A Software-Based Solution for Distributing and Displaying UHD Video Content over Packet Networks with Applications to Telemedicine and Culture

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Abstract

Since 2009, RNP has participated in demonstrations related to streaming ultra-high-definition (UHD) content over packet networks. However, working UHD media requires the use of specialized equipment that usually is expensive and has limited availability in developing markets like Brazil.

This has led RNP to foster the development of national technology for 4K equipment. Since 2011, RNP has funded a research group to develop a low-cost solution for 4K video-player and streamer. This approach relies on an architecture of distributed and parallelized software components that enables the building of 4K systems using COTS (commercial off-the-shelf) hardware. This represents an alternative to traditional 4K systems, presenting a better cost-effectiveness ratio and may be useful to facilitate the large-scale deployment of such systems, especially in contexts where access to technological innovation is limited.

In 2013, a pilot project funded by the Brazilian Ministry of Culture is deploying the RNP-funded 4K player/streamer in a set of six cinemas connected to the RNP backbone. Also this year, it was possible to attach a 4K camcorder to our player/streamer, enabling the live streaming of 4K content. This was first used to stream an open-heart surgical procedure from a university hospital, member of the Telemedicine University Network RUTE [MCTI], to a visualization room, both located in the Brazilian city of Natal, around 30km apart.

This paper presents this low-cost software-based solution for 4K player/streamer, in addition to describing the two aforementioned use cases.

Keywords

4K, telemedicine, cinema, multimedia, RNP

1. Introduction

1.1 Background and Motivation

Although motion pictures have existed for more than a century, digital video quality has not been able to match the quality of 35-mm films until recently. The first commercially available ultra-high-definition (UHD) cameras, with resolution around 4,096 x 2,160 pixels (4K), started to appear on the market in 2006.

Today, it is possible to capture, edit, and exhibit digital videos at ultra-high resolutions, profiting from the inherent advantages of digital-over-analog media without losing image quality. With the advent of high-resolution cameras, digital projectors, modern digital-image-compression standards, high-speed networks, and faster and larger storage devices, it became possible to build systems that allow the packaging, distribution and playback of UHD content, thus enabling the development of the digital cinema era.

Nevertheless, few movies are distributed or even displayed in 4K resolution, even though 4K projectors are available in many cinemas. For the vast majority of moviegoers, 4K and 4K-3D movie screenings are still relatively rare.

Most current solutions for handling UHD multimedia content rely on dedicated single-purpose hardware. These hardware-based approaches are hard to deploy, maintain, and update, which might have contributed to the slow adoption of this technology.

1.2 RNP's UHD visualization programme

In July 2009 RNP provided network support for an unprecedented demonstration at the FILE (Electronic Language International Festival) event, where a 4K feature film was simultaneously streamed from Brazil to the US and Japan [Margolis 2011]. Since then RNP has continued to participate in demonstrations related to streaming ultra-high-definition content over networks. However, working with such a high-resolution media requires the usage of specialized equipment, which, until recently, was not available for the consumer market. Usually, UHD equipment, like displays, projectors, cameras and video-players, is expensive and has limited availability in developing markets like Brazil. In addition to the high prices of such equipment in world markets, import tax collected by the Brazilian government doubles the final cost.

This has led RNP to foster the development of national technology for 4K equipment. To do so, in 2011 a new programme called "Advanced Applications for Remote Visualization" funded a research group to develop a low-cost solution for a 4K video-player and streamer. Groups of researchers and specialists in video from universities were funded, with the intent of developing an infrastructure that allows transmission, coding/decoding and exhibition of UHD visual content. This result was obtained through creation of three complementary Working Groups (WGs). The first WG – led by the Mackenzie University, located in São Paulo, Brazil - was responsible for producing a short UHD film content to be screened during technological demonstrations; the second WG – led by the Laboratory of Computer Networks and Architecture (LARC) at the São Paulo University, located in São Paulo, Brazil - was responsible for testing and using tools for UHD exhibition and collaboration; and the third WG - led by the Laboratory

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for Applications of Digital Video (LAViD) at the Federal University of Paraíba, located in João Pessoa, Brazil - was responsible for developing the low-cost 4K player and streamer which is presented in this paper.

Named "Fogo Player", the solution developed by the third WG was first demonstrated at the 11th Annual Global Lambda Integrated Facility Workshop (GLIF2011), in September 2011 in Rio de Janeiro, Brazil. The second public demonstration was at the Annual CineGrid Workshop in December 2011 in San Diego, USA.

Following its successful results, the Visualization Programme was continued in 2012. The teams from the three 2011 WGs were reorganized via a single WG, with five objectives. Three of these goals were directly related to the Fogo Player: (i) the deployment of a UHD digital media repository; (ii) the development of a component to enable on-demand transmission of UHD content between two Fogo players/streamers and (iii) to develop a solution for live streaming of UHD content by attaching a 4K camera to the streamer. This latter achievement was demonstrated in 26 February 2013 and is further explained in Section 3.3 of this paper.

The remainder of this paper is organized as follows: Section 2 briefly presents the technical details of the Fogo Player architecture. Section 3 illustrates the application of Fogo Player in two real use cases from the areas of medical education and culture. Finally, Section 4 concludes the paper.

2. The "Fogo Player 4K" UHD solution

The Fogo Player 4K solution requires only COTS hardware, and relies on specialized software components for encoding, transmission, decoding and playback. In this Section, these components are briefly explained. Further details are available in [Aquino 2013].

1.3 High-Level Architecture

To solve network bandwidth limitations and minimize the delay between transmission and exhibition, UHD videos can be transmitted in a partitioned way from a set of distributed streamers. To use this approach, a player must combine the different partitions into a single video stream before displaying them on screen. Our proposed architecture consists of four main subsystems - distribution, preprocessing, streamer, and player - and includes an auxiliary coordination subsystem (the main coordinator). Each subsystem further consists of a set of minor components that are responsible for specific subsets of the system requirements. The subsystems are shown in Figures 1a and 1b. They are listed as follows:

- Distribution Subsystem: This is responsible for receiving the raw content from a video source, spatially slicing the video into quadrants, and transmitting these quadrants to intermediate storage elements, like a storage cloud.

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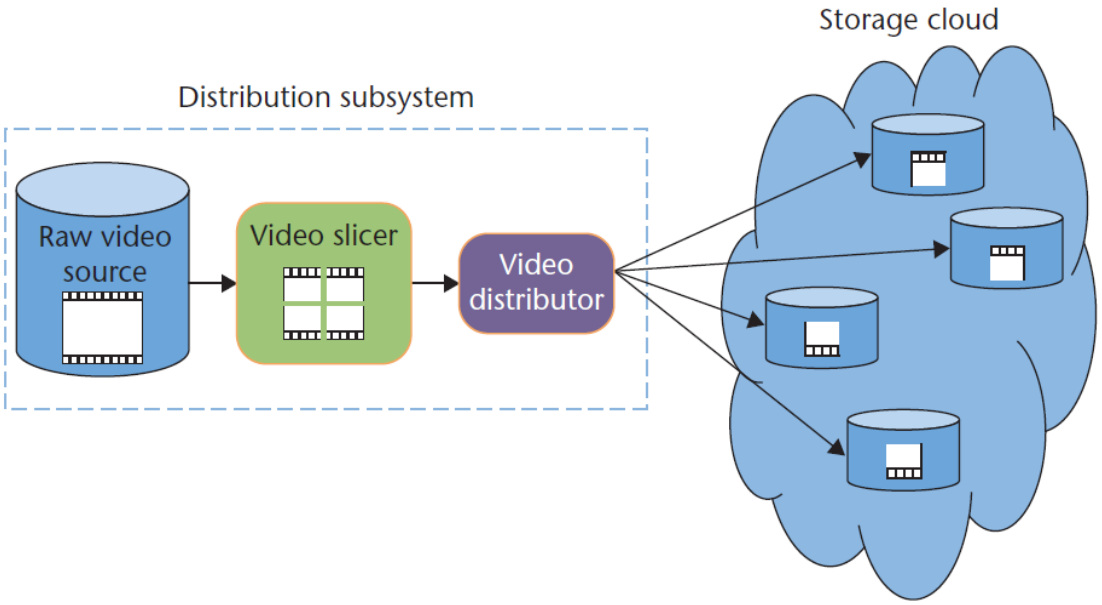

Fig. 1a: High-level architecture distribution subsystem

- Preprocessing Subsystem: This encodes the video quadrants using an encoding standard that is independent of the proposed system architecture. The quadrants located in the storage components are read, encoded, and saved back into the storage infrastructure.

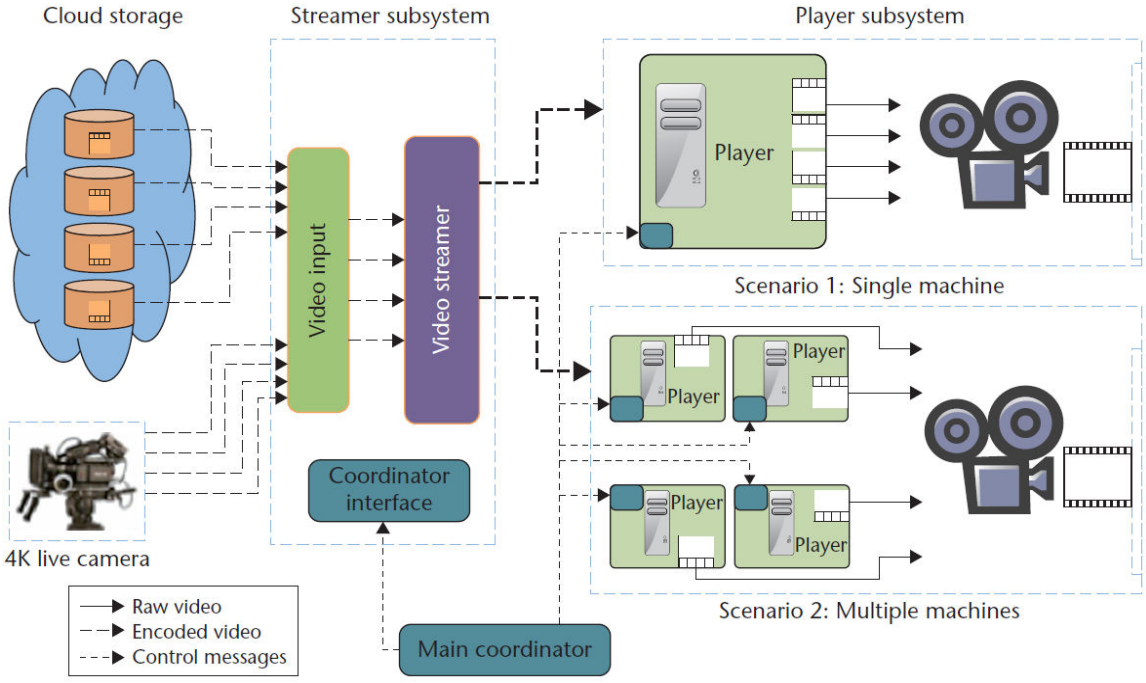

Fig. 1b: High-level architecture streamer, player and main coordinator

- Streamer Subsystem: This represents an abstract video source that encapsulates the acquisition and transmission processes. It consists of three main components: video input, video streamer and coordinator interface. The video input component is responsible for

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encapsulating the source of the video being transmitted (through the video streamer component) over the network, handling either data captured from a live camera attached to the system or previously recorded data held in a storage system. The coordinator interface component communicates with the main coordinator and is responsible for receiving the control messages to synchronize the streamer's processing.

- Player Subsystem: The player subsystem consists of four main components: video receiver, video decoder, hardware abstraction layer (HAL), and coordinator interface. The video receiver component receives the video streams from the streamer subsystem. The video decoder component decodes the video after receiving it from the video receiver component, and it is independent of encoding standards. The HAL component receives the decoded video from the video decoder and displays the frames at the right time. The coordinator interface component communicates with the main coordinator and is responsible for receiving the control messages to synchronize the exhibition.
- Main Coordinator: The main coordinator controls the whole system's execution. Its main task is to keep the software components with the same time reference.

1.4 The Fogo Player

We implemented our proposed architecture in the Fogo Player, which can display several partitions of a UHD video, with or without stereoscopy, in a synchronized way, even when different parts of the video are transmitted from streamers geographically distributed. At a high level, the Fogo Player consists of a set of brick player components, an audio player component, a controller component, and the Fogo streamer. These components work as follows:

- Brick Player: A brick player receives the data from one of the video quadrants, decodes the content, and displays the decoded frames. The Fogo Player decodes and displays the quadrants of a single video in a parallel way, using multiple brick players, each one responsible for processing a different partition of the target video.
- Controller: The controller component implements some of the requirements of the main coordination subsystem and ensures the synchronization of all the brick players. It is also responsible for detecting trends for emptying or overloading the buffers. When it detects such trends, the controller commands small changes in the video exhibition rate.
- Audio Player: The audio player handles the audio associated with the content being displayed.
- Fogo Streamer: The Fogo streamer is the implementation of the streamer subsystem and is responsible for transmitting each partition of the video to a brick player. The bit rate is controlled according to the video partition's compression rate, which can vary along the video stream.

Altogether, the Fogo Player 4K is currently built on a Linux server, with Intel® Xeon® 2.5GHz processor, 32GB of RAM memory and 2 ATI FirePro™ graphics cards, each one with 4 display

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ports. An additional Synchronization module for ATI FirePro™ is required for ensuring the correct synchronization of quadrants. The network card is the Intel® X520-DA2.

3. Use Cases

1.5 Network of Digital Cinemas

The first real use case derived from Fogo Player is the Network of Digital Cinemas (provisional name), which is a pilot project coordinated by RNP and funded by the Brazilian Ministry of Culture (MinC) in cooperation with the Brazilian Ministry of Science, Technology and Innovation (MCTI).

This project deployed a network of cinemas by installing a "Digital Cinema Kit" in 6 screening rooms connected to the RNP academic network. The main node of this network is the Brazilian Cinematheque – a public institution responsible for archiving and restoring one of the largest audiovisual collections in Latin America, with around 40 thousand movie titles. Additionally, 5 other screening rooms were selected, all managed by public universities and cultural institutions, giving a total of 6 cinemas participating in the project. Figure 2 shows a map of the selected cinemas.

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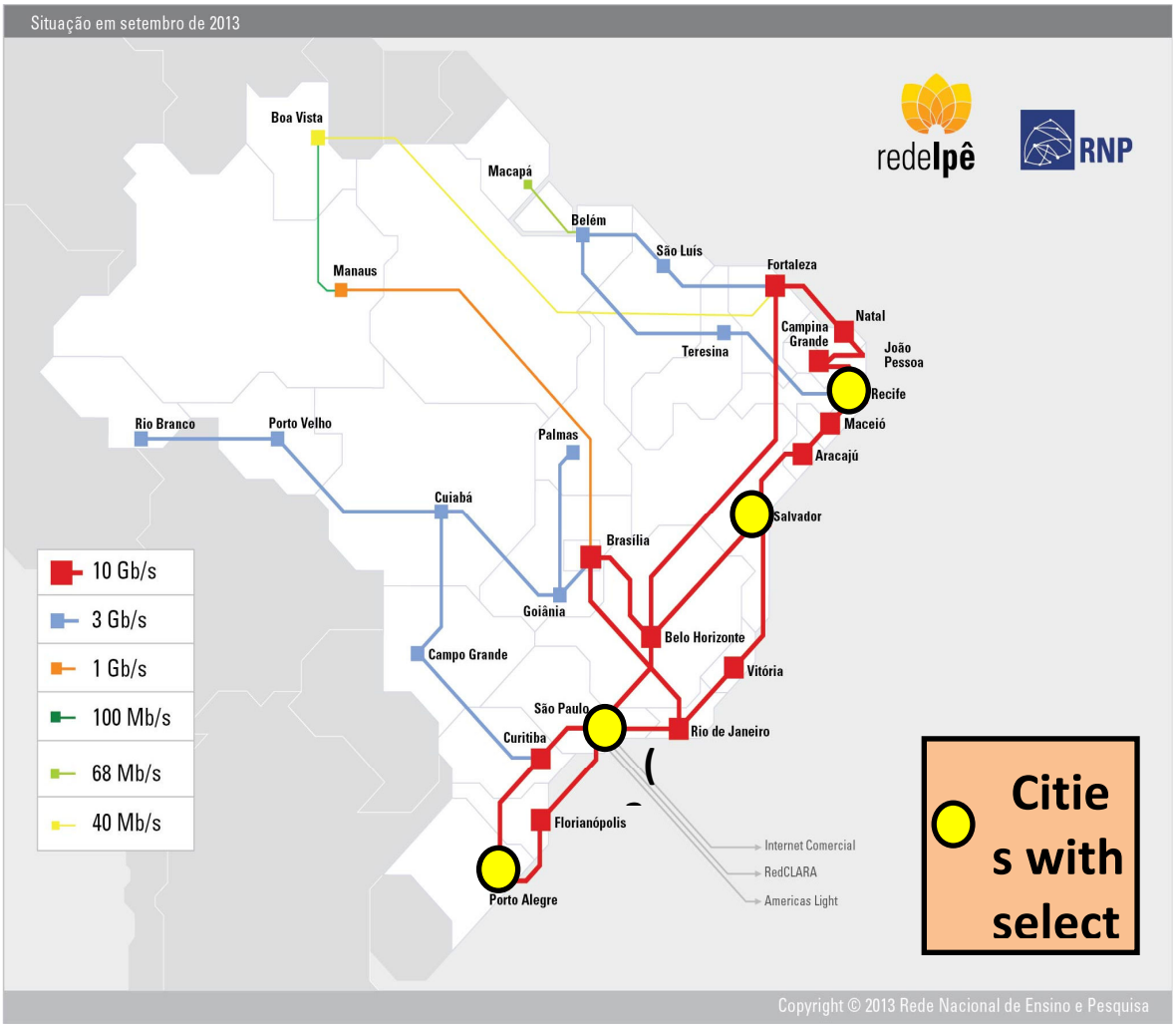

Fig. 2: Cities with selected cinemas shown over the RNP academic network backbone

As most of the selected cinemas do not have 4K projectors, we are using a cheaper version of Fogo Player, with Full-HD video output. This approach also reduces the cost of a kit, in order to make it more affordable to equip smaller cinemas in smaller population centres.
In addition to the Fogo Player, a complete system to enable the exchange and management of movie content among the cinemas has also been developed. Basically, the system architecture also consists of:

- A "Digital Content Exchange system" (ICD in the Portuguese acronym). This works as a local movie repository. Each cinema has one ICD server, where local playlists can be created or shared with other cinemas. It is also possible to protect the content by defining which cinema or user is authorized to receive each content.
- A "Cinema Controller", which is a desktop application where the projectionist can load playlists from the ICD system and schedule/start/stop screening sessions. In our

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architecture, it runs on a Linux PC and works as an interface between the ICD server and the Fogo Player.

In summary, each Digital Cinema Kit contains at least:

- 1 Fogo Player.
- 1 Desktop PC for Cinema Controller;
- 1 Server for ICD System;
- 1 LCD display monitor, cables and peripherals.

This architecture also allows the simultaneous screening of movie sessions, empowering the cinemas to promote online debates among the distributed audience right after the movie screenings (additional videoconferencing equipment is required). It is also worth saying that our solution is also seen as an alternative standard to the technological packets distributed by Hollywood.

Besides contributing to increase the access to audiovisual content – especially from independent and historical movies outside the "blockbuster" circuit – the Network of Digital Cinemas intends to constitute a distributed laboratory for investigating the problems related to distributing audiovisual content over networks.

1.6 Early results of 4K visualization applied in telemedicine

One of the main outcomes of RNP's UHD visualization programme was reached at the end of 2012, when the LAViD team managed to attach a 4K compact camcorder[1] to Fogo Player, enabling the feature of live streaming of uncompressed UHD content.

This complete solution was first demonstrated in February 2013, by streaming an open-heart surgical procedure from the Onofre Lopes Teaching Hospital (HUOL) to a visualization room in the Federal University of Rio Grande do Norte (UFRN), both located in the city of Natal (RN), Brazil, around 30 km apart. The uncompressed video stream consumed 3.5 Gbps of bandwidth. Both locations are connected through a 10Gbps ring in the metropolitan network of Natal. The scheme of this demonstration is illustrated in Figure 3.

In addition to connecting universities and research centres in Brazil, RNP also participates in the Brazilian Telehealth initiative by linking public health institutions, university and teaching hospitals to its R&E network, constructing the eHealth community under RUTE [Coury 2010, 2010-2], which counts today to 82 Telehealth Nuclei in all 27 Brazilian states and 56 Special Interest Groups in health specialties and sub-specialties, with 2 to 3 scientific virtual sessions everyday, 600 a year, with ca. 300 participating institutions. The demonstration of this compelling application for collaboration and training in medicine – taking advantage of the deployment of high-speed research networks and innovations in visualization technology – is now attracting the attention of the Brazilian Ministries of Health and of Education, which are now planning further investments to adopt this technology in about 30 teaching hospitals around Brazil.

[1] JVC model GY-HMQ10

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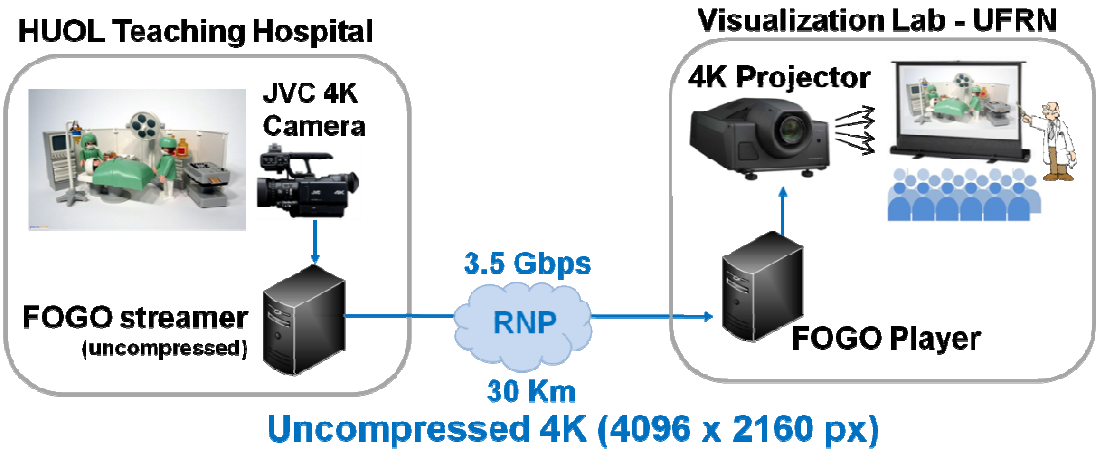

Fig. 3: 4K Live surgery demonstration diagram

4. Conclusions and Future works

The solution described in this paper represents an alternative to traditional UHD systems, presenting a better cost-effectiveness ratio. Additionally, the presented solution may be useful to facilitate the large-scale deployment of such systems, especially in contexts where the access to technological innovation is limited. This is the case, for instance, in large, developing countries like Brazil, where there are about 4.800 cities without a single cinema.

Excited about the possibilities of enabling access to audio-visual content to hundreds of towns, and also creating an alternative standard to the commercial movie packets, the Brazilian ministry of Culture is now funding a new version of Fogo Player featuring a satellite receiver. This will allow the installation of a Digital Cinema Kit even in small cities without high-speed Internet connection. Their plan is to deploy about 300 public viewing sites in 2014. The Network of Digital Cinemas is also planning an expansion phase in 2014, by adding new screening rooms, some of them with 4K capabilities. Some improvements in the user interface and the overall system is also expected, profiting from the feedback of the participating institutions in the initial project phase in 2013.

In the telehealth field, the successful 4K transmission of open-heart surgery early this year attracted the attention of the telemedicine community. Some surgeons, nurses and representatives from the government were impressed with the high-quality of the images. "I can see that gland in much more detail than when I am in the operating room!", said one of nurses watching the live streaming in an eight square metres screen of the visualization room. As a result, the Ministry of Education – which supervises the teaching hospitals in Brazil – will fund a new project in 2014 aiming at equipping around 30 hospitals with a 4K capture/streaming kit. We believe that a network of teaching hospitals with 4K streaming capabilities will be an additional tool for formative second opinion and continuous education for doctors and medical students.

The quality of the streamed images from Fogo Player is been continuously tested and evaluated by experts, thanks to demonstrations that are regularly organized in specialized fora, such as the annual CineGrid International Workshop and the Brazilian Cinematography Association's week.

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The next demonstration at CineGrid will be held in December this year, and will promote the merging of the telemedicine and digital cinema communities. Four different surgeries will be simultaneously captured in four teaching hospitals around Brazil and simultaneously streamed to Brasilia (Brazil's state capital) and San Diego, USA (Int'l CineGrid Workshop venue). From Brasilia, the audience will be formed by invited doctors and representatives from the ministries of Health and Education. In San Diego, the workshop participants will have the opportunity to evaluate the quality of the images.
Besides all the foreseen expansions and new developments thanks to the aforementioned new projects, future improvements in the Fogo Player system within the RNP's Visualization Programme includes:

- Integrating the Fogo Player with RNP's Dynamic Circuit Network service, allowing user-initiated *ad hoc* dedicated allocation of network bandwidth for movie streaming over RNP's backbone.
- Integrating Fogo Player with tiled display walls controlled by SAGE middleware (Scalable Adaptive Graphics Environment).
- Investigating the scalability of Fogo Player architecture targeting 8K visualization.

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Biographies

Leandro Ciuffo is a Manager in the Directorate of R&D at RNP, in charge of interacting with scientific communities concerning new approaches to advanced network use. From 2006 to 2009 he worked at INFN-Catania (Italy) in two e-Science projects: EELA (FP6) and its successor EELA2 (FP7), being responsible for dissemination and user support activities. Leandro holds a B.Sc. in Informatics from the Federal University of Juiz de Fora (UFJF) and a M.Sc. in Computer Science from the Federal Fluminense University (UFF), in Brazil.

Guido Souza Filho is an associate professor and the coordinator of the Laboratory for Applications of Digital Video (LAVID) at the Federal University of Paraíba, Brazil. His research interests include dependability in multimedia systems, hypermedia, Digital TV, distributed systems, distributed multimedia applications, and computer networks and video. Souza Filho has a PhD in computer science from the Catholic University of Rio de Janeiro, Brazil.

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Michael Stanton is Director of Research and Development at RNP. After a PhD in mathematics at Cambridge University in 1971, he has taught at several universities in Brazil, since 1994 as professor of computer networking at the Federal Fluminense University (UFF) in Niterói, Rio de Janeiro state. Between 1986 and 2003, he helped to kick-start research and education networking in Brazil, including the setting-up and running of both a regional network in Rio de Janeiro state (Rede-Rio) and RNP. He returned to RNP in 2001, with responsibility for R&D and RNP involvement in new networking and large-scale collaboration projects.

Clayton Reis is Coordinator of Research and Development at RNP. Clayton has B.S. and M.S. degrees in Computer Science at Federal Fluminense University (UFF) in 2009 and 2011, respectively. He works at RNP since 2012, coordinating R&D projects involving advanced internet, advanced visualization applications and big data transfers.