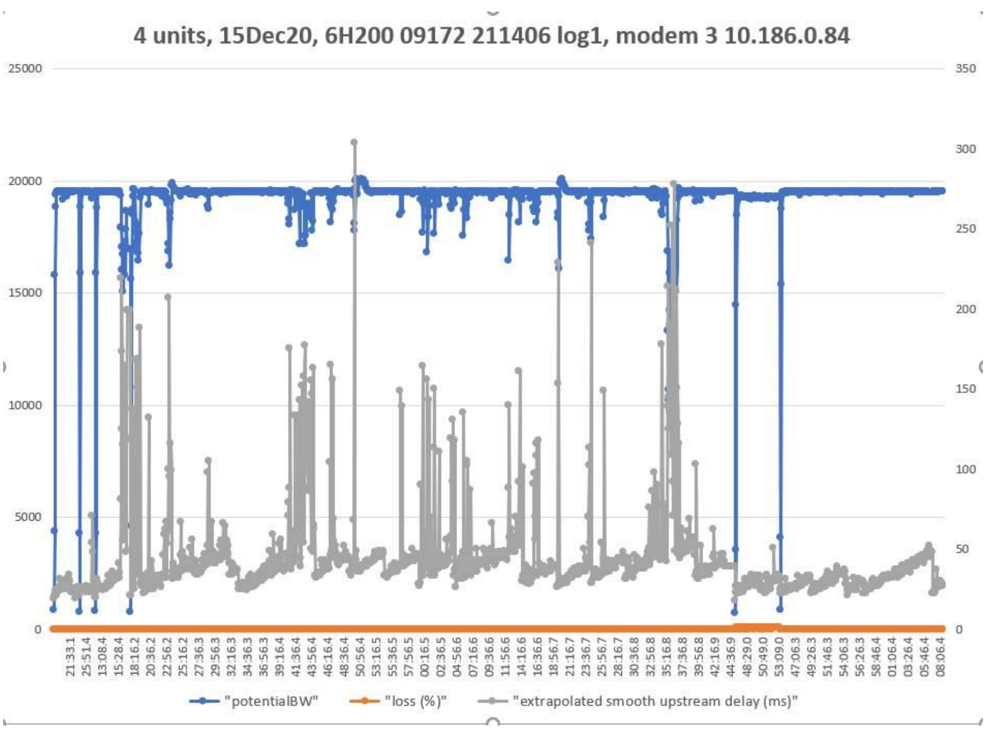

Figure 8 – LiveU Unit trial statistics

THE ARTISTIC PART OF THE EXPERIMENT

The experiment requires very low and stable delays, an ultra-reliable capability and a very large bandwidth capacity to reach a challenging final result, but it is also an artistic challenge. The composer Andrea Molino (14) composed a specific musical score in order to emphasize the use of new technologies as a central element of the theatrical and musical language. From June to December 2020 test and trials on the field were carried out to target final concert planned in autumn 2021, in Turin, in Palazzo Madama.

In December 2021 the first trial (Figure 9), dedicated to solve technical aspect and feasibility of the concert, involved one cello player and the orchestra director inside the hall in Palazzo Madama. These musicians, coordinated by Andrea Molino in the control room, played together with two moving musicians (clarinet and saxophone) and a nearby actress who recited some verses.

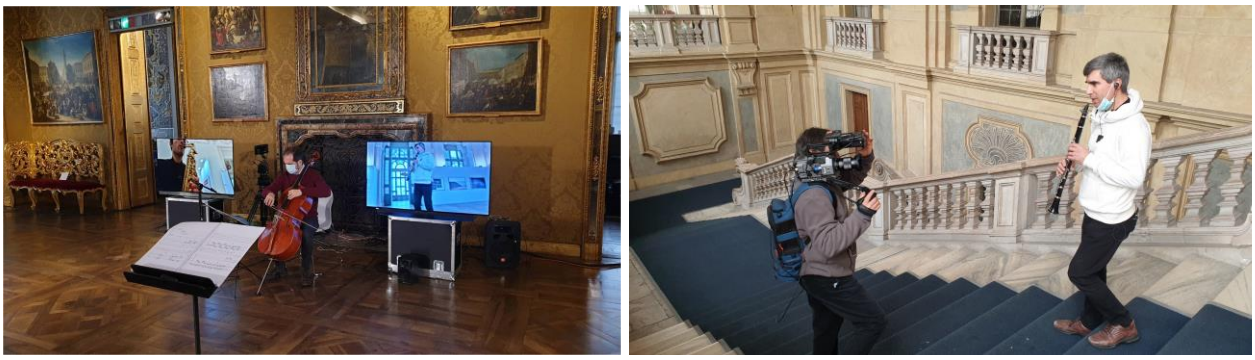

Figure 9 – Musicians are playing together during the trial

The expected final event planned in autumn 2021 will involve an ensemble of six musicians playing in the hall of Palazzo Madama together with four saxophonists and four actors performing in the Piazza Castello and joining the orchestra located in the concert hall. The Itinerant Orchestra experiment will be also documented as a video documentary backstage telling the history of technical and artistic activities from the first test reaching the final concert. The final event will be live broadcasted and recorded in 4K.

As said by Andrea Molino, that is engaged in innovative, multimedia-oriented music theatre: in this experiment an important role is played by the involvement of new communication technology as a central element of the theatrical and musical language, especially for live performances. In this direction, a number of new projects are under investigation, revolutionizing the realization and the enjoyment of live shows based on marching bands playing around an urban context, maximizing the visibility of differences and similarities between different populations in different urban areas.

CONCLUSIONS

In the context of the 5G-TOURS European project, the paper presented the implementation of the Itinerant Orchestra experiment showing the architecture for outdoor and indoor 5G network coverage performed by TIM and Ericsson, the whole integration of the technical solution for the television remote production performed by Rai Radiotelevisione Italiana and LiveU, and relevant collected measurements and KPI analysis from the network and functional perspectives.

The next steps in this context are to work to improve the performance of the entire system and in particular on the video latency and the synchronization of multiple camera contributions. Also, the impact in the traditional TV production workflow has to be further investigated targeting the final concert planned in autumn 2021.

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