PART III

Research PROJECTS and CASES Using Experimentation TESTBEDS

14

Estimating the Dimension of Your Wireless Infrastructure by Using FIRE Testbeds

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14.1 Introduction

Nowadays, the audience for live events such as: concerts, theatre, sport matches, etcetera is demanding real-time information more than ever. Spectators require data about all possible details of who is taking part and what is happening on the event. This phenomenon takes special relevance for instance on sports events where spectators continuously consult handheld devices to view additional information such as: statistics, repeated plays, players' information, comments from professionals, friends' points of view and etcetera. This information is attractive to them because they are able to best judge what is going on. Summing up, providing additional premium content in real-time while a sports event is being broadcasted makes a huge difference to the spectators' experience.

LIVEstats platform has been developed to reach this demand, providing live statistical information and 3D replays of sports events to the audience on their Smartphone or Tablet. Even though it was originally devised to serve as second screen application to be consumed at home premises, we realized that it had a huge potential if it were to be offered to the audience on site, at stadiums during football matches.

Nevertheless, as usual, in order to properly define both business and cost models, we had to perform the processes of testing the platform in real environments. Due to the special characteristics of the target venues considered, this process becomes unaffordable for an SME. This is how Fed4Fire tools became relevant to us and here is where the experiment titled ***LIVEstats On Fire*** came to life.

The experiment aimed to assess the performance of LIVEstats as an innovative cloud-based platform for the provision of enhanced 3D interactive content during a sports event in an outdoor scenario as if it was a real Stadium. We wanted to overcome the difficulties of testing the provision of this content using wireless technologies to serve hundreds of spectators through their devices at the same time.

In LIVEstats On Fire experiment we made use of the FIRE wireless facilities (including Wi-Fi, WiMAX and LTE) to assess the viability to provide LIVEstats service to the spectators in a real case scenario, with a massive number of users accessing the platform simultaneously while ensuring the delivery of a good quality of service. For that purpose we conducted a comprehensive evaluation of the required topology and configuration of the wireless network that should be deployed.

Results were analysed and incorporated to our business model with the objective to get aligned with the leading edge of technology for second screen applications in the sports market. Results also provided us with the appropriate knowledge in order to become able to characterize the physical infrastructure that is needed to provide content from our platform over wireless technologies to a large audience on real-time during a sports event on site on a sports stadium. With this information, we were able to enrich our business model for the platform by preparing an adjusted cost model in addition to the information and the required models for the deployment and commercialization of the system in real-case scenarios.

The experiment consisted of 3 set-ups to perform particular tests by using Wi-Fi, LTE and WiMAX nodes available at FIRE's NITOS testbed infrastructure.

Those tests were focused on:

1. Specifying the **relationship among the characteristics and number of nodes** of the network and the number of spectators that could be able to enjoy the service with a suitable Quality of Service.
2. Analysing the **factors and characteristics of the infrastructure** that are critical for the streaming experience, this is, which features make the difference about the number of spectators accepted by the system.
3. Defining the **relation among the topology of the network and the Quality of service** offered. Results will guide us to adapt the network distribution configuration to a specific stadium.

From results we have been able to answer many questions related to relevant and useful aspects and we are now in a much better position for understanding and modelling the physical infrastructure that may be needed in any real case scenario that we may face in the future. We obtained valuable information that will allow us to prepare a detailed cost model and prepare marketing actions in order to approach our key partners and potential customers.

We wouldn't be in this position now if we hadn't had access to Fed4FIRE facilities, because the particular scenario for our platform required human, time and physical resources that are too costly for us to address.

The experience has also been significantly enriching for our company in a variety of aspects, since we have been able to access in depth to a very interesting federation of testbeds, counting with dedicated support all along the process.

14.2 Problem Statement

The market for global sports rights has increased by an average of 5% over the past 5 years, reaching around €22 billion in 2014. This trend is expected to continue thanks to the continuous advances in technologies and premium sports services that allow providing more sophisticated and compelling contents to the audience. In Europe, the football industry is one of the most powerful and has a huge impact, attracting annually tens of millions of spectators to the stadiums and many hundreds of millions of viewers at their homes.

The factors that influence the decision making process of buying a ticket or to watch a football game at home are very diverse; but clubs have already faced the reality that watching a match on TV at home is most of the times much cheaper, easier and more comfortable for spectators. A recent Cisco study showed that 57% of fans prefer to watch the game at home. Therefore the latest trend is to redefine the concept of living the match on-site by offering a unique experience for the spectators, thus making it more appealing than ever before to attract fans to the stadium.

Adding connectivity, offering new ways of interacting with spectators and providing additional services and apps within the stadiums can vastly improve fan experience and keep people coming to games even when they have a 50-inch TV and comfortable chair at home. With the additional features over wireless technologies, spectators get an experience at the stadium that they cannot get anywhere else.

LIVEstats platform was born to enter the audio visual sports market and add value to the broadcasting of sports events by improving multiplatform viewer experience through an innovative concept of enhanced information access. It is a Cloud-based platform deployed currently using Amazon Web Services. It provides real-time on demand 3D content generation to enhance the interactivity between the viewer and a sporting event through a "second screen" approach (Tablet, Smart TV, and Smartphone). Using an innovative image recognition system that positions players in a specific area of the field on real-time, the platform creates an accurate 3D recreation of each play. These plays can be accessed and manipulated on demand by the viewer with their smart device through a web-based application built on HTML5, rotating field, changing angles and moving the timeline forward or backwards. Such information is supplemented by the statistical information provided by television operators during the sporting event.

Even if originally LIVEstats was thought to provide second screen capabilities in indoors scenarios, because of the current challenges that the live sports market is facing, in the business model of LIVEstats platform we are considering, as a way for commercialization, offering the service at stadiums during football games, as an optimized and more personalized way of interacting with spectators and bring them closer to the action. We strongly believe that the platform, providing a new level of interactivity and immersivity, has a great potential to lure the audience to the stadiums. With this idea in mind and in order to better define our value proposition and previous to setting the cost structure, we are facing right know a new challenge: we need to run specific tests and make validations that let us acquire detailed information about the specific infrastructure that would be required within a stadium to provide such a service. However, demonstrating the service and assessing its performance on a real environment would be too costly for us.

Here is where FED4FIRE comes into play, and, in particular, NITOS infrastructure. The NITOS outdoor testbed with multiple wireless interfaces will allow us to test the performance of the platform with heterogeneous (Wi-Fi, WiMAX, LTE) wireless technologies and check the viability and select the most suitable infrastructure to offer the service to a large audience through different devices on real time.

The main objective of the experiment was:

To characterize the physical infrastructure that is needed to provide LIVE-stats platform premium content over wireless technologies to a large audience on real-time during a sports event on site on a sports stadium.

In order to achieve this main objective, our specific goals will be:

1. Defining and running **3 specific test scenarios** to assess the service performance with the different wireless technologies offered by NITOS: **Wi-Fi, WiMAX and LTE**. Results will later guide us to decide upon the most suitable configuration (including hybrid networks) for each specific scenario.
2. Specifying the relationship among the characteristics and number of nodes of the network and the number of spectators that could be able to enjoy the service with a suitable Quality of Service. This will be done by specifying the **maximum number of spectators** that would be able to simultaneously connect to the service through the wireless nodes provided by the NITOS infrastructure with a suitable Quality of Service in order to able to extrapolate the results for a wider audience (typically for stadiums with a capacity of 25.000 to 100.000 spectators) Our goal would be that at least 40% spectators in a stadium (users that are geographically very close from each other) would be able to simultaneously access to the 3D replays and get a good quality of experience.
3. Analysing the **factors and characteristics of the infrastructure** that are critical for the streaming experience, this is, which features make the difference about the number of spectators accepted by the system. From the extracted features, specifying on what basis they are relevant for the performance of the system and their specific values for each configuration in order to provide a good Quality of Service (starting from latencies at or below 200 msec.). This will let us know about the most cost-effective solution for each case.
4. Defining the **relation among the topology of the network and the Quality of service** offered. Results will guide us to adapt the network distribution configuration to a specific stadium.

14.3 Background and State-of-the-Art

14.3.1 Background

Planet Media is a leader company in the development of multichannel technological solutions (B2B, B2C & B2E) oriented towards Digital Transformation, Comprehensive Mobile and Web applications for Smart Cities, Media, Mobile marketing and loyalty strategies systems.

Planet Media leaded the creation of LIVEstats platform in the context of a research and innovation project with funding from the Spanish Ministry of

Economy. The platform was created to enter into the audio visual sports market and add value to the broadcasting of sports events by improving multiplatform viewer experience through an innovative concept of enhanced information access. It is a Cloud-based platform deployed currently using Amazon Web Services. It provides on demand interactive 3D replays of the most relevant plays during a sports event while the spectator is watching the TV. The replays are provided through a “second screen” approach (Tablet, Smart TV, and Smartphone) and are interactive, imitating cloud-gaming platforms, therefore enhancing the experience of the viewer during the sporting event. For that purpose, the platform uses an innovative image recognition system that positions players in a specific area of the field on real-time, and creates an accurate 3D recreation of each play. These plays can be accessed and manipulated on demand by the viewer with their smart device through a web-based application built on HTML5, rotating field, changing angles and moving the timeline forward or backwards. Such information is supplemented by the statistical information provided by television operators during the sporting event (Figure 14.1).

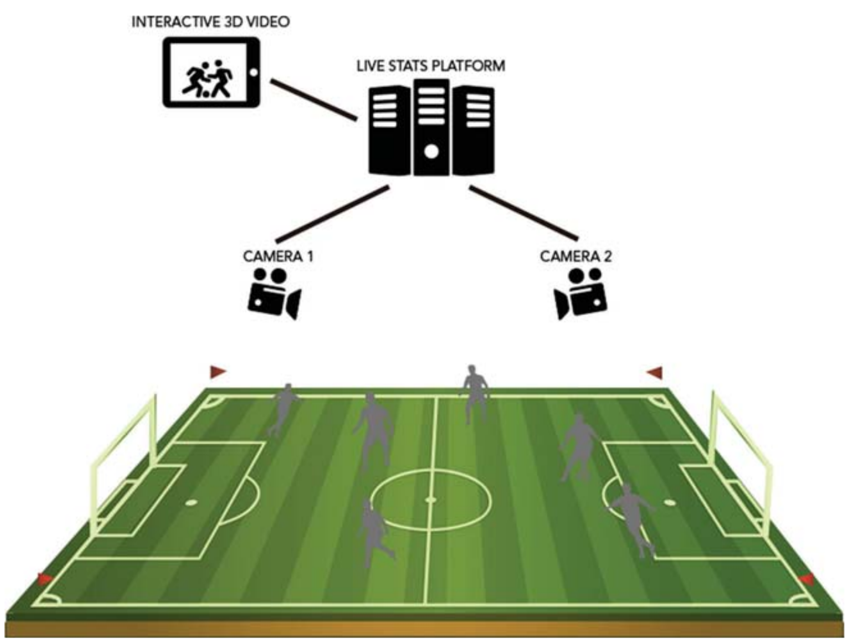


Figure 14.1 LIVEstats platform main use case scenario.

Originally LIVEstats was thought to provide second screen capabilities in indoors scenarios as we have described; but because of the current challenges that the live sports market is facing and the knowledge of the market that we have acquired thanks to our privilege position as service provider for some of the main broadcasters in Spain, such as RTVE, we have extended our vision. We have considered, for the business model of LIVEstats platform as a way for commercialization, offering the service at stadiums during football games, as an optimized and more personalized way of interacting with spectators and bring them closer to the action. We strongly believe that the platform, providing a new level of interactivity and immersivity, has a great potential to lure the audience to the stadiums. With this idea in mind and in order to better define our value proposition and previous to setting the cost structure, we were facing the challenge to run specific tests and make validations that let us acquire detailed information about the specific infrastructure that would be required within a stadium to provide such a service. However, demonstrating the service and assessing its performance on a real environment would be too costly for us.

Here is where FED4FIRE has come into play, and, in particular, NITOS infrastructure. By running an experiment using the NITOS outdoor testbed with multiple wireless interfaces we wanted to assess the performance of the platform with heterogeneous (Wi-Fi, WiMAX, LTE) wireless technologies and check the viability and select the most suitable infrastructure to offer the service to a large audience through different devices on real time.

Therefore, our main objective with this experiment has been:

To characterize the physical infrastructure that is needed to provide LIVEstats platform premium content over wireless technologies to a large audience on real-time during a sports event on site on a sports stadium.

The Figure 14.2 shows the concept of this infrastructure characterization. In a real scenario, the Stadium where the sports event takes place will have a certain number of Wireless nodes (which may be WiFI, LTE, WiMAX or a hybrid network), each of them with N instances of the service running. At each moment, there will be a number of users accessing the nearest node in their zone in order to request a 3D interactive replay from the match. The configuration and topology of the network that needs to be available will depend on the specific stadium infrastructure and the requirements of LIVEstats platform for providing an acceptable QoS. The modelling of these

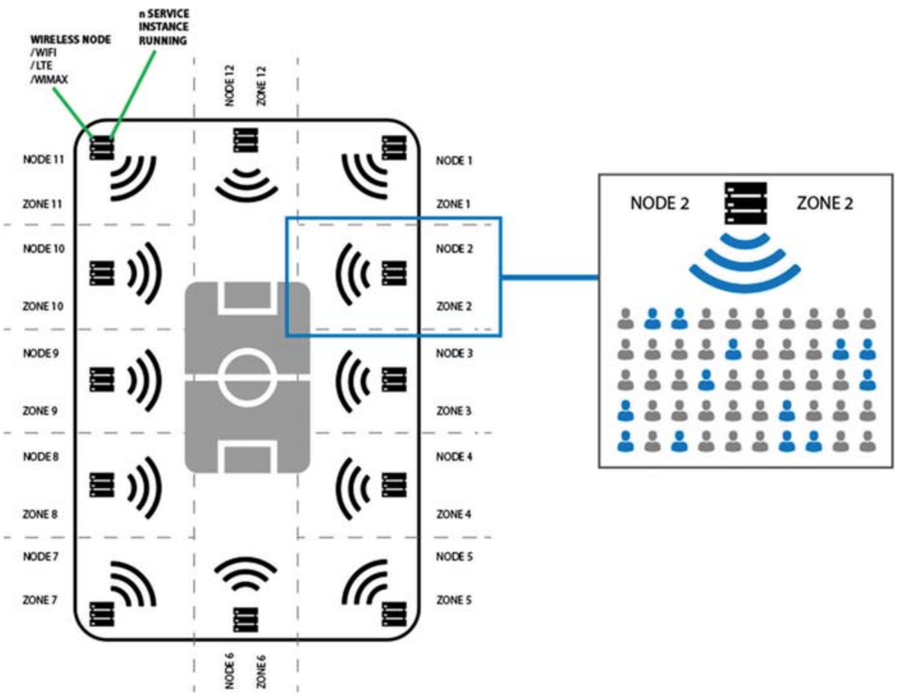


Figure 14.2 Infrastructure characterization in a Stadium.

requirements is the main objective of running the experiment with NITOS infrastructure.

Our specific goals included:

1. Defining and running **3 specific test scenarios** to assess the service performance with the different wireless technologies offered by NITOS: **Wi-Fi, WiMAX and LTE**. We want to use results to be able to select the most suitable configuration for each specific scenario that we may face in the future.
2. Specifying the relationship among the characteristics and number of nodes of the network and the number of spectators that could be able to enjoy the service with a suitable Quality of Service. This is done by specifying the **maximum number of spectators** that would be able to simultaneously connect to the service through the wireless nodes provided by the NITOS infrastructure with a suitable Quality of Service in order to able to extrapolate the results for a wider audience (typically for stadiums with a capacity of 25.000 to 100.000 spectators). Our goal would be that at least 40% spectators in a stadium (users that are geographically

very close from each other) would be able to simultaneously access to the 3D replays and get a good quality of experience.

3. Analysing the **factors and characteristics of the infrastructure** that are critical for the streaming experience, this is, which features make the difference about the number of spectators accepted by the system. From the extracted features, specifying on what basis they are relevant for the performance of the system and their specific values for each configuration in order to provide a good Quality of Service (starting from latencies at or below 200 msec.). This will let us know about the most cost-effective solution for each case.

Defining the **relation among the topology of the network and the Quality of service** offered. Results would guided us to adapt the network distribution configuration to a specific stadium.

LIVEstats on FIRE aimed at defining the specific infrastructures needed for suitable service provision and therefore the proper definition of its costs and scaling-up characteristics for a viable and beneficial exploitation plan. Carrying out the experiment described in this proposal will allow the identification and specification of the characteristic and requirements of the infrastructure capable of supporting the service provided.

LIVEstats solution is highly dependent on the infrastructures under which the data transmission is accomplished. Consequently, the main impact of this experiment, by means of NITOS support, was the definition of the technical requirements of the needed network. It will also allow the detection of emerging obstacles that might work as blocking issues regarding current technical features that may need to be further adapted. Additionally, the specification of the relationship between the technical infrastructure, the streaming experience and the number of spectators that can be served by it, allows the definition of a more precise cost model required to reach the market with adequate estimations about the required investments, pricing models and strategically partners needed to the efficient provision of the service.

This information also allows characterizing our suitable customer segments: by facilitating the description of the precise technical prerequisites that the stadium hosting the service must have and allowing the estimation of the cost that an itinerary infrastructure may have, the experiment will bring to light if smart stadium are necessary or if it is economically feasible having itinerant network infrastructures.

Moreover, the application of our solution in a real scenario provided us with valuable evidences for promotion and marketing activities towards our target customers. These are mainly the providers of audio visual content that have the rights for broadcasting the sports events and the sports clubs owning the stadiums where the events take place. With the results of this experiment, Planet Media is now in a better position to get its products closer to the market and reinforce their expertise on multi-device and multi-channel services related to the creation of content for the sports industry. Besides, this customer and market knowledge might evolve in relevant strategic alliances to be exploited with commercial purposes.

In summary, the experiment helped us to prepare an adjusted cost model for our business model in addition to the information and the required models for the deployment and commercialization of the system in real-case scenarios. Lastly, from a technical point of view, the technology assessed in this experiment has set the basis for further potential applications and platforms not only in the sports environment but others. The experiment was contextualized within the strategic plan of the company, which includes the following action areas:

- Progress on the international dimension of the company, by promoting the internationalization of the R&D activities and increasing participation in international reference projects strengthening our participation in FIRE and FIWARE communities.
- Increasing our competitiveness by adjusting our estimation of infrastructure costs in relation to new media and streaming products.

Boosting a favourable environment for the investment on sustainable R&D&I through active participation in national and European technological platforms.

14.3.2 State-of-the-Art

Professional sports leagues around the world are embracing the advances of technology by adding connectivity at the stadiums to enhance the fan experience. The Levi's stadium in Santa Clara, California (USA), which serves as the home of the San Francisco 49ers of the National Football League, is currently the most connected stadium in the world. Opened in August 2014, it has 1.500 access points and infrastructure to support Wi-Fi 30x faster than any other, allowing 60.000+ fans to simultaneously connect. It is followed by Barclays Center in Brooklyn, a multi-purpose indoor arena with seating capacity over 18.000 fans, which serves as the home for Brooklyn Nets basketball team. It supports large volumes of high-definition video and Wi-Fi traffic during the events through Cisco StadiumVision Mobile solution[1], which

[1] https://www.cisco.com/web/strategy/sports/stadiumvision_mobile.html

enables more effective use of scarce Wi-Fi spectrum by enabling reliable multicast (the same Wi-Fi transmissions can be shared by all mobile devices requesting the same content); high-quality and reliable video delivery to a massive number of mobile devices; and low delay delivery of in-venue content (including streaming video, audio, and data).

In Europe, Stadiums such as Real Madrid's Santiago Bernabéu, Manchester City's Etihad, Bayer Leverkusen's BayArena, Glasgow's Celtic Park and several stadiums in Scandinavia, have been converted into digital, connected, football venues. Through platforms such as Cisco® Connected Stadium Wi-Fi, all these stadiums aim to provide an all-encompassing multimedia fan experience through an average 10- to 20-Mbps connectivity, so that they for example may upgrade their seats when they walk into the stadium, get real-time video of the event, access to social media, order drink and food from their seats, get information about closest services and restrooms, etc.

There are specific solutions such as the freeD Arena System infrastructure[2] installed in the AT&T Stadium in Arlington, Texas (USA), which is composed of more than 24 cameras allowing offering a unique way for fans to view replays, creating a 3D effect and depth of field on a 2D plane.

In general, the replays that are offered currently at Stadiums are broadcasted through the stadiums HDTV's. The providers of such services are currently working to offer the streaming individually to users through their mobile phones and enable interactivity. With this experiment we would be aligning with the current market supply trend and get **on to the cutting edge for the provision of these services,** especially in Europe.

14.4 Approach

14.4.1 Methodology

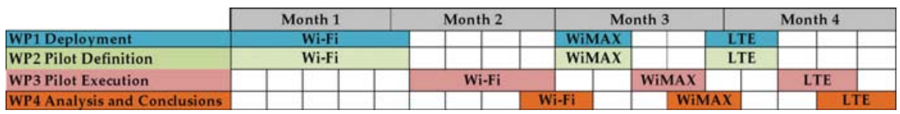
The work plan for the experiment implementation was based on a three cycle methodology. Each cycle put the main focus on one of the wireless technologies supported by NITOS testbed (Wi-Fi, WiMAX and LTE) and was composed of 4 phases: 1) deployment of the LIVEstats platform over the specific configuration of NITOS testbed; 2) definition of the goals, conditions and indicators that need to be assessed during the experiment, 3) execution of the experiment and 4) analysis of results and extraction of conclusions. The first cycle focused on Wi-Fi technology and was the leading one, in the sense that the experience acquired during this test provideed relevant feedback

[2] http://replay-technologies.com/technology/

that served as guide for the performance of the subsequent tests. Phases 1, 2 and 3 were documented and further analysed in phase 4 in order to extract conclusions and provide valuable feedback for the Fed4Fire consortium.

14.4.2 Associated Work Plan

According to the described methodology, the work plan was divided in the following Work Packages (WPs) during the timeline of the experiment:



WP1 Experiment deployment. This WP was in charge of the deployment of LIVEstats system under the infrastructures provided by NITOS testbed. An exhaustive previous analysis was done to adapt our system to the specific characteristics provided by Fed4Fire. A first phase of resources discovery, requirements, reservation and provision was also performed.

WP2 Pilot definition. Concurrently with the previous WP, the definition of the pilot to carry out the experiment was defined. Here we defined the test battery to be performed in the corresponding tests. In addition, we precisely defined the indicators to be evaluated. Pilot definition phases for tests 2 and 3 were based on the first one over Wi-Fi, taking into account the experience acquired and the lessons learnt in order to improve the test battery and obtain more specific-feature focused, precise and detailed results.

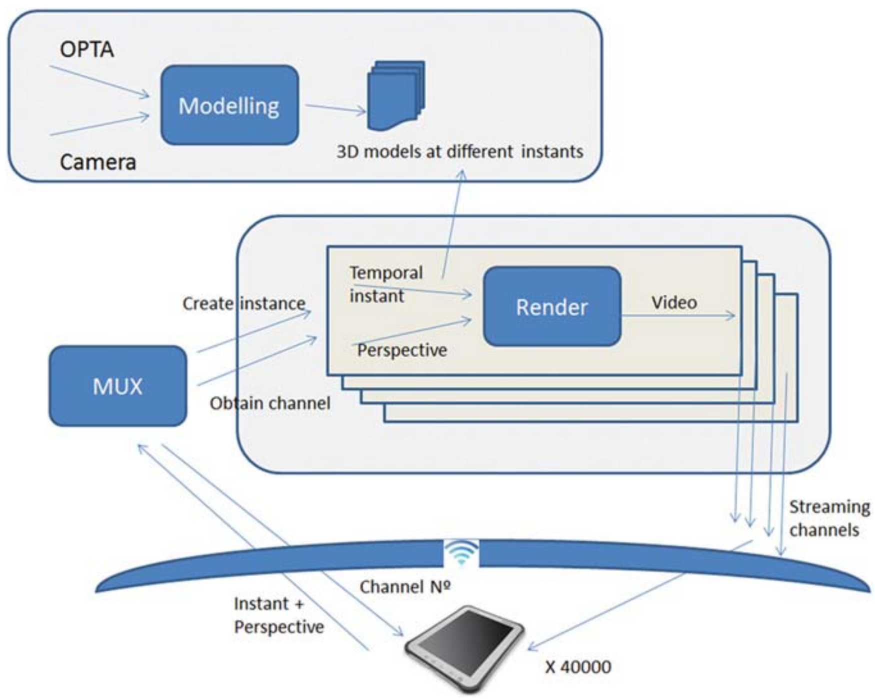
WP3 Pilot execution. This WP took the responsibility for the execution of the experiment by means of the accomplishment of the test defined within the previous WP. Three experimentation tests were done focusing on the three wireless technologies offered by NITOS: Wi-Fi, WiMAX and LTE. The tests to be performed were classified in two different collections; (1) Functional tests and (2) Performance tests.

WP4 Analysis and conclusions. The analysis of all the information extracted during the experiment timeline were done within this WP. Based on results we were able to specify the most relevant indicators and their level of priority for the deployment of a network in a real case. Moreover, relations among them and specific values required in order to provide a good quality of experience (e.g. relationships such as Bandwidth and number of spectators supported by the system; topology of the network and number of spectators) were described.

This WP also compiled all the feedback about the experience and results of running the experiment over the testbed facility. All this information was detailed in the **final report** of the experiment.

14.4.3 Experimentation Methodology

The tests performed were focused to assess the Quality of Service provided when the system is accessed according to the following diagram:



The spectator (using a tablet or smartphone) will request the visualization of a specific play at a specific instant in time from a specific perspective of a virtual camera.

1. The MUX (multiplexor module) verifies which of the current videos that are being rendered fits the most with those parameters. If there is no play fitting these parameters, a new render requested to the corresponding streaming channel. The MUX returns the selected channel to the user.
2. The render module takes the 3D model generated by the modelling server and generates the streaming from the model. (NOTE: a 3D play in

LIVEstats is generated using the video signal of a camera at the stadium and additional information coming from OPTA[3] information).

3. The user receives the streaming through the selected channel.

Specifically the tests to be performed were grouped into:

- Functional tests, aiming to verify that the system is working accordingly to the functionalities contemplated once it is implemented under NITOS infrastructure.
- Performance tests:
    - Stress test. This test aims to break the system under test by overwhelming its resources or by taking resources away from it. The main objective is to make sure that the system fails and recovers gracefully.
    - Load test. This test aims to put demand on a system and measuring its response so as to see until where it is able to work adequately. The main objective is to identify the maximum operating capacity of an application as well as any bottlenecks and determine which element is causing degradation.

Some of the indicators evaluated had been already identified, despite the fact that a more precise specification was to be done within WP2.

- *Network latency and packet loss*
- *Graphic quality*. Indicates how faithful is the quality of the streamed system screens on a thin client and how the graphic quality is degraded over imperfect network conditions.
- *Traffic characteristics*
    - Network delay. Time required transmitting a user's command to the server and a system screen back to the client.
    - Processing delay. Time required for the cloud system server to receive and process a user's command, and to encode and packetize the corresponding frame for the client.
    - System delay. Time required by the system software to process a user's command and render the next system frame that contains responses to the command.
    - Playout delay. Represents the time for the client to receive, decode, and display a *frame*.

[3]http://www.optasports.com/en/about/what-we-do/live-performance-data.aspx

- *Scalability of the render server*: We tested the most suitable configuration (regarding scalability) of the render server in order to offer the best experience with the minimum possible hardware cost.
- *Multiplexing capacity*: We tested the capacity of the multiplexing module that shares the signal among users.

14.5 Technical Work

14.5.1 Set-up of the Experiment

The tests performed aimed to assess the Quality of Service provided when the system is accessed were design according to the following Figure 14.3:

During the sports event, after a specific play (e.g. after a goal occurred during the football match) the spectator using a tablet or smartphone requests the replay on 3D on his/her device. This happens at a specific instant in time from a specific perspective of a camera.

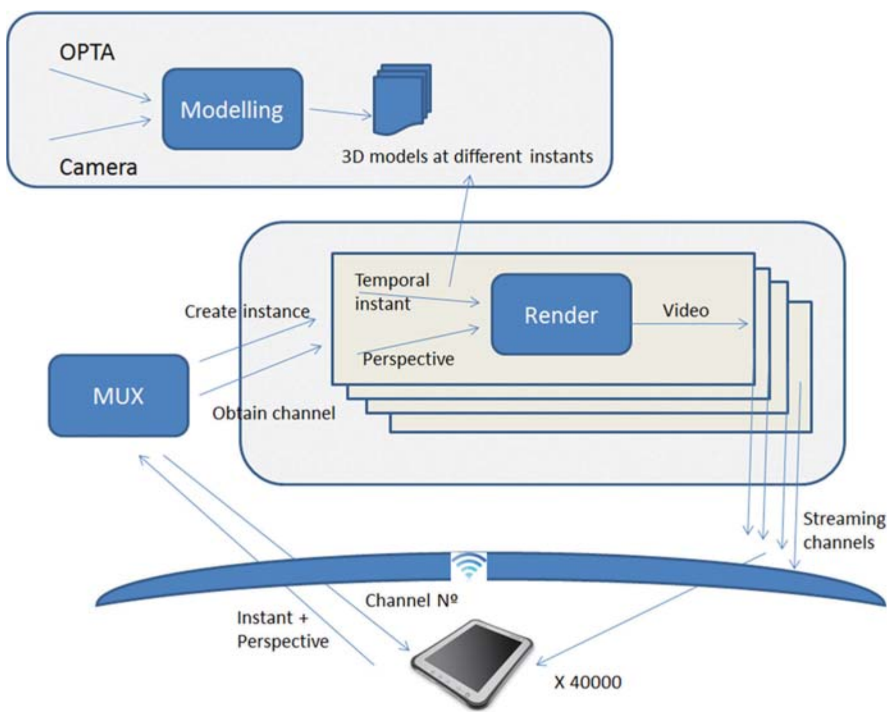


Figure 14.3 LIVEstats platform general architecture diagram.

1. The MUX (multiplexor module) verifies which of the current videos (3D replays) that are being rendered fits the most with those parameters (in terms of time and perspective). If there is no play fitting these parameters, a new render is requested to the corresponding streaming channel. The MUX returns the selected channel to the user.
2. The render module takes the 3D model generated by the modelling server and generates the streaming from the model. (NOTE: a 3D play in LIVEstats is generated using the video signal of a camera at the stadium and additional information coming from OPTA[4] information)
3. The user receives the streaming through the selected channel.

The Multiplexor module is needed because we are talking about providing an instant 3D replay to hundreds of users at the same (or very similar) time. This will probably happen during the most interesting plays or football players' actions: goals, offsides, faults, etc. The platform must be prepared to manage a high number of requests and deliver the 3D replay with an acceptable QoS within a delay that does not exceed the acceptable margins. The tests that we have performed in this experiment aim to verify that the system works accordingly (functional test) and is able to serve all clients.

We have designed tests to measure the following data, in the following available environments: WiFi, WiMAX and LTE.

- **Latency time**: How long does it take for the client to make the initial handshake with the server, thus connecting to it via WebSocket.
- **BPS in streaming**: The amount of data that can be sent through the WebSocket, in a given time measure.
- **Network stability**: We want to find out what kind of wireless environment is the best, has less drops in speed, and is able to be up for as long as possible. The idea is that sometime the network may fail, and we also want to gauge this.

The experiment attempted to measure the time it takes to serve N clients by X servers, using the NITLab nodes architecture. The diagram of the general set up for the experiments is the following, using the JFED tool provided by the testbed (Figure 14.4):

Given the characteristics of the use case we are considering, the optimal scenario for the experiment would require the reservation of as much nodes as possible: a high number of servers and a higher number of clients accessing

[4]http://www.optasports.com/en/about/what-we-do/live-performance-data.aspx

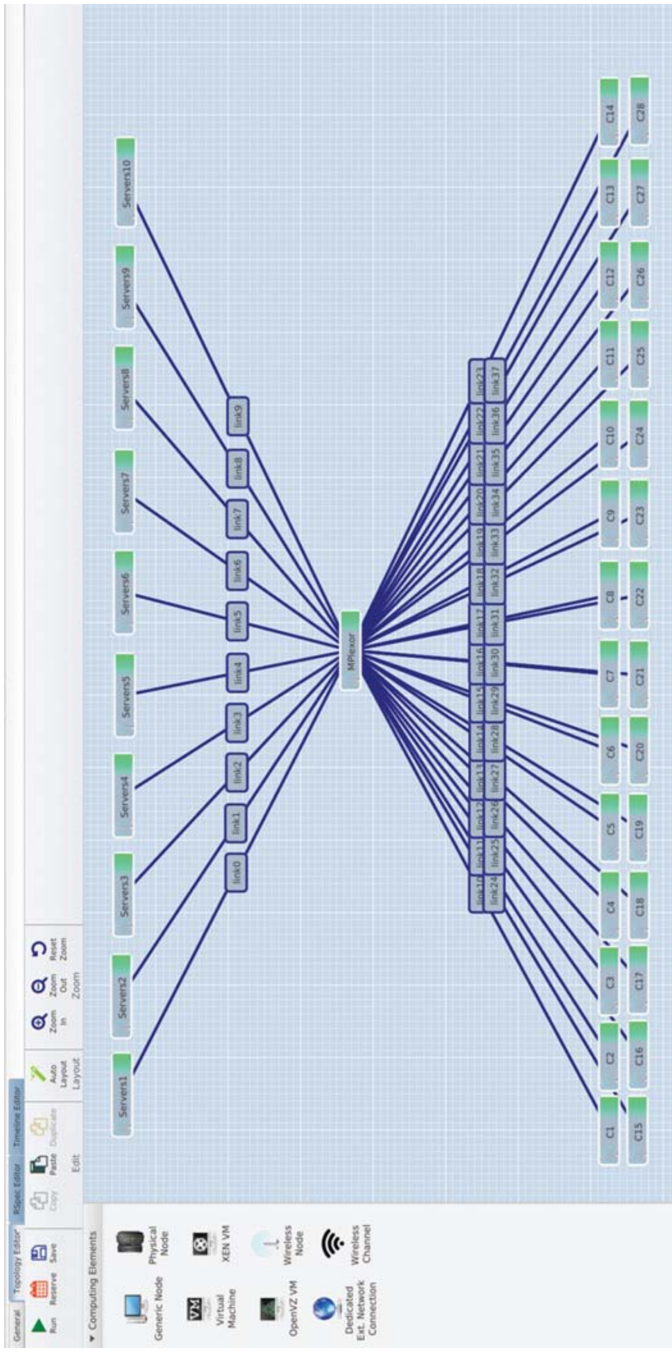


Figure 14.4 General setup of the experiments – JFED tool.

to those servers through different wireless channels; all of them orchestrated by the multiplexor module.

The preparation tests with the testbed (the initial tests that were made in order to get to know the testbed environment and tools) showed that not all nodes were working as expected, or the reservation tool did not allow the reservation of a high number of nodes at a time. Hence, given that we could not use an unlimited amount of servers, we designed the experiments in order to use two nodes for each experiment. One of the nodes acts as server hub, and the other nodes acts as client hub, that is, all instances of server live in a single node, and all instances of client live in a single node. The deployment fits the same initial concept, but the number of nodes is reduced to 2, server and client hub, according to the following Figure 14.5.

The servers were going to be sending, via WebSocket, a file of 8 MB for the client to receive, attempting to emulate the streaming capability of the WebSocket implementation. Also, there is a Multiplexor component for the test, whose functionality is to attend the client first, receive the parameters the client is sending to get an instance, which are the width and height of the client viewport, in order to emulate a number of distinct devices to connect to the streaming server. If there is one free server instance, the multiplexor component forwards the WebSocket address for the client to connect to it. If there is no free instance at the moment, it tells the client, so it can wait some time (2–3 seconds), and try to get the instance again. In the end, all of the clients must be attended and the file must be served to all of them.

In the preparation phase, some adaptations had to be made so that our platform complied with the requirements of the testbed. For this purpose, the following technologies were used:

- **Node.js**: This tool is used to develop the server, client and multiplexor. Due to its capacities for asynchronous operation, and due to the fact that node is non-intensive in resource use, we believe it is the more adequate tool for the experiment, instead of using other tools, like .NET or PHP.
- **Node.js modules**: The node.js standard distribution does not have all of the tools we will need to correctly implement the experiment, so we also use some node.js modules, that are detailed next:
  - **Express**[5]: This framework is considered the standard for node.js. It is very useful for the creation and managing of routes, along with the fact that it is considered the node.js standard of development.

[5]http://expressjs.com/

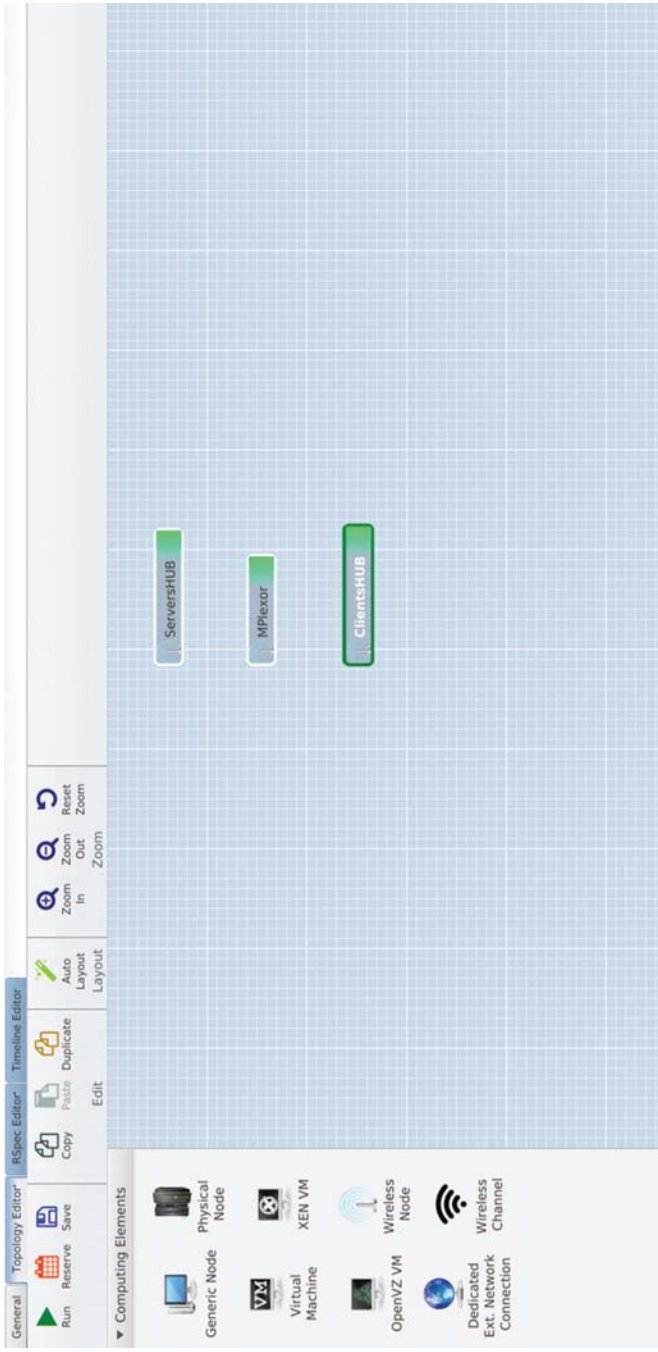


Figure 14.5 Setup of the experiments – JFED tool.

- **BinaryJS**[6]: This module contains functionality for the creation of a server that emits binary data via WebSocket, and clients that know how to connect to said server, and read the data sent by the server. There is no such functionality in the node.js standard distribution, therefore we use this module.
- **MySQL**[7]: We use a MySQL database to be able to store data regarding the instances, whether they are occupied or free. The communication with the MySQL engine is made thought the node.js module 'mysql'.
- **Chance**[8]: A library for random data generation. Due to the fact that we need to randomize certain aspects of the application, this library is very useful.
- **Chalk**[9]: This module is included in order to write to console, because it provides styling for text, and is therefore very useful for reading the results of the tests.

14.5.2 Preparatory Tests

This phase includes all the testing that was run in order to prepare for the core of the experiment: the tests to get to know the tools and the testbed environment: the possibilities for reservation and the best approaches for deploying our platform and tools in order to run the experiment:

Testbed Infrastructure Used	Tests Description
iMinds WiLab2	Reserving and accessing nodes (jFed, SSH) Mounting images on nodes Testing connectivity
NITOS lab:	
NODE1–040 (Nitos Outdoor Testbed: Grid, Orbit)	Reserving and accessing nodes (jFed, SSH)
NODE041–049 (Nitos Office Testbed: Icarus)	Mounting images on nodes
NODE050–085 (Nitos Indoor RF Isolated Testbed)	Testing connectivity
Results	Section B.2.1.1

[6]http://binaryjs.com/
[7]http://www.mysql.com/, http://github.com/felixge/node-mysql/
[8]http://chancejs.com/
[9]https://www.npmjs.com/package/chalk

Figure 14.6 Components for the general set up of the experiments.

14.5.3 Laboratory Use Cases

The following sections describe the design of the experiments that were the core of our project. All of them follow the structure that was presented earlier in this document, using a server and a client hub, according to the set up (Figure 14.6).

14.5.3.1 Wi-Fi experiments

Identifier	WiFi 001	WiFi 002	WiFi 003
NITOS lab infrastructure used	WiFi nodes	WiFI nodes	WiFi nodes
No. of server instances	>30	>20	>40
Number of Clients	15–360	15–360	15–600
Repetitions	2	3	3
Objective	Time to serve all clients. Independent result and median value for the three of them together		
Results	Section B.2.1.2.1	Section B.2.1.2.2	Section B.2.1.2.3

14.5.3.2 LTE experiments

Identifier	LTE 001	LTE 002	LTE 003
NITOS lab infrastructure used	LTE nodes	LTE nodes	LTE nodes
No. of server instances	30	10	40
Number of Clients	15–360	15–360	15–600
Repetitions	3	3	3
Objective	Time to serve all clients. Independent result and median value for the three of them together		
Results	Section B.2.1.3.1	Section B.2.1.3.2	Section B.2.1.3.3

14.5.3.3 WiMAX experiments

Identifier	WiMAX 001	WiMAX 002	WiMAX 003
NITOS lab infrastructure used	WiMAX nodes	WiMAX nodes	WiMAX nodes
No. of server instances	30	30	30
Number of Clients	15–360	15–360	15–600
Repetitions	3	3	3
Objective	Time to serve all clients. Independent result and median value for the three of them together		
Results	Section B.2.1.4.1	Section B.2.1.4.2	Section B.2.1.4.3

14.5.4 Resources and Tools Used

Resources	
Virtual Wall (iMinds)	At first, we used iMinds because we had to test the experiment somewhere, and there was a certain confusion regarding the testbed we had to use. After speaking to Donatos Stravopoulos, we began using NITOS.
w-iLab.t (iMinds)	This testbed was used at first, when we were still in the learning process of how to interact with the platform via the jFED application. After a process of learning how to use the platform, we began using SSH to access it.
NITOS (UTH)	This is the testbed we used mainly. The nodes we used are mainly the following ones: Grid Nodes in the “Outdoor testbed” (node16 to node35). The Orbit nodes seemed to be working quite well (node02 to node09), we were advised not to fully rely on them, due to the fact that they are not very modern, and apparently, there was some errors associated with said nodes. In the “Indoor RF Isolated Testbed”, we mainly used the LTE nodes (node054 to node058), that were AMAZING in response time and speed.
Tools	
Fed4FIRE portal	The reservation system works really well, allowing us to see beforehand what nodes are available, and specifying the kind of node in each case (this last bit was really useful).
JFed	We started using jFed at first, but the inability that it had to correctly interact with the scheduling functionality made it a bit cumbersome after a time, preferring, in time, to use SSH and other console commands to access the gateway and nodes.
OMF	OMF was used to create and mount images on the nodes. It was really useful, because once the node was reserved, and the image had been created, with all of the tools (and even source code) that we were going to use, it was a no-fuss kind of procedure. Really smooth, and

	very appreciated in order to maintain the homogeneity of the distinct environments.
JFed timeline	At first, we used jFed almost exclusively, so we consulted the availability of nodes via this tool. Later on, we developed a series of command-line aliases and tools that, together with the web portal reservation system, allowed us to be more efficient.
Other tools used	For the experiment, we have been using the following technologies mainly: NodeJS, WebSockets, MySQL and SSH, this last one being the main way to communicate between the client machine and the gateway, and then between the gateway and the node itself.

14.6 Results and/or Achievements

14.6.1 Technical Results Obtained

14.6.1.1 Preparatory tests

Initial testing gave many problems when trying to access resources. Reservation of nodes could not be completed, and, once they were finally reserved, attempts to mount images failed. Some of those attempts are described in the Table 14.1:

Table 14.1 Battery of preparatory tests with NITOS and IMinds WiLAB2 testbeds

Identifier	TESTBED	RESOURCE	EXPERIMENT	RESULT
Prep_001	NITOS	Nodes 005, 006, 007, 014, 015, 016, 021, 024, 046	Creating an image	Resource reservation failed
Prep_002	NITOS	Node 029, 033, 035, 005, 007	Creating an image	Resource reservation failed
Prep_003	NITOS	Node 035, 033, 014, 015, 021, 023	Creating an image	Resource reservation failed
Prep_004	NITOS	Node 005, 052, 085, 062,095	Creating an image	Resource reservation failed
Prep_005	NITOS	Node 033	Creating an image	Resource reservation failed
Prep_006	NITOS	Node 007	Creating an image	Reservation OK → SSH → Connection closed by remote host (KO)

(*Continued*)

Table 14.1 Continued

Identifier	TESTBED	RESOURCE	EXPERIMENT	RESULT
Prep_007	NITOS	Node 006	Creating an image	Reservation OK → SSH → Connection closed by remote host (KO)
Prep_008	IMinds WiLAB2	Internet	Creating an Image	Reservation of resources failed
Prep_009	IMinds WiLAB2	Airswitch	Creating an Image	Reservation of resources failed
Prep_010	IMinds WiLAB2	Coreswitch	Creating an Image	Reservation of resources failed
Prep_011	IMinds WiLAB2	Poeswitch	Creating an Image	Reservation of resources failed
Prep_012	NITOS	Node 005+ Channel 2 (wireless)	Creating an Image	Reservation OK → SSH → Connection closed by remote host (KO)

The very first errors were produced due to our lack of knowledge of the platform, we were not even aware about the reservation process that had to be followed. Once we got to know the reservation process, issues arised with the jFed tool, which didn't seem to work with the expected behaviour, and therefore returned fails with the reservations. We started then trying accessing the nodes via SSH, and here we got some errors with nodes about connection closed by remote host.

We need to remark that the feedback from the tools were limited in most cases. We were able to understand what was going on with the process only thanks to the support of NITOS technical team.

All these tests allowed us to gain a lot of knowledge about the testbeds. We concluded that for our experiment, we would be able to use only a couple of nodes at the same time.

We figured out that more than 200 clients would not be advisable because it would make the system clog itself.

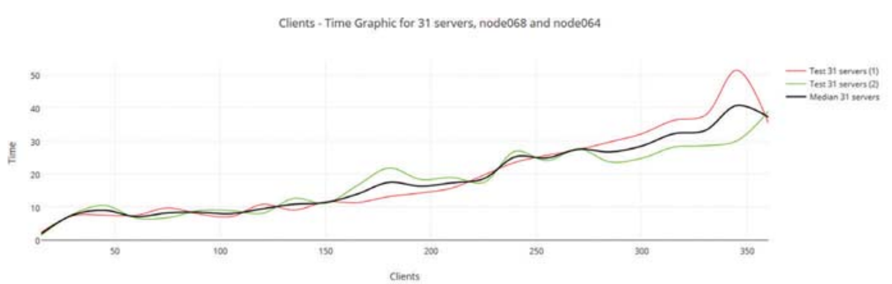
Also, while running tests, we observed a curious behaviour: when servers were just started, the process was slower than when the servers had already made some executions. This could be due to several factors (cache, mostly), but it was interesting to see. After a "training"/warming up process they worked much better.

14.6.1.2 Wi-Fi experiments

14.6.1.2.1 *Wi-Fi 001*

Identifier	WiFi 001
NITOS lab infrastructure used	Servers hub: Node 068 Clients hub: Node 064
No. of server instances	31
Number of Clients	15–360
Repetitions	2
Objective	Time to serve all clients. Independent result and median value for the three of them together
Results	Completed

This experiment uses **WiFi** nodes ***node068*** as servers' hub and ***node064*** as clients hub. The amount of server instances used is 31. The experiment was repeated 2 times. The number of clients goes from 15 to 360, and the time results are shown in the graph below, showing the time it took each single experiment to run and the median time for the three of them.



Nº CLIENTS	15	30	45	60	75	90	105	120	135	150
TIME SEC (TEST1)	2,359	7,344	7,527	7,485	9,725	7,89	7,054	10,803	9,067	11,577
TIME SEC (TEST 2)	1,433	78,378	10,495	6,664	6,748	8,903	8,104	12,367	11,117	16,515
MEDIAN	1,896	42,861	9,011	7,0745	8,2365	8,3965	7,579	11,585	10,092	14,046

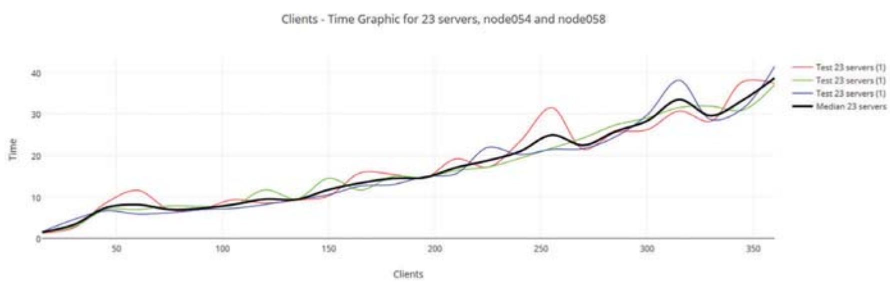
Nº CLIENTS	165	180	195	210	225	240	255	270	285	300
TIME SEC (TEST1)	11,325	13,164	14,241	15,753	19,667	23,56	25,67	27,389	29,723	32,188
TIME SEC (TEST 2)	21,807	18,349	18,949	17,48	26,888	24,046	27,628	23,637	24,77	28,128
MEDIAN	16,566	15,7565	16,595	16,6165	23,2775	23,803	26,649	25,513	27,2465	30,158

Nº CLIENTS	315	330	345	360
TIME SEC (TEST1)	36,24	37,74	51,451	35,535
TIME SEC (TEST 2)	28,128	28,56	30,021	38,968
MEDIAN	32,184	33,15	40,736	37,2515

14.6.1.2.2 *Wi-Fi 002*

Identifier	WiFi 002
NITOS lab infrastructure used	Servers hub: Node 054 Clients hub: Node 058
No. of server instances	23
Number of Clients	15–360
Repetitions	3
Objective	Time to serve all clients. Independent result and median value for the three of them together
Status	Completed

This experiment uses **WiFi** nodes ***node054*** as servers hub and ***node058*** as clients hub. The amount of server instances used is 23. As usual, we repeated the experiment three times, and we show the time value for each experiment, along with the median time. The number of clients goes from 15 to 360, and the results are shown in the char below:



Nº CLIENTS	15	30	45	60	75	90	105	120	135	150
TIME SEC (TEST1)	1,344	2,563	8,517	11,55	6,869	7,006	9,301	8,515	9,189	10,209
TIME SEC (TEST 2)	1,593	2,809	6,916	6,911	7,807	7,698	7,9	11,666	9,528	14,467
TIME SEC (TEST 3)	1,561	4,549	6,644	5,861	6,163	6,908	7,201	8,152	9,361	10,499
MEDIAN	1,499333333	3,307	7,359	8,10733333	6,94633333	7,204	8,134	9,44433333	9,35933333	11,725
Nº CLIENTS	165	180	195	210	225	240	255	270	285	300
TIME SEC (TEST1)	15,782	15,416	14,446	19,143	17,111	23,265	31,452	21,442	25,455	26,127
TIME SEC (TEST 2)	11,615	14,872	14,595	16,352	17,164	19,265	21,699	24,158	27,278	28,965
TIME SEC (TEST 3)	12,598	12,935	14,849	15,57	21,892	20,156	21,419	21,614	24,427	29,7
MEDIAN	13,33166667	14,4076667	14,63	17,0216667	18,7223333	20,8953333	24,8566667	22,4046667	25,72	28,264
Nº CLIENTS	315	330	345	360						
TIME SEC (TEST1)	30,653	28,173	37,672	37,345						
TIME SEC (TEST 2)	31,476	31,801	30,838	37,008						
TIME SEC (TEST 3)	38,037	28,592	31,205	41,354						
MEDIAN	33,38866667	29,522	33,2383333	38,569						

14.6.1.2.3 *Wi-Fi 003*

Identifier	WiFi 003
NITOS lab infrastructure used	Servers hub: Node 054 Clients hub: Node 058
No. of server instances	40
Number of Clients	15–600
Repetitions	3
Objective	Time to serve all clients. Independent result and median value for the three of them together
Status	Failed

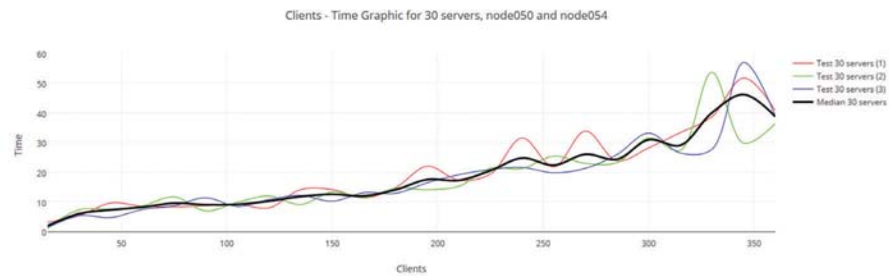
This experiment collapsed the nodes. There were too many instance servers and clients defined for the experiment. The test failed to be completed.

14.6.1.3 LTE experiments

14.6.1.3.1 *LTE 001*

Identifier	LTE 001
NITOS lab infrastructure used	Servers hub: Node 050 Clients hub: Node 054
No. of server instances	30
Number of Clients	15–360
Repetitions	3
Objective	Time to serve all clients. Independent result and median value for the three of them together
Results	Completed

This experiment uses **LTE** nodes ***node050*** as servers hub and ***node054*** as clients hub. The amount of server instances is 30. As usual, we repeated the experiment three times, and in the following chart, the median time, along with each attempt time, is shown:

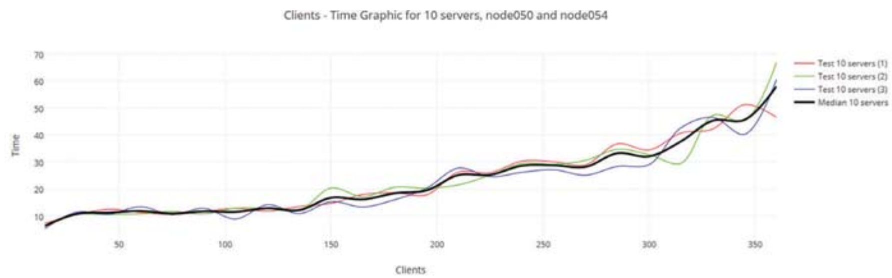


Nº CLIENTS	15	30	45	60	75	90	105	120	135	150
TIME SEC (TEST1)	3,248	5,464	9,71	8,609	8,426	8,798	9,297	8,074	14,216	14,258
TIME SEC (TEST 2)	1,406	7,409	7,663	8,727	11,787	7,044	9,906	12,058	9,174	13,429
TIME SEC (TEST 3)	1,406	5,448	4,787	7,536	8,766	11,474	8,538	10,283	13,197	12,965
MEDIAN	2,02	6,107	7,38666667	8,29066667	9,65966667	9,10533333	9,247	10,1383333	12,1956667	13,5506667
Nº CLIENTS	165	180	195	210	225	240	255	270	285	300
TIME SEC (TEST1)	11,432	14,886	22,074	17,377	19,446	31,604	21,845	33,924	23,902	28,258
TIME SEC (TEST 2)	11,581	14,637	14,19	15,337	21,35	21,279	25,476	23,023	23,314	31,567
TIME SEC (TEST 3)	16,511	19,231	20,988	21,645	19,881	21,645	19,881	21,362	26,026	33,235
MEDIAN	13,17466667	16,2513333	19,084	18,1196667	20,2256667	24,8426667	22,4006667	26,103	24,414	31,02
Nº CLIENTS	315	330	345	360						
TIME SEC (TEST1)	33,394	38,766	51,785	40,878						
TIME SEC (TEST 2)	27,421	53,664	29,843	36,468						
TIME SEC (TEST 3)	26,527	27,766	56,997	39,003						
MEDIAN	29,114	40,0653333	46,2083333	38,783						

14.6.1.3.2 *LTE 002*

Identifier	LTE 002
NITOS lab infrastructure used	Servers hub: Node 050 Clients hub: Node 054
No. of server instances	10
Number of Clients	15–360
Repetitions	3
Objective	Time to serve all clients. Independent result and median value for the three of them together
Results	Completed

This experiment uses the same nodes and methodology as the previous one for LTE, the difference is the number of server instances, in this case they are 10. As seen, the time goes up quite a lot.



Nº CLIENTS	15	30	45	60	75	90	105	120	135	150
TIME SEC (TEST1)	7,287	10,411	12,461	11,364	10,53	11,644	12,768	11,724	13,51	14,656
TIME SEC (TEST 2)	6,312	10,502	10,504	10,771	11,652	10,754	12,891	12,71	12,044	20,335
TIME SEC (TEST 3)	5,319	11,384	10,592	13,426	10,474	12,796	8,864	14,163	10,885	15,287
MEDIAN	6,306	10,7656667	11,1856667	11,8536667	10,8853333	11,7313333	11,5076667	12,8656667	12,1463333	16,7593333
Nº CLIENTS	165	180	195	210	225	240	255	270	285	300
TIME SEC (TEST1)	17,959	18,602	17,817	26,25	26,04	30,299	30,074	28,941	36,709	34,436
TIME SEC (TEST 2)	17,106	20,6	20,27	21,501	25,087	29,42	29,126	30,562	34,664	32,679
TIME SEC (TEST 3)	13,321	16,017	20,276	27,722	24,535	26,172	27,139	25,089	28,365	29,041
MEDIAN	16,12866667	18,4063333	19,4543333	25,1576667	25,2206667	28,6303333	28,7796667	28,1973333	33,246	32,052
Nº CLIENTS	315	330	345	360						
TIME SEC (TEST1)	40,686	42,206	51,229	46,548						
TIME SEC (TEST 2)	29,507	47,281	45,387	66,844						
TIME SEC (TEST 3)	42,672	46,499	40,236	60,542						
MEDIAN	37,62166667	45,3286667	45,6173333	57,978						

14.6.1.3.3 *LTE 003*

Identifier	LTE 003
NITOS lab infrastructure used	Servers hub: Node 050 Clients hub: Node 054
No. of server instances	40
Number of Clients	15–600
Repetitions	3
Objective	Time to serve all clients. Independent result and median value for the three of them together
Results	Failed

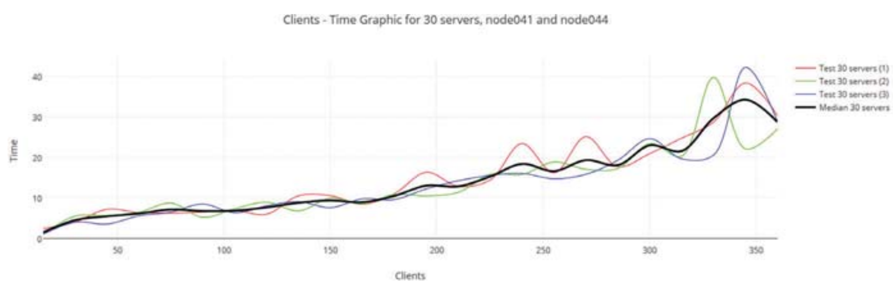
This experiment collapsed the nodes. There were too many instance servers and clients defined for the experiment. The test failed to be completed.

14.6.1.4 WiMAX experiments

14.6.1.4.1 *WiMAx 001*

Identifier	WiMAX 001
NITOS lab infrastructure used	Servers hub: Node 041 Clients hub: Node 044
No. of server instances	30
Number of Clients	15–360
Repetitions	3
Objective	Time to serve all clients. Independent result and median value for the three of them together
Results	Completed

This experiment uses **WiMAX** nodes ***node041*** as server hub and ***node044*** as clients hub. The number of instances is 30. The methodology to show the values in the graph are the same as in previous graphs:

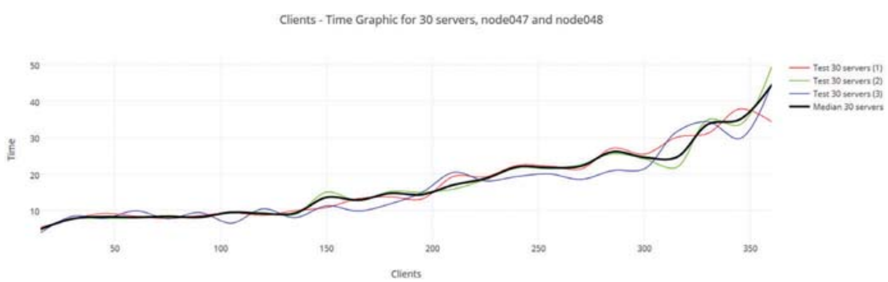


Nº CLIENTS	15	30	45	60	75	90	105	120	135	150
TIME SEC (TEST1)	2,404	4,403	7,185	6,371	6,235	6,511	6,88	5,975	10,52	10,551
TIME SEC (TEST 2)	1,04	5,483	5,671	6,458	8,722	5,213	7,33	8,923	6,789	9,937
TIME SEC (TEST 3)	1,04	4,032	3,542	5,577	6,487	8,491	6,318	8,046	9,065	7,609
MEDIAN	1,494666667	4,63933333	5,466	6,13533333	7,148	6,73833333	6,84266667	7,648	8,79133333	9,36566667
Nº CLIENTS	165	180	195	210	225	240	255	270	285	300
TIME SEC (TEST1)	8,46	11,016	16,335	12,859	14,39	23,387	16,165	25,104	17,687	20,911
TIME SEC (TEST 2)	8,57	10,831	10,501	11,349	15,799	15,746	18,852	17,037	17,252	23,36
TIME SEC (TEST 3)	9,766	9,594	12,218	14,231	15,531	16,017	14,712	15,808	19,259	24,594
MEDIAN	8,932	10,4803333	13,018	12,813	15,24	18,3833333	16,5763333	19,3163333	18,066	22,955
Nº CLIENTS	315	330	345	360						
TIME SEC (TEST1)	24,712	28,687	38,321	30,25						
TIME SEC (TEST 2)	20,292	39,711	22,084	26,986						
TIME SEC (TEST 3)	19,63	20,547	42,178	28,862						
MEDIAN	21,54466667	29,6483333	34,1943333	28,6993333						

14.6.1.4.2 *WiMAx 002*

Identifier	WiMAX 002
NITOS lab infrastructure used	Servers hub: Node 047 Clients hub: Node 048
No. of server instances	30
Number of Clients	15–360
Repetitions	3
Objective	Time to serve all clients. Independent result and median value for the three of them together
Results	Completed

This experiment uses **WiMAX** nodes ***node047*** as server hub and ***node048*** as clients hub. The number of instances is 30. The methodology, value and graph wise, are the same as in past experiments:



Nº CLIENTS	15	30	45	60	75	90	105	120	135	150
TIME SEC (TEST1)	5,392	7,704	9,221	8,409	7,792	8,617	9,448	8,676	9,997	10,845
TIME SEC (TEST 2)	4,671	7,771	7,773	7,971	8,622	7,958	9,539	9,405	8,913	15,048
TIME SEC (TEST 3)	3,936	8,424	7,838	9,935	7,751	9,469	6,559	10,481	8,055	11,312
MEDIAN	4,666333333	7,96633333	8,27733333	8,77166667	8,055	8,68133333	8,51533333	9,52066667	8,98833333	12,4016667
Nº CLIENTS	165	180	195	210	225	240	255	270	285	300
TIME SEC (TEST1)	13,29	13,765	13,185	19,425	19,27	22,421	22,255	21,416	27,165	25,483
TIME SEC (TEST 2)	12,658	15,244	15	15,911	18,564	21,771	21,553	22,616	25,651	24,182
TIME SEC (TEST 3)	9,858	11,853	15,004	20,514	18,156	19,367	20,083	18,566	20,99	21,49
MEDIAN	11,93533333	13,6206667	14,3963333	18,6166667	18,66333333	21,1863333	21,297	20,866	24,602	23,7183333
Nº CLIENTS	315	330	345	360						
TIME SEC (TEST1)	30,108	31,232	37,909	34,446						
TIME SEC (TEST 2)	21,835	34,988	33,586	49,465						
TIME SEC (TEST 3)	31,577	34,409	29,775	44,801						
MEDIAN	27,84	33,543	33,7566667	42,904						

14.6.1.4.3 *WiMAx 003*

Identifier	WiMAX 003
NITOS lab infrastructure used	Servers hub: Node 047 Clients hub: Node 048
No. of server instances	30
Number of Clients	15–600
Repetitions	3
Objective	Time to serve all clients. Independent result and median value for the three of them together
Results	Failed

As it was expected, this experiment collapsed the nodes. There were too many clients defined for the experiment. The test failed to be completed.

14.7 Discussion

During the development of the experiment, there has been a catch, and that is the fact that NITLab was not able to work in the way we expected. Due to the fact that we received some errors, while trying to reserve nodes via jFed at first, and later, when trying to mount the image onto the node, we have decided to use two nodes, a server hub and a client hub, in the expectation that they will be useful to measure the architecture we have designed. Had we been able to reserve and use dozens of nodes, we may have been able to see a different outcome, so with that idea in mind, the experiment was repeated three times each, to get a median measure. We are now confident that more nodes would have not influenced the measures we have taken, because they would have acted in the same way, with some nodes acting as servers hubs, and others as clients hubs. The most interesting conclusion we have obtained is that, indeed, for large file sizes, LTE and WiMAX are much better than normal WiFi, but for less data, or a small file size, the overhead of many clients supersedes the benefits we could have obtained from a better network. With the tests that we have been able to perform the topology has not seemed critical for the performance of the platform.

Obviously, the architecture could be implemented, if we had enough machines, so we think the experiment proves that such an application could be indeed implemented and distributed, if the server architecture is powerful enough.

Our main motivation to run the experiment was the possibility to easily access infrastructures that otherwise would not be reachable for our company at this stage:

- Test in real environments for a 4-month period.
- Diversity of nodes that let us make different selections and configurations according to our needs.

In particular, the main asset was the access to LTE and WiMax nodes. Wi-Fi is in principle more reachable, but again, the dimension of the particular scenario that we are considering is not easily accessible for our company in a regular context.

From the experiment itself and the results obtained, the main value perceived is the knowledge that we have acquired to characterize the physical infrastructure that we would need to provide LIVEstats platform premium content over WiFi, LTE and WiMAX technologies to a high number of spectators on site on a sports stadium. We have been able to answer a number of questions and got insights about the relationship among parameters and characteristics of the different components of the platform and the wireless infrastructure that should be deployed.

Also, the preparation of the experiment required us to set up some developments and adaptations of the platform (in particular from Windows to Linux) that lead to improvement and fine-tune of the product, something that was not the main objective of the experiment, but has resulted in a very positive side effect.

The original aim of the experiment was to ascertain the amount of servers needed to be able to attend at least 40% of clients in a stadium in a timely fashion. According to the data we have obtained from the experiment, we extracted the following results:

14.7.1 Small File: From 0.5 to 2 Megabytes

1. According to our calculations, there is not a linear progression with the file size, meaning that a smaller file will most likely be served before than a bigger one. In a WiFi environment, considering 30 instances per machine, we would need between 30 and 50 machines to serve 25.000 clients, with a maximum waiting time of 10 seconds.
2. In an LTE environment, given that is at least 25% faster than a normal WiFi, we would be OK with maybe 30 machines, with 30 instances

per machine, for 25.000 clients. For a whole 100.000 people stadium, between 100 and 120 machines should be sufficient.

3. WiMAX is, in this case, very similar to LTE. Due to the small file size, the benefit would most likely be marginal, so we calculate around 100 machines for the whole stadium.

14.7.2 Normal File Size: From 8 to 12 Megabytes

1. For a WiFi connection, and between 8 and 12 megabytes of information to be transfered via WebSocket, we would need around 6000 server instances. Considering we could have as many as 30 instances per server, we would need around 200 different machines with WiFi connection to serve around 25.000 clients. To serve 100.000 clients (the maximum amount for our estimations), we would need around 800 machines, with 30 instances per machine, and the clients would be attended in less than 8 seconds.
2. For a LTE connection, and between 8 and 12 megabytes of information, we would need around 75% of the machines in the previous architecture. According to our calculations, 180 clients could be served, in less than 10 seconds, by a single machine with 30 server instances. Therefore, for 25.000 clients, around 120–135 machines would be needed. To serve 100.000 clients, we believe 500 machines would be sufficient.
3. For a WiMAX connection, and between 8 and 12 megabytes of information, we would need around 75% of the machines in the LTE architecture. That means, between 90 and 105 machines for 25.000 clients, and around 400, rounding, machines for a whole stadium with 100.000 clients trying to access the data.

14.7.3 Large File Size: From 30 to 50 Megabytes

1. As we stated before, there is not a linear progression in this case, so a larger file, in a WiFi environment, would need something between triple and quadruple the amount of machines for the same number of clients. This is due to the fact that, with a bigger file, the multiplexor will not be able to serve them so fast, the clients will require more time to download the information, so more servers would be advised in this particular case.
2. LTE gives a definite improvement over normal WiFi in large file sizes. We believe that with 150% of the servers used in the normal file size experiment, all the clients could be served in a timely manner, that is, no more than 10 seconds wait time for each one.

3. WiMAX is the most potent 4G wireless type of network there is, so we are quite confident that with between 125% and 150% of the machines specified in the normal file size experiment, we could serve all the clients in no more than 10 seconds per each client.

The aforementioned results assume that we are going to have all clients trying to try and obtain the server instance simultaneously, and that is why the number of machines/instances is so large in certain cases. If, assuming that no more than 20% of users are going to try to get the data at the same time, we are looking at something like 10% to 25% of the amount of server instances/machines that we would need for this architecture and serving times.

14.8 Conclusions

The results obtained brought great value for our company and our action plan: In a short time period we have had access to varied wireless technologies and infrastructures: Wi-FI, LTE and WiMAX in outdoor and indoor locations. Thanks to the testing we have gained knowledge for characterising the physical wireless infrastructure, so that we are now able to continue with the improvement and development of the business model for our product LIVEstats. This was the main objective of the experiment and we have met most of our expectations in this sense.

Conclusions extracted from our experiment have set the starting point that will let us define the real potential of our product. We will use and extrapolate results to model the service requirements and capabilities that the platform may offer:

- What seems to be the best wireless technology to implement our solution.
- What is the minimum required infrastructure required in order to be able to offer the service.
- What is the average number of users that we can serve with the platform as it is now in a concrete context.
- What is the average size of the video file that can be sent in order to assure an acceptable QoS.
- What is the minimum and maximum time to serve users in specific conditions.

Our next steps are to improve and redesign the business model according to the conclusions extracted from the experiment.

Apart from LIVEstats platform itself and its business model related aspects, the experiment brought value to our company in a very specific sense: what we have tested specifically during the experiment is the multiplexor module and its capacity to balance the load among server-client. This module is direct candidate to be integrated in more product developments of the company, and, in particular, in the field of Media and Entertainment, which is one of the main business lines of Planet Media. The company have consolidated clients in the area that require the latest innovations from us. In this sense, the experiment has given us the opportunity to test and validate the capacities of the module and gain knowledge about the possibilities of the tool, pros and cons, and experience to adapt results to further developments that may use it.

If we had not been allowed to make our experiment using Fed4FIRE facilities, we wouldn't have been able to progress on the development of the business model in the scenario for stadiums. We would have continued, at least for the moment, with the scenario of providing the service at the spectators' homes. We would have continued testing the platform and the multiplexor module with load and stress tests in the regular manner that we do with the rest of applications that are developed in our company. No wireless technologies (especially LTE and WiMAX) would have been tested at this stage, and for sure the dimension of the testing hypothesis and objectives would have been much more conservative, according to our test labs capabilities in our offices.

The knowledge acquired during the experiment on the performance of the platform using wireless technologies, and the conclusions extracted about the minimum requirements to serve a high number of clients constituted an enriching validation process: we have now a better understanding of the challenges and opportunities from now on to bring the product to a close to market stage.