

Collaborative Distributed Laboratories: Technical Issues

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ABSTRACT: *In this work we address the concept of cooperative distributed telemeasurement in which all the instruments belonging to a measurement benchmark can be distributed over a network of interconnected laboratories. Hence more laboratories can cooperate joining their own resources to create a sort of super-laboratory with extended potentiality.*

To realize the concept of cooperative distributed telemeasurement, some new aspects have to be evaluated: the signals that are the objects of the process of measure, have to be free from the geographically location of the source instrument; hence the measure should take place without have locally all necessary instrumentation. Another point is the management of resources in a distributed environment, in particular we focused the attention on the management of the availability, booking, keeping and releasing of resources.

These aspects are analyzed in the paper highlighting open problems and possible solutions. We also proposed the experimental approach we are developing in our laboratories.

1 INTRODUCTION

The characterization of sophisticated systems and devices needs high cost instruments; for this reason in the last years the trend of laboratory research centers within and outside Europe has been to develop few but high level laboratories (also called excellence centers) where sophisticated measurements can be done by means of relevant and sophisticated instruments. In Italy, since 1994 the CNIT (Consorzio Nazionale Interuniversitario per le Telecomunicazioni) [1] has been founded to create a research network in the field of communications able to improve the research activity among universities and the results obtained. In particular, based on previous experiences made in Bologna and Genoa, the LABNET (Laboratorio Nazionale di Comunicazioni Multimediali) [2] has been created in Naples with the aim of defining a methodology for remote access to complex instrumentation and a test bed concerning communications systems and networks. A way to increase the relevance of these centers is to make available their capabilities regardless the physical location of the users. To this aim, the remote measurement (telemeasurement) gains a particular interest allowing set-up, monitoring, and data post-processing from a remote location. The increasing amount of the number of potential users is important since small laboratories do not have the instrumentation, but can remotely utilize the instruments of these specialized centers. The concept of the telemeasurement is well known: in fact, several commercial products, like GPIB Enet [3] make it feasible, also via WEB, providing a "bridge" between the IEEE 488.2 [4], [5] and TCP-IP protocols [6]. Moreover, software packages like LabView and VEE [7], [8], [9] enable the virtual instruments technology [10]. In particular, this allows the realization of the virtual instrument concept, where functionalities of different real instruments can be collected and made

remotely available as a new virtual interface. Recently, the characterization of communications systems by means of measurements gained a lot of interests due to their market penetration (e.g., cellular systems and wireless local area networks) and the increasing of their complexity, that makes the performance evaluation a relevant topic. In this field, where several standards have to coexist on the same device, the software radio technology (SWR) is going to play a fundamental role since it moves typical hardware functionalities into software by means of general purpose platforms as digital signal processor (DSP), field programmable gate array (FPGA), etc. [11].

Then, we extend the telemeasurement concept remotely defining and configuring the software defined radio circuits under analysis in addition to instruments.

The concept we are introducing belonging to the collaborative distributed measurement instruments and laboratories. Today a measure instrument is intended like an object with specific characteristics and generally composed by three functional units: back-end (elaboration unit), front-end (control unit and user interface) and bus (interconnection unit). These units are physically placed in only one device (normally expensive) that needs to be positioned in proximity of the source of the signal that has to be characterized (the object of the measure). Besides the control and the results representation, even the signals to be measured could be on a remote site, in this case, not only the object we are measuring can be far from the measure instrument, but functionalities of geographically distributed instruments can also be aggregated, increasing the added value of a network of laboratories. This scenario is based on the key concept that concerns the definition, the project and the realization of technologies to create the paradigm of distributed cooperative telemeasure. It represents a geographical extrapolation of the basis structure of a typical measure instrument (front-end, back-end, bus), where each single unit could be in the same laboratory but also distributed in space with mutual cooperation among the units through the network. These concepts to increase the measurement capacity without have locally all necessary instrumentation.

The users experiment the access to a sort of super-laboratory composed by different cooperative distributed instruments.

If the signal is free from the geographically location of the signal source, the measurement process could be geographically extended to different laboratories on the territory. This platform is pictured in Fig. 1: the signals (objects of the measure) used to characterize the devices which are variously placed, are sent to the measure network using an appropriate interface. The measure network is also connected to the instruments that are controlled by the support network for measure; all these elements give shape to the cooperative distributed platform that is accessible from users by the user network that is of heterogeneous nature (wireless or wired local network, GPRS, UMTS, satellite network). The wide survey of possible applications includes: the realization of measure with complex and sophisticated instruments or systems, that are no available nearby the user, environmental monitoring, laboratories network for professional and didactic purposes.

Possible applications of this architecture range from educational, where many people access to the measurement test bed (e.g., a class with many students) [12,13,14] to advanced research where people access to valuable instrumentation.

A first group of problems bears approaching the transport of the signals to be measured through the network in fact, the impact of the communications network on the quality of the measure needs to be carefully taken into account. Of course not all kind of measurement can support this feature. A second aspect to take into account belongs the problems due to the multiple accesses by various clients to the distributed telemeasurement platform, the management of the resources (instruments) in a distributed environment (e.g. the reservation and the release of the instrumentations, the choice of an alternative resource in another laboratory when the first is occupied or etc). Some open considerations and solutions are reported to face these aspects.

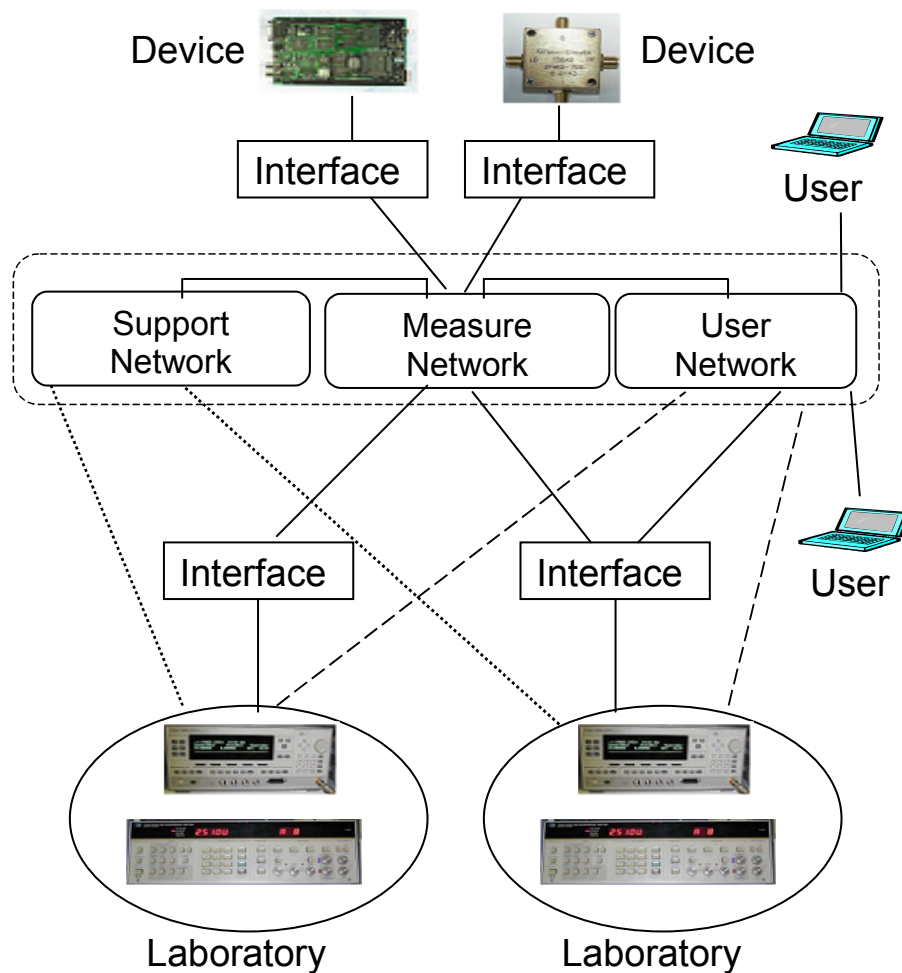


Figure 1 Cooperative Distributed Telemeasurement Platform

2 THE TRANSPORT OF THE SIGNAL TO BE MEASURED

This is the most critical operation within a cooperative network of geographically distributed instrumentation. A possible architecture scheme is reported in Fig. 2, note that the acquisition and packaging units could be a unique block and the reconstruction and unpacking units could be another single block. The processes on the analog signal could be summarized as:

- Acquisition: the analog signal is converted in a digital form and is memorized in the internal memory on the acquisition board;
- Packaging: once a network connection is opened, the buffers of samples are packaged and transferred using a suitable network transport protocol;
- Real-time transfer on the network: the digital data are transferred between two or more points, that can be connected by a network of heterogeneous nature;
- Unpacking: the received packets are ordered then the digital samples are unpacked and passed to the Digital to Analog Converter;
- Reconstruction: the digital samples arriving on the reconstruction board that convert them in analog form for the instrument input.

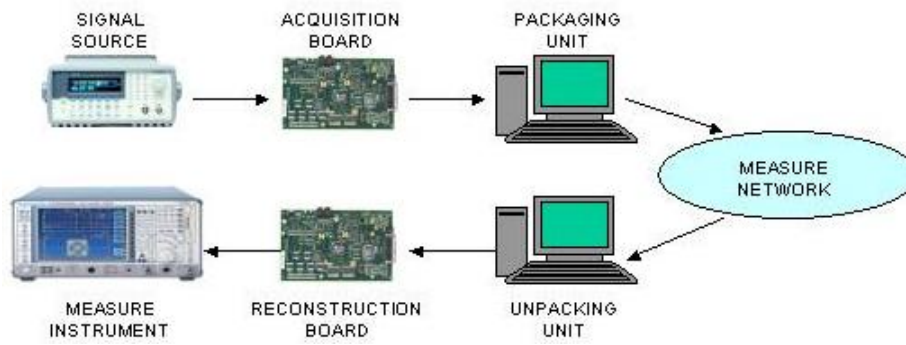


Figure 2 Ideal hardware architecture for the transport of the signals

The quality of service for applications of cooperative distributed telemeasurement is wide and complex. The large number of different quantities to be measured, the wide typology of the measuring processes and the different methodologies of measure make not unique the definition of an hardware and software platform for cooperative telemeasures. The most important thing that must be guaranteed when we made a measure on a signal elsewhere generated is that the result of the process of measure should be within a certain fixed tolerance the same we have measuring the signal near the source. At the contrary of other real-time applications, like video or sound transmissions, the transported signals are received by a measure instrument and not by an human sensorial organ; hence the integrity of the signal or better the quantification of the deterioration suffered by the signal acquires more importance and the use of analog or digital operations on the signal, like the introduction of analog stages, amplifiers, matching stages or the introduction of loss or un-loss coding techniques or other digital signal processes, should be opportunely evaluated. The integrity of the transported signals can be corrupted due to two different aspects: the non-ideality of the hardware architecture and the transportation of the signal through the measure network.

3 DETERIORATION INTRODUCED TRANSPORTING THE SIGNALS

The hardware architecture plays an important role on the deterioration of the signals; the required characteristics for this kind of applications are various, a short description of the most critical aspects is reported above. First of all the speed of the application strictly concerns with the bandwidth of the signals we are transporting. Looking at Fig. 2 the restrictions in bandwidth are imposed by different factors such as the sample frequency of the A/D and D/A converters, the chosen technology to carry the samples of the signal between the pre-post elaboration units and the A/D and D/A converters and between the packaging and unpacking units and the network interfaces, finally the speed of the network connection that is locked at the type of the used physical protocol. Hence the speed of this kind of application is directly connected to the throughput we can reach transporting the signals on the network. In the A/D and D/A converters the causes of errors are quite note and widely investigated. In particular during the quantization process is introduced a well known quantization noise that decreases the SNR like expressed by the note equation [15]

$$SNR_{dB} = 10 \log_{10} P + 10,8 + 6n \quad (1)$$

Where P is the power of the signal and n the number of resolution bits. The absolute accuracy of the converter can also be affected by static causes like an offset error, a gain error, a non linearity error or a differential non linearity error present in the quantization function or by dynamic causes that influence the settling and the conversion times of the converter. Finally an effect of constant attenuation on the reconstructed signal is present, it is due to the impedance un-matching between stages, it could be recovered in the digital processor at the reconstruction side. The acquisition and reconstruction boards are geographically distributed so the local oscillator in each board is different from the others. In Fig.3 the presence of an offset between the sample frequency of the A/D (F_c) and D/A (F'_c) converters $\delta F_c = F_c - F'_c$.

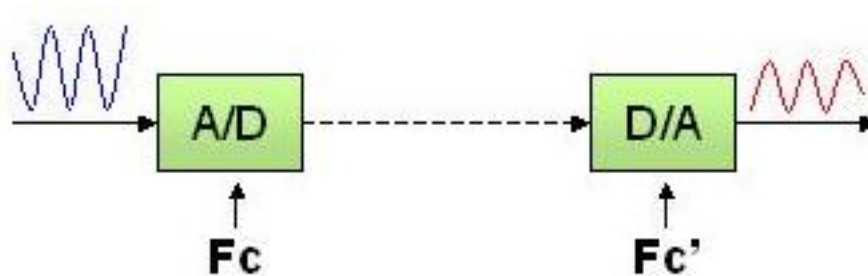


Figure 3 Difference between sample frequencies

This offset causes a difference between the frequency spectrums of the reconstructed and the source signals. In addition to this the D/A converter reads the receiver buffer that contains the samples of the signal with cadency equal to F_c' ; so if $\delta F_c > 0$ or $\delta F_c < 0$ the receiver buffer will be stuffed or emptied. The adopted solutions to synchronize the transmitter and receiver sides could be: the choose of a geographically reference clock like GPS system or NTP [16] internet protocol; also the use of digital techniques at the receiver side like interpolation-decimation [15] is not the best choose because it requires an high amount of computational and memory resources, in fact δF_c should be very little so this techniques need an elaboration of a big number of received samples. We implemented a solution (see Fig.4) where stuffing the samples, each time the thresholds are exceeded there is the suppression or the duplication of one or more receiver samples.

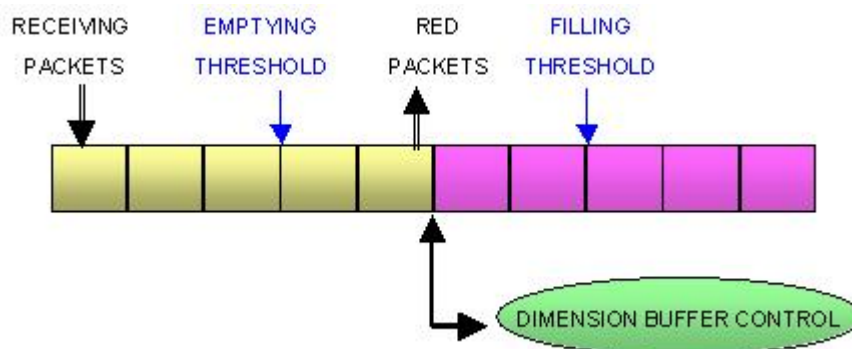


Figure 4 Receiver Buffer: software correction of δF_c

As mentioned below, the introduction of a network connection between instruments of measure is the more interesting cause of deterioration we are investigating. The phenomenons like delays introduced by the network, the congestion, the packets loss can produce signal deterioration. All these aspects are time variable but characterized by a measurable statistic and we can contrast or reduce their negative effects with appropriate software techniques. The delays introduced by a network connection are reported in Fig.5.

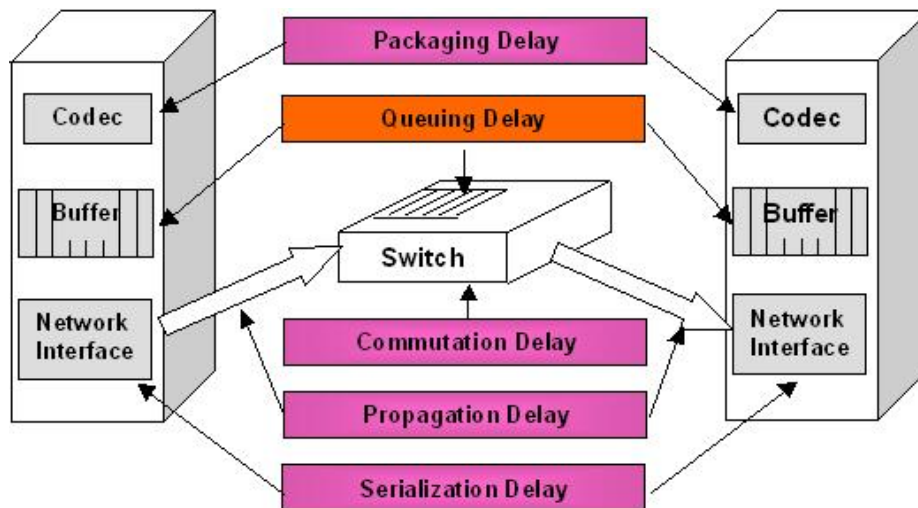


Figure 5 Network delays experimented during signal transportation

The delays are principally due to:

- Packaging/Depacking: time needed by terminals to create or to read a packet of samples; it depends on the dimension of the packets and on the sample rate of the converters;
- Serialization: time needed to put one packet in the network interface;
- Propagation: time needed to transmit the signal through the physical channel;
- Queuing: time during the packets wait in the buffers to be transmitted. This delay is accumulated in more points of the network such as routers or switches. The causes are the traffic and the congestion of the network. This is a variable delay;
- Commutation: time needed to store and forward the packets in the network.

In a transmission process, the latency is defined as the mean delay between transmission and reception of a packet. The latency represents the constant contribute to the delay given by the network; another important parameter is the jitter on the network delay, that is caused by the variable delays added by the network (queuing) and it represents a fluctuation of the latency. The jitter on the network delay is a problem for all real-time applications; generally to solve this problem it is useful to introduce a receiver buffer of right dimension, where the cadency of entries is characterized by the aleatory time introduced by network and the cadency of leaves is driven, in a constant way, by for example the sample rate of the D/A converter. In this way the variable delay becomes a fixed delay which value depends on the dimension of the receiver buffer. The right dimension for the receiver buffer can be obtained from a statistic characterization of the network behavior. Generally for real-time applications, if the buffer is too small, there is a short added delay but an increased loss of packets; if the buffer is too big, there is a more long added delay but a decreased loss of packets. In our real-time application the degradation that affects the signal to be measured can be unacceptable when the transmission of packets meets a congested link. Looking at the transport layer, using UDP protocol [17], the congestions can involve losses of packets because packets too delayed are discard from the application. With TCP protocol [6], the congestion involves the slow down flow of packets. With TCP protocol the lost packets are recovered using a retransmission mechanism with the introduction of delays that could be too much higher for real-time applications. Otherwise, using UDP protocol the losses are not recovered.

4 EXPERIMENTAL APPROACH: SOME RESULTS

We developed a hardware and software platform to make first experimentation on signal transportation. The platform is realized in the context of the software defined radio (SDR) technique in which the algorithms that realize system functionalities can be remotely uploaded, started and stopped, through the communication network. In particular we use a DSP-based architecture to acquire and reconstruct the signal [18], these boards are interfaced with two personal computers that use C++ sockets [19] to transfer the packets containing the samples through the network. To test the platform, we equipped a network of three telecommunication laboratories in Bologna. The three laboratories in Fig.6 are connected with an HDSL link with a guaranteed rate of 512Kbit/sec and a peak rate of 2Mbit/sec;

furthermore there is a wireless bridge IEEE 802.11b with a speed of 11Mbit/sec between two laboratories. Internally, in each laboratory is equipped a LAN based on IEEE 802.3u fast ethernet protocol at 100Mbit/sec.

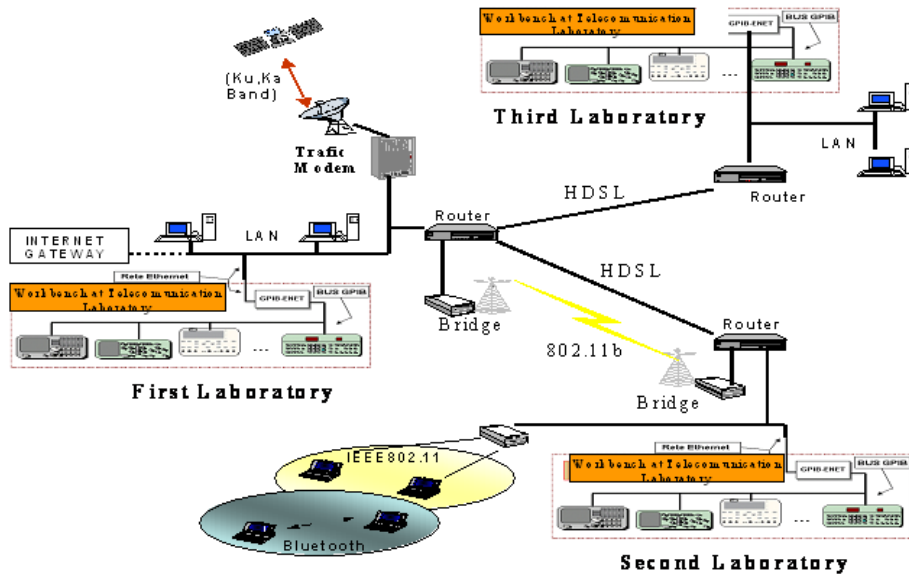


Figure 6 Heterogeneous network in Bologna.

The developed architecture is right away, so we limited to transport signals with low dynamic. The architecture has been tested with each typology of network physical link. In this work we will not enter into details of the hardware and software implemented architecture but we will show some measured results and give some open considerations.

We consider that:

- $x(t)$ is a wide sense aleatory stationary process with limited bandwidth B ;
- B is the probability to lost samples with independent errors;
- At the receiver side we have a linear reconstruction (low pass filter at Nyquist frequency) $F_c = 1/T = 2B$;

F_c Is the sample rate; $S_y(f)$ is the Power density of the reconstructed signal, while $S_x(f)$ is the power density of $x(t)$, $q = 1 - p$ and P_w is the power of $x(t)$.

Starting from the results obtained in [19], it is to see that:

$$S_y(f) = q^2 S_x(f) + qpP_wT \quad (2)$$

$$\frac{S}{N} = \frac{q^2 P_w}{qpP_w 2TB} = \frac{1-p}{p 2TB} = \frac{1-p}{p} \quad (3)$$

From (2) we can see that the power spectrum of the reconstructed signal is composed by two parts: the first one represents the power spectrum of $x(t)$ that is attenuated proportionally to q^2 ; the second part is a contribute of added noise that increases proportionally to the number of lost samples. The signal-to-noise ratio (3) depends only on the percentage of losses and decreases when the number of lost samples increases. We transmitted on the measure network a sinusoidal tone with frequency of 1KHz and amplitude of 0,5V , we imposed on the acquisition board a percentage of independent distributed single errors (substituting zero values) and we measured the received power of the signal and the power of the noise added losing samples of the signal. The theoretical and measured results are reported in Fig.7.

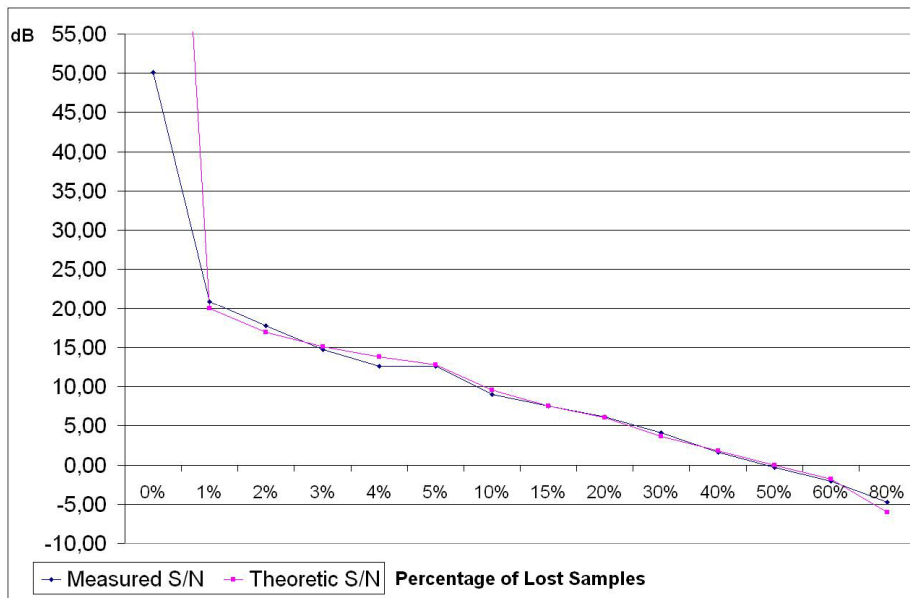


Figure 7 Theoretical and measured behavior of the ratio between the power of the reconstructed signal and of the power of the added noise vs. the percent of lost samples.

5 DISTRIBUTED COOPERATIVE RESOURCE MANAGEMENT

When a remote user accedes to the cooperative distributed platform for telemeasure is interested in using some particular measure instruments, he must know which kind of instruments are available in each laboratory and where the instruments are located, chose and reserve the resources and finally obtain the remote controls. From the point of view of a remote user, the complete availability of an instrument means that one instrument must be turn on and nobody else toke the control of that instrument. In this section we are proposing a server-based architecture realized in our laboratories that could solve the problems when more remote users have access to the distributed instruments present in a network of laboratories. In the proposed solution the server shows to the remote user the instrumentations that is available, reserves and gives to the user the remote control of the chosen instruments and keeps continually upgraded a special table with the state of the resources. The proposed server-based architecture on two levels is represented in Fig.8

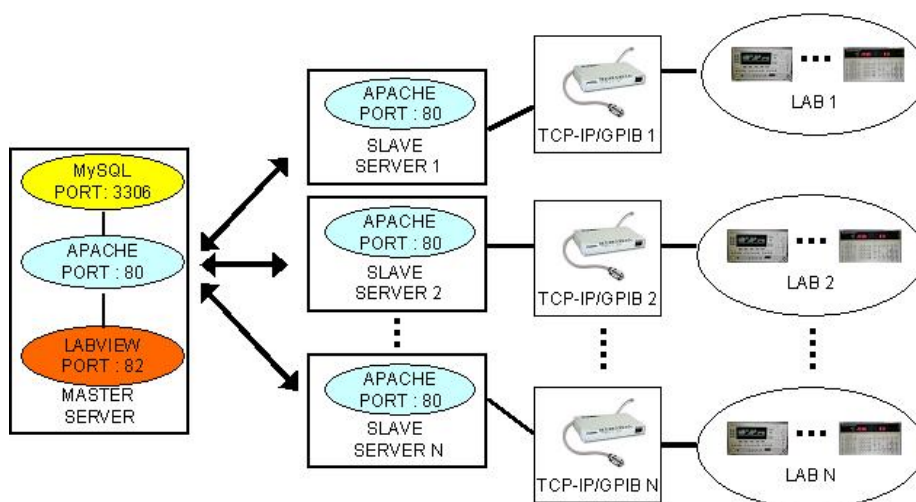


Figure 8 Two level's Server Architecture

The architecture is composed by a first level of slave servers one for each laboratory, and a second level composed by one manager of resources, called master server (Apache [21], MySQL [22], Labview Server [9]), that could be positioned in one of the laboratory in the network. Each server belonging to the first level based on Apache software and is connected through the local area network to a GPIBnet [3]

that communicates with the local instrumentation using IEEE 488.2 protocol. The role of the slave servers is to test if the local instrumentation is turn on and so keep information about his partial availability. When the client needs to know the availability of the distributed resources, the master server queries to a slave server which instruments are turn on, the slave server run locally a particular Common Gateway Interface (CGI) that asks it to the GPIBEnet. The manager of resources is based on a parallel architecture of three servers:

- A web server Apache: his rule is to dialog with the client. It contains the static (HTML language) and dynamic (PHP language) pages viewed by the remote user;
- A Database server MySQL: his rule is to keep and manage the information about the instrumentation present in the network of laboratories. The MySQL database server dialogs only with the Apache web server;
- A Labview server: his role is to keep and send to the clients the executable Virtual Panel to control the chosen instruments

6 CONCLUSIONS

In this paper we addressed the new concept of distributed collaborative telemeasurement. The subject is wide and complex interesting all kind of applications that involve measuring processes. We approached the problems from the point of view of the characterization of telecommunication systems but this theme could be more developed and opened to other interesting research environments. Nevertheless some applications of the cooperative distributed telemeasurement could be still proposed for example in educational or industrial purposes increasing the potentiality of little laboratories by using resources that are not available; measuring signals generated in a dangerous environment, where is not possible to bring a precious instrument; making environmental monitoring etc. The proposed and partially investigated problems about the transport of signals that are objects of the measure process, should be developed, for example investigating the modalities to increase the rate of the application by introducing digital compression techniques, finding hardware solutions, with better performances, for acquisition, reconstruction and networking boards. For each typology of measure the degradation on the measured signal introduced by the communication network has to be quantified.

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