TITLE: C-theatre: light speed connected geo-distributed performances

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Abstract
The pervasiveness of broadband connections and high capacity telecommunications networks have changed the way of conducting scientific research, how to learn and produce culture. The performing arts are no exception to this revolution.The new paradigm introduced with ultra-high speed networks growing both in commercial and research frameworks is triggering a redesign of the performing space that will be something else from theatre as we know it and will make William Shakespeare's "all the world's a stage" a feasible scenario also for real-time performances.
Given this premise GARR investigated in a synergy with a renowned experimental-theatre director, namely G.B. Corsetti, the possibilities offered by the physical fragmentation of the stage space.

Keywords
C-theatre, distrActive artwork, network performance, optic fiber performance, lightspeed theatre, distributed performance

1. GARR and the performing arts
For many years now the Italian Research and Education Network, GARR, has been collaborating with the performing arts community in order to promote performing arts and the creative use of advanced network infrastructure and innovative tools for real-time musical, dance and artistic shows.
In supporting a community with multiple use cases characterised by a specific set of requirements in terms of bandwidth, network reliability, jitter and latency, GARR researches and tests the use of specific audio, video and lighting techniques, tools and applications to support teaching activities, auditions and networked performances.
Particularly in the areas of music and theatre, this close collaboration has led to explore new possible creative applications of digital infrastructure and technologies, such as:

- reduction **of the latency** in the ultra-HD audio/video transmission through the elimination of the compression phase and the use of ultra-broadband networks for the transmission of the uncompressed signal in real time.
- use of **direct optical transport** for audio and video streams.

The first approach has been used mainly for music performances, also thanks to the development of LoLA system (see 1.1). The second approach has recently led to a collaboration with theatre director Giorgio Barberio Corsetti and his company, who staged a networked live show, which was performed in two different locations in Rome.

Theatre and networking, actors and musicians interact in real-time and high-definition from remote locations. Past, present and future merge in a virtual environment through the use of new languages, and distr-Active technologies (distributed and interactive), providing a vision that goes beyond networking as is perceived today. The collaboration with Corsetti is rooted in the search for expression of those artists who see the high level technology as a disruptive element that changes the very way of making art.
Through these collaborations with avant-garde artists, GARR has kept alive the attention to the community of performing arts , using innovative technologies and promoting the contamination between science and the humanities.

1.1. LoLA

For more than ten years, GARR has been collaborating with the Tartini Music Conservatory of Trieste in the creation of LoLA (Low Latency) a system for the streaming of audio and video signals in high definition between two locations with such a limited latency that it can be used also in networked music performances.

The research and continuous testing allowed GARR to make a number of improvements and introduce new features in the system. The latest version of the system, now in pre-release, also allows for the simultaneous connection of multiple locations, while it is currently under development a new series of specific services for the innovative teaching and a very advanced study for the reproduction and simulation of complex sound environments,in collaboration with the Tartini Music Conservatory, the University of Music and Performing Arts of Vienna and Sennheiser research division.

FIG 1- thanks to Distr-Active technologies we can fragment the theatrical space - photo courtesy of O. Nigris Cosattini

2. The peculiarity of the C-theatre: il Ratto d'Europa

Theatre, dance and music arts are witnessing a fundamental change in their relationship with time and space, the perception of both performer and spectator is radically changed by network technologies, which can connect distant places literally at the speed of light (or c, as it is commonly denoted in physics).

The awareness of this change is one of the starting points of the work staged in *Il ratto d'Europa* which was performed during the Romaeuropa Festival in 2016 and directed by Giorgio Barberio Corsetti thanks to an innovative setup that allows the direct optical data transmission of HD audio and video flows, a setup , applied by GARR for the first time in this sector.

The experiment started in 2015[1] with the idea to stage a theatre performance by using the distr-Active technologies for the creation of a show to be performed simultaneously in several interconnected locations in front of two (or more) audiences, who would follow the scene from two (or more) different points of view.

The locations chosen for the show were the Octagonal Hall of the Baths of Diocletian and Palazzo Altemps, already connected to GARR fibre optic network on request of the Special Commission for the Colosseum and the central archaeological area of Rome.

Fig 2 - the two selected location for "Il Ratto d'Europa"

2.1. The artistic performance

The inspiration for this play comes from the mythical story of the return from Colchis of the Argonauts after their conquest of the Golden Fleece. Also, at the basis of the show there is a desire/need to rediscover the stories and myths of our Western culture in a modern reconstruction, through the magic of theatre, its capacity to explore in-depth the human soul with evocative and poetic words and with its

[1] The successful experience of Corsetti's *La nave Argo*, an experimental show staged at the Colosseum and the Octagonal Hall on October 2015, provided the first test-bench for the evolution of the technologies used in *Il Ratto d'Europa*.

ability to integrate images and visions.

Maddalena Crippa plays the mythological creature Europa, symbolizing the present, the juncture between the past, represented by the archaeological sites of the Octagonal Hall and the Crypta Balbi, and the future, represented by DAFNE, (Double Annular Factory for Nice Experiments) the particle accelerator of the Laboratories of the National Institute of Nuclear Physics, in Frascati. The play itself is a time machine - said Giorgio Barberio Corsetti - moving from the glorious vestiges of the past, to our present crisis and subdued violence, and to the future of scientific research, which brings us back again to the beginning of time, at the origins of Cosmos.

Archaeology and optical fibre, theatre and networking, actors and musicians are all interconnected in high-definition from distant locations. Past, present and future are combined together in a virtual environment with new languages and distributed and interactive (distr-Active) technologies.
This project originated from the contamination of different spheres of knowledge and offers new insights on technology, redefining the boundaries of research in the humanities field.

If this show succeeds in acting like a time machine, it is thanks to GARR network which connects hundreds of science and culture hubs in Italy at the speed of light. This fibre optics network, which relies on the most advanced technological instruments, is used by Barberio Corsetti to virtually connect these sites in an experiment that fragments the space on stage and unites distant locations into a single, digitally augmented representation.

FIG 3 - in the play staged by director Giorgio Barberio Corsetti, the stage and audience are spatially fragmented using high-speed optical connectivity

2.2. The technical setup

From the technological point of view the innovation lies in the choice of transmitting audio/video signals directly on the optical layer, without going through the IP one. The different locations of the show are interconnected through a dedicated lightpath: an absolute novelty in the context of a live artistic performance. Thanks to this approach, the performance really goes at the speed of light, which on the optical fibre travels to approximately 200.000 km/s: from here the idea to call it “C-Theater” as *c* is how speedlight is commonly denoted in physics.

The chosen technology represents a creative reuse of hardware elements which are normally available at the commercial level which we reengineered in order to make the experience as transparent as possible both from the point of view of the performer and of the public.

This choice responded to the need to create a system that could be used by the theatrical team without the support of network technicians. This goal was successfully achieved, to the point that for the art director's the use of a remote or local camera was almost equivalent. At the same time, the latency introduced by a remote actor was maintained at 3ms, far below the level of latency of a normal camera used in this type of setup and well below the human perception threshold (50ms).

For the setup of the show, we used devices specifically designed for the implementation of point-to-point audio/video unidirectional links, which process the A/V signals generated by a camera and turn them into an optical signal at a given frequency, which is compatible with the CWDM (Coarse Wavelength Division Multiplexing) standard. At the receiving end the inverse transformation is carried out, with the decoding of the optical signal coming from the network and its transformation into A/V signals sent respectively to an audio speaker and a monitor.

The initial tests, aimed at verifying the interoperability of this system with GARR infrastructure, was conducted between devices of two urban PoPs of GARR network, defining on the Huawei network a new service (client trail) with HD-SDI framing, that ended on the client ports of the two devices. An optical signal was injected in the DWDM (Dense Wavelength Division Multiplexing) node of one of the PoPs and extracted after a round trip, measuring a delay of about 3ms.

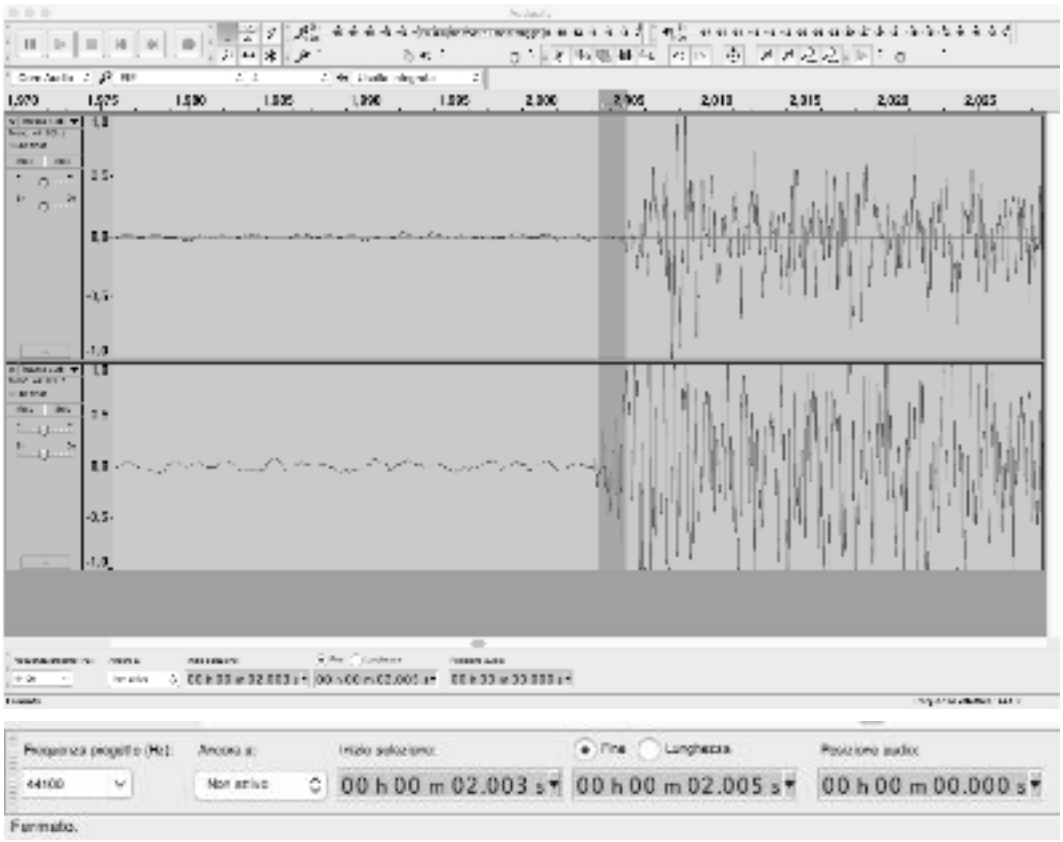

FIG 4 - Trial results: delay measured in the "back to back" configuration (zoom on time 2±1ms)

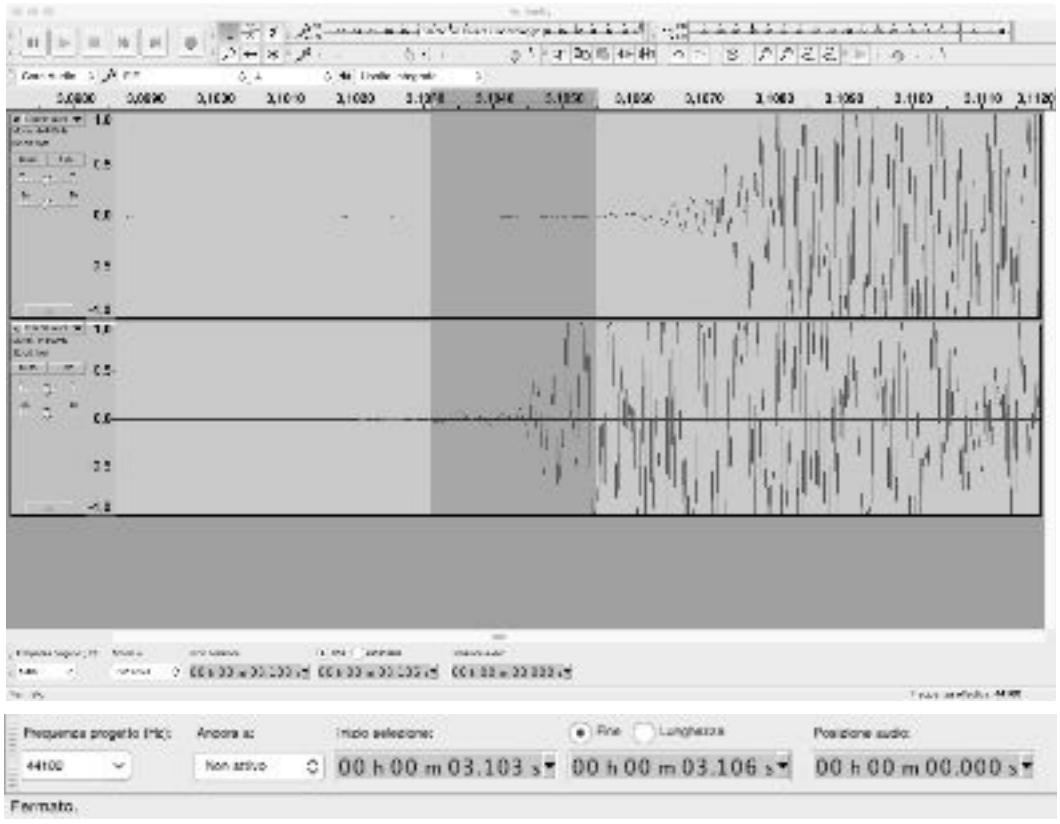

FIG 5 - trial results: delay measured with a configuration foreseeing a distance of 300 km (zoom on time 3±2ms)

At this point, with the help of an audio editing application, we proceeded with the evaluation of the performance, comparing the transmitted audio track with the one received from the network.

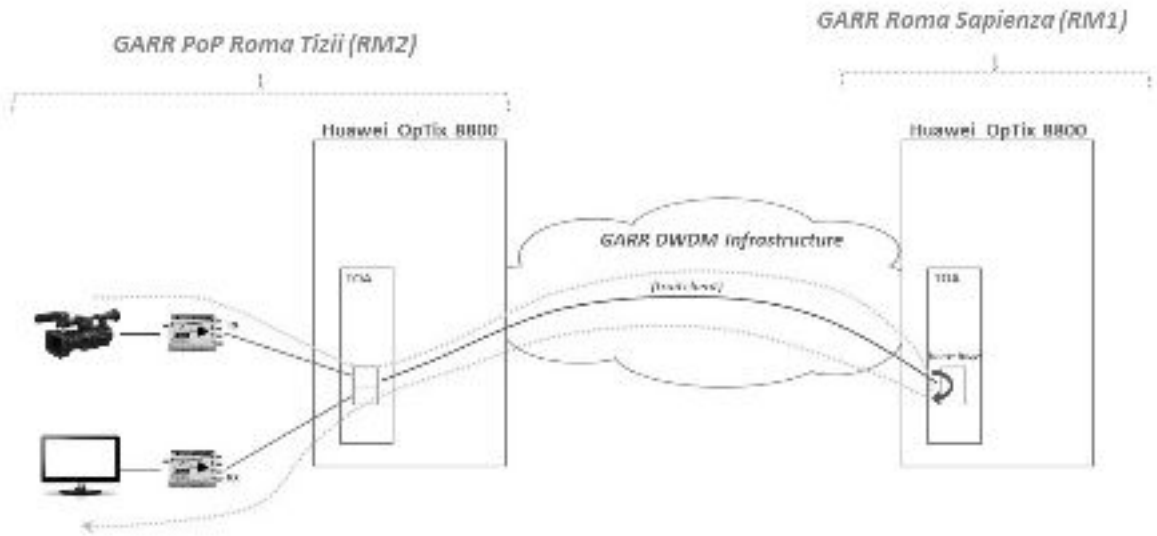

FIG 6 - The trial setup at a glance

Once the two devices have proved to be compatible, the second stage of the trials experimentation involved the study, implementation and testing of a network architecture that would involve the two locations where the performance would take place.

Among the requirements of the performance there was the availability of two bidirectional audio/video channels between Palazzo Altemps and the Octagonal Hall. In order to do so, two separate optical channels were mapped, which were obtained by multiplexing two different wavelengths on the fibre optical access to the Roman GARR PoP, to which both locations are connected. A third optical channel was used to ensure the continuity of the IP access service at the two locations during the event.

2.2.1. The network setup

The network design has thus involved a total of four sites: the two locations where the show was played; the Museum of the Diocletian's Baths, where the dark fibre connection to the Octagonal Hall is located; and the GARR PoP in Rome .

The realization of this network model requires the availability of dark optical fibre single mode between the locations to connect: a necessary requirement in order to multiplex optical signals between urban locations with CWDM technology. Optical fibres connecting Palazzo Altemps and the Diocletian's Baths to the Rome GARR PoP are all single mode, as it normally happens in urban areas, therefore no intervention was required on these routes. However, it was necessary to lay a multi-fibre cable between the Octagonal Hall and the data centre of the Museum of Diocletian's Baths and another in Palazzo Altemps, in order to have the availability of single mode fibre along the entire route.
Through the CWDM device at the Museum of the Diocletian's Baths, the two optical signals related to audio/video channels have been multiplexed onto the connecting optical fibre of the venue to GARR

PoP, where a pair of CWDM device operated the demultiplexing of the two lambdas coming from the connection with the Diocletian's Baths, and the subsequent multiplexing of the same wavelengths on the fibre that connects the PoP with Palazzo Altemps. The CWDM device installed at Palazzo Altemps operated the de-multiplexing of the optical signal, extracting the two wavelengths which were then decoded and sent to audio and video speakers (projectors, screens,…).

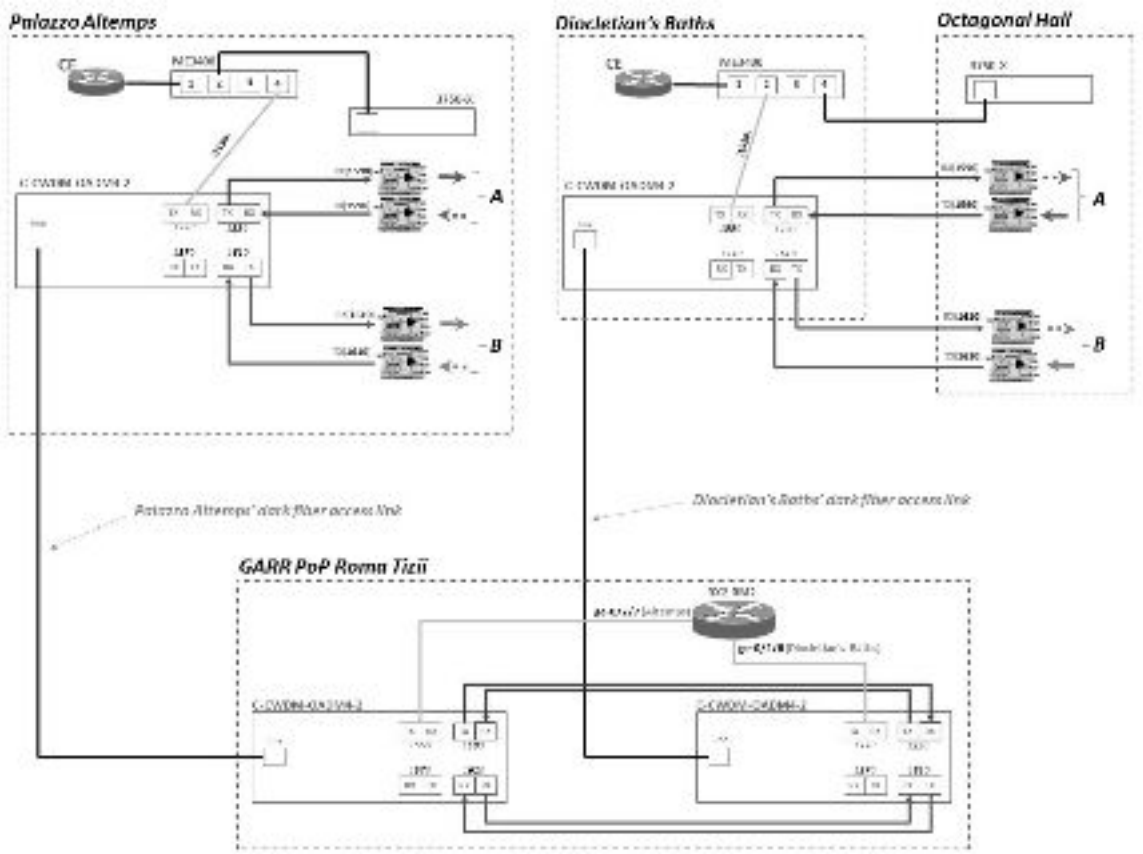

FIG 7 - Overall scheme of the setup designed for the live performance

The experience has been a success from the technological point of view, having demonstrated that by placing a fibre optic network on an urban scale (50-80 km), you can literally create a real-time distributed performance, without the need for technical support dedicated to the network and with a relatively low budget, since the used devices are affordable (in the order of few thousands euros) and easily available at the commercial level.

2.2.2. The audio/video setup

The network setup was followed by the study of a multimedia configuration that could be suitable for the collection and delivery of video streams within the locations of the show.

Throughout the technical testing stage and audiovisual set-up in the locations where the play would take place, we were supported by the Network Electronics Company personnel, retailer of Italian Yellowbricks LYNXTecnich devices (http://www.lynx-technik.com) .

The play requirements involved the use of Millumin video mapping and audiovisual shows software. Millumin (http://www.millumin.com/v2/index.php) can collect video streams (live or deferred) and process them in a single frame up to 4K (3840x2160). A timeline is then in charge of distributing and mapping the sequences that can subsequently be played live on one or more projection devices.

The video streams involved in the theatrical performance were:
1. 1 signal FullHD (1920 x 1080 30fps) Remote - Camera 1
2. 1 signal FullHD (1920 x 1080 30fps) Remote - Camera 2
3. 1 signal FullHD (1920 x 1080 30fps) Local - Camera 3
4. 1 signal FullHD (1920 x 1080 30fps) Local - Camera 4
5. Balbi Crypt Video Contribution FullHD (1920 x 1080 30fps)
6. INFN LNF FullHD Video Contribution(1920 x 1080 30fps)
7. Scooter journey HD Video Contribution (1280 x 720 30fps)

In one of the sites, the Octagonal Hall, there were 3 projection surfaces and 3 projectors. In the second site, the stage of Palazzo Altemps, only one large screen was installed together with a large projector.

The use of Millumin, in this configuration, required a computer capable of collecting the video streams indicated above, process them and return them as outputs on the three projectors.

In addition, in order to limit the latency introduced by capture cards and computers, the local FHD-SDI signals needed to be directly sent on LYNXTecnich PDM 1383, so to be then transmitted to the remote location.

Because of these technical conditions the use of SDI splitter was necessary. The choice went for LYNXTecnich DVD 1714, able to divide the signal coming from the cameras and distribute it on the PDM 1383 as output and simultaneously on a LYNXTecnich device PMV 1841 quad split multiviewer.

The role of LYNXTecnich PMV 1841 is to collect 4 FHD-SDI video streams and convey them in a 4K (3840x2160) HDMI matrix.

The 4k HDMI stream is then sent as input to the directing computer and edited through Millumin. Unfortunately, the LYNXTecnich PMV 1841 later proved to be unsuitable for this project. The outflow, in fact, was FHD (1920x1080) rather than 4K (3840x2160).
As an alternative, we tested a device with the same functions but with output 4K (3840x2160) HDMI: AJA's Hi5-4K Mini-Converter. However, even in this case the test was not satisfactory. This device requires perfectly homogeneous input signals whereas the cameras used by the theatre crew were not all alike so another solution needed to be found.

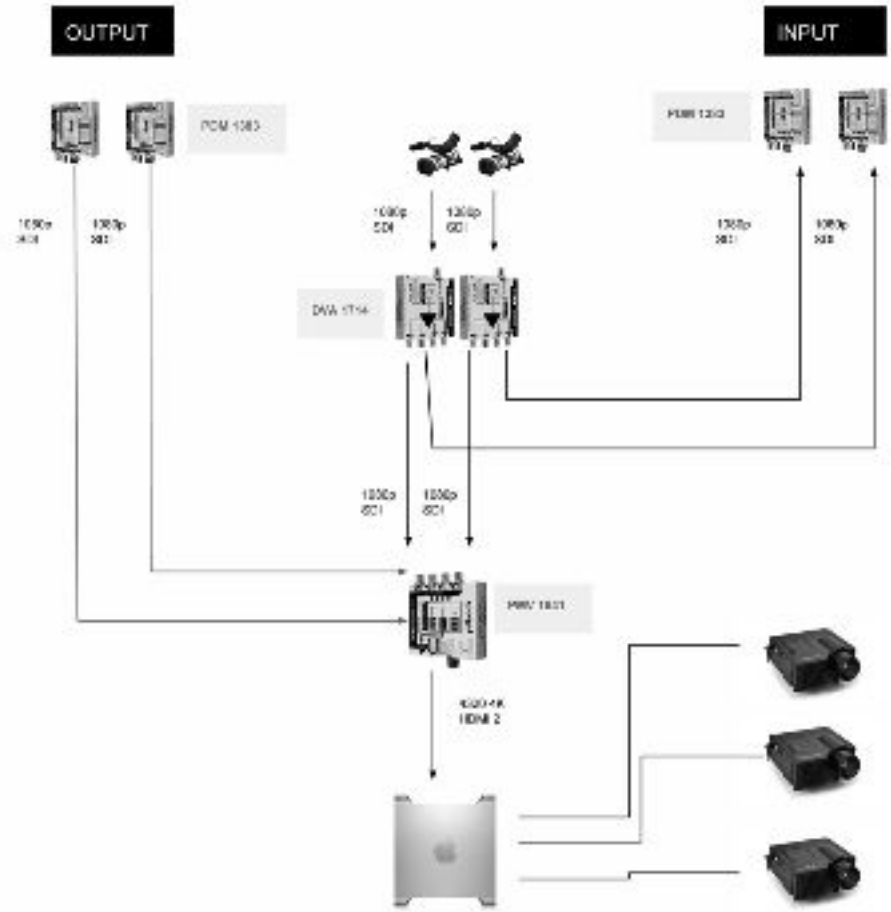

FIG 8 - local and remote input and output flows at Octagonal Hall

Eventually, the use of a MacPro equipped with 6 thunderbolt inputs and 4 USB3 has allowed us to gather all the input signals with no need for a quad split device.
In Palazzo Altemps a similar configuration was requested, although slightly simplified. Here, the solution was a video mixer for the direction of video streams and a single projector.
The use of a quad split was not necessary. Here, the local signals were splitted with 2 LYNXTecnich DVD 1714 in order to resend the signals to the LYNXTecnich PDM 1383.

The management of audio streams has been delegated to a service. The audio streams were obtained from the 4 outputs and 4 XLR analog inputs of each PDM 1831.

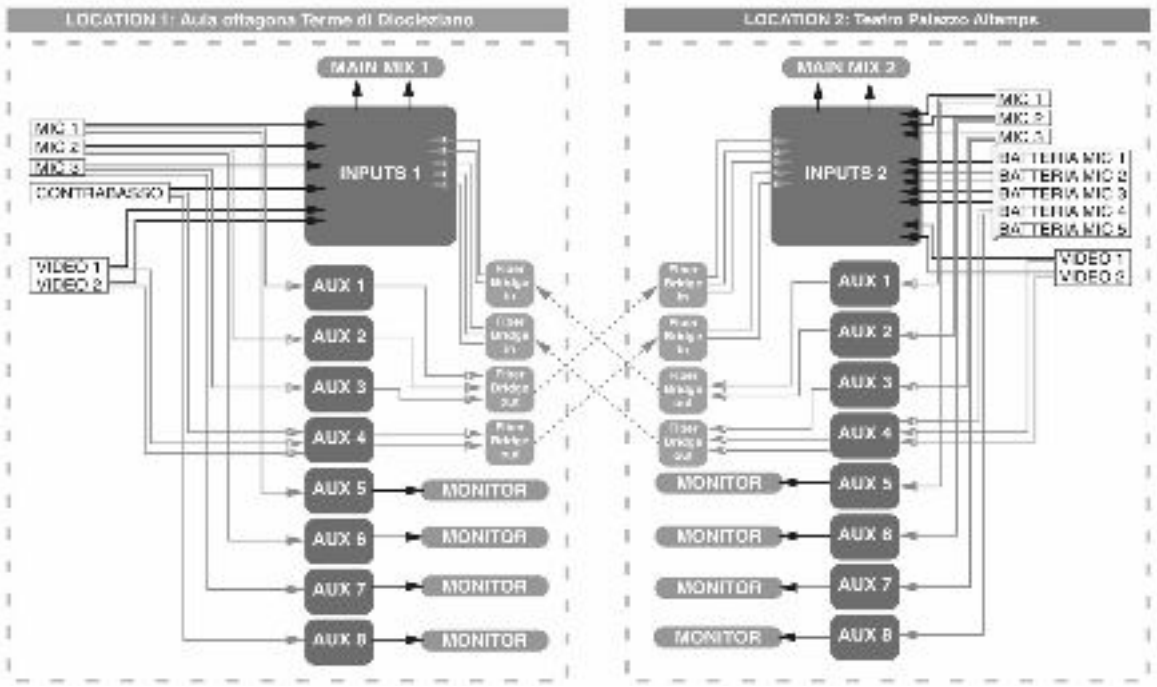

FIG 9 - Audio signals routing schemes at the two locations

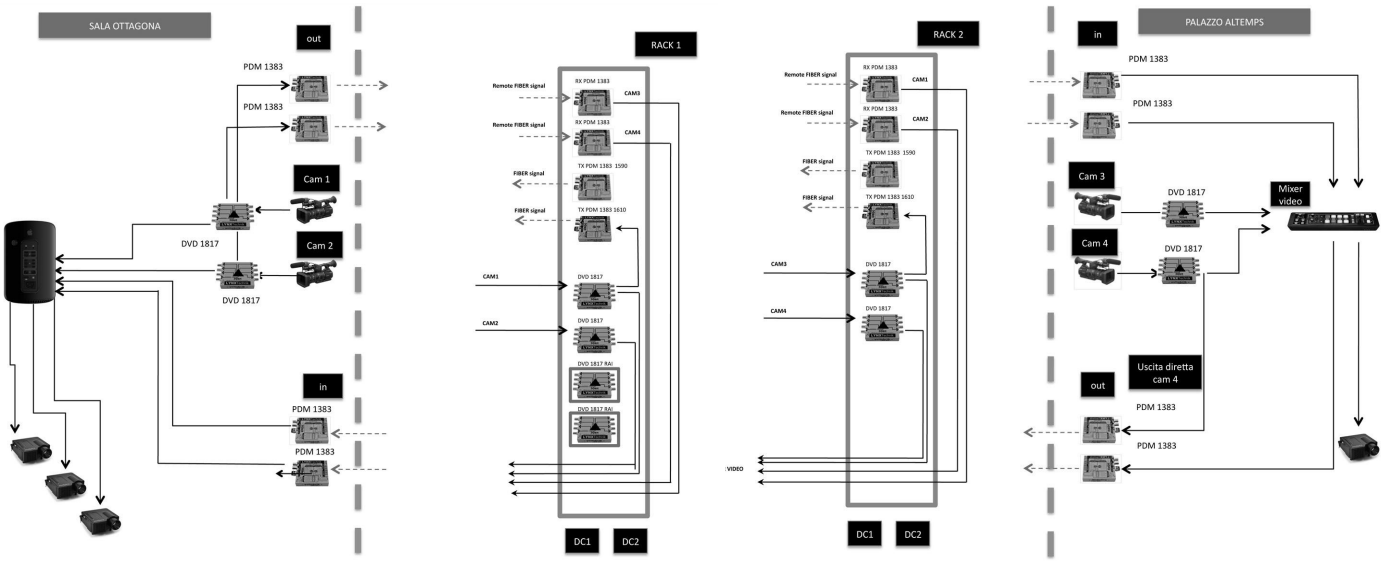

FIG 10 - Audio and video setup at the two locations

3. Conclusions

It is clear how an optic fibre infrastructure (like the one that many NRENs have already available) could open the technical possibility for a "low investment" development in several fields not last the one of performing art. We demonstrated a theatre play could be designed to span among different interconnected stages to foster the rethinking of theatre spaces in terms of a network of interconnected locations.

The technology is not only relatively cheap, but also portable to different scenarios: from 3D video virtual presence to different applications in other disciplines (with SDI ultra high FPScameras) that could require ultra reliable and ultra fast real-time audio/video connections.

In a future scenario we can imagine an extension of this trial on the geographical scale. At the level of transmission, in fact, delays are in the order of 1ms every 100 km (one-way delay), plus two additional ms for the signal input and output. Given that 50ms is the minimum perceivable delay, in principle it a real-time interaction would be possible in a range of less than 5000km: therefore, it would be feasible, for example, to set up a distributed performance between any location in Europe provided that a suitable connection is available.

Obviously, in this case the complexity of the project would increase because of the multi-domain environment, but this challenge could just make this trial more more interesting.

What we experienced with *Il Ratto di Europa* represents a technologically different approach than LOLA, which instead uses the IP layer of the ISO/OSI stack being able to contain also the delays acting during the encoding and decoding phases, and which must be able to use the capillarity of the IP network. Without the use of ultra fps cameras the solution adopted with *Il Ratto d'Europa* is a suitable option for distributed theatre performances, but not for musical concerts. This is because the delay related to the transmission must then be added to the one generated by commercial SDI cameras, which today introduce latencies in the order of 150 ms: perfectly compatible with acting and (partly) dancing but not with music.

Other possible areas of experimentation are on the one hand the use of direct optical transport even for LoLA, which would cover intercontinental distances also in the music field, and on the other hand the hybridization of the two transport systems in a single infrastructure that could provide optical transport over long distances, and then move to IP level for the "final delivery" of the data, thus solving the possible problem of the unavailability of a native end-to-end optical transport .

FIG ... - a moment of the bi-located play - photo courtesy of O. Nigris Cosattini

4. References

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Biographies

Claudio Allocchio studied Astrophysics and Particle Physics and then worked at CERN, where he started to work in computer science since the early ‘80s. With GARR since its beginnings, Claudio currently holds the position of Advanced Application Services coordinator. He is one of the world computer networking pioneers, having contributed to create the GARR network in Italy, the European backbone (now GEANT) and the Internet at large as an author to many RFCs since 1990. He contributed to design and engineer a number of application services, from global email in the 80's, to videoconferencing and advanced real-time services, including LOLA. Claudio was also a pioneer in bringing technology into the arts and humanities arena.

Edoardo Angelucci has got more than 5 years experience as hardware IT specialist and currently works as system administrator at GARR, with main tasks focusing on multimedia service events support,
customer support and desktop hardware and software management.
He has also background skills in h.323 and SIP protocols, multimedia systems, videostreaming protocols and

applications.

Alex Barchiesi is a creative physicist with a PhD in Particle physics, researcher at European Organization for Nuclear Research (CERN ATLAS experiment), associate professor of new media art and informatics at Art Academy of Rome, associate professor and senior researcher at EPFL Computer Science department. His artistic work has been presented around Europe including in IRCAM centre Pompidou Paris and Auditorium Parco della Musica in Rome and received international awards. Invited researcher of the Planetary Collegium and member of GARR.

Elis Bertazzon holds a MAs in International Relations from the University of Trieste and a university degree in Institutional Communications from the University of Strasbourg. She joined GARR in 2016 as part of the communications and external relations team with experience in advocacy and institutional communications, communication strategy development and implementation as well as media relations for both private and nonprofit sectors.

Paolo Bolletta graduated in Telecommunications Engineering and joined Fondazione Ugo Bordoni in 2009 as a research fellow. He is with GARR since 2011, when he started as a network engineer at NOC, working in particular on infrastructure assurance and maintenance; he then moved to work on other aspects of the optical and IP/MPLS network infrastructure, including delivery and commissioning, and optical network design and procurement. Recently he was part of a research team working on alien wavelenghts trials.

Bruno Nati has a degree in Multimedia and Audiovisual Communication Technologies. He started in 2002 to deal with educational technology and production of media content for schools. Since 2008, he deals with web communication for the GARR. He participates in the implementation of projects and provision of e-learning training, production of multimedia educational content and tutoring. His interest in educational technology has led him to work on techniques of live streaming and broadcast audiovisuals for GARR and user community events.
Bruno builds and manages many GARR web channels and he takes care of production and post-production of content and audiovisual products.

Marco Paniccia holds a degree in Political Sciences from University of Rome “La Sapienza”. He has got a 20 years experience in the design and creation of traditional and digital media and websites, both static and dynamic. In 2015 he joined GARR, where he takes care of web communication through the institutional website and other sites dedicated to specific services, projects and events. He is also involved in multimedia activities including streaming and web TV. Among his other interest are 3d Graphics and photography.

Andrea Salvati has been working since 2000 with GARR, where he is part of the Operation team, in charge of installing, configuring and maintaining the network infrastructure's DWDM equipment and routers. He is also part of the Planning team, dealing with the analysis of requests for network connectivity and services and the tailored access link planning and user support activities. In addition, he has been involved in several multimedia activities (streaming, support to live performances exploiting ultra-broadband links).

Federica Tanlongo holds an ICT Master’s degree in New Media and Communication from the “La Sapienza” University of Rome. Since 2004 she has been with GARR, where she currently holds the position of communication and external relations coordinator. Besides institutional communication and dissemination activities, she has been involved in the design and management of a number of international projects, from FP6 to H2020 and in international cooperation (ENPI, EuropeAid, Interreg) programmes and has gained an extensive experience in project management and team leading in an international - and often intercontinental - context.

Giancarlo Viola was born in Cosenza in 1971. After attending high school in Calabria, he moved to Pisa to attend the School of Telecommunications Engineering, where he graduated in 2001. He began his career in 2002 with Infotel Italy company, where he worked for two years as a IP network technician. In 2003 he arrives at Ericsson, where he held the position of IP Network designer for four years. Currently he is a Senior Network Engineer at GARR, where he works since 2007.

Carlo Volpe works, since 2007, in the External Relations and Communications Office at GARR, the Italian Research and Education Network that provides ultrabroadband connectivity to the community of education, research and culture.
He handles institutional communication and activities of relationships with users. He looks after the aspects of media relations, concept and the layout of graphic information materials, web and editorial content, corporate and institutional events.