



# **Tomas Bata University in Zlín**

## **Faculty of Applied Informatics**

Doctoral Thesis

### **Cloud computing solutions and security of EU remote interactive laboratories network**

**Cloudcomputingové riešenia a bezpečnosť siete vzdialených  
interaktívnych laboratórií EU**

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## **Abstract**

The submitted work deals with the problems, which has faced the Consortium REMLABNET of remote laboratories – Tomas Bata University Zlin, University of Trnava in Trnava and Charles University in Prague after inaugural and habilitation processes and 4 PhD theses with the subject matter of individual remote laboratories, work on administration system REMLABNET and its introduction into teaching process of natural sciences since 2006 until present.

The submitted work deals with these open and unsolved problems and mainly concentrates on management system of remote laboratories REMLABNET and its embedding into the cloud system. Especially in focus were cloud's computation mechanisms, security testing and verification of its functioning by testing optical routes, penetration testing and introducing special cloud services. The thesis also brings solutions, contributing to the current trend of federalization of world and EU remote laboratories.

The thesis also briefly describes the building trajectory of both the joint laboratories, and the contribution of the present thesis since 2011 of its start, till present with outlook for its future development.

## **Abstrakt**

Predložená práca rieši otvorene problémy, ktoré ostali v systéme vzdialených laboratórií konzorcia REMLABNET – TBU Zlín, TU v Trnave a KU v Prahe. Po obhajobe 6 postupových prac, inauguračnom, habilitačných konaní a 4 PhD dizertáciách, ktoré boli obsahom prác na vzdialených laboratóriách, práce na administratívnom systéme REMLABNET a ich zaradením do výukového procesu prírodných vied od roku 2006 do súčasnosti.

Predložená dizertácia rieši tieto stále otvorené problémy a to predovšetkým v nadväznosti na systém vzdialených laboratórií REMLABNET a ich vnorenie do cloudového systému a jeho výpočtových mechanizmov, ošetrovanie bezpečnosti a overenie tohoto nového cloudového systému testovaním optických tras, penetračným testovaním a vytváraním špeciálnych cloudových služieb. Súčasťou dizertačnej práce sú tiež riešenia prispievajúce k súčasnému trendu federalizácie svetových a EU vzdialených laboratórií.

Dizertácia tiež spätne stručne hodnotí trajektóriu budovania ako spoločného laboratória, tak aj príspevok tejto dizertácie od roku 2011, rovnako ako výhľad pracoviska pre ďalšie obdobie.

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# 1. REMOTE LABORATORIES - STATE OF THE ART

Let us summarize the standing and level achieved in remote laboratories, this new informatics teaching and dissemination tool, which emerged in the 21th Century, from the point of view of history and results achieved.

Practical learning and teaching activities in general and laboratories in particular, play an important role both in undergraduate engineering [1] and high school education. On top of this it is difficult to offer distance education students sufficient opportunities to develop those skill. Besides, the requirement emerges to have an access to scientific laboratories all over the world, especially to special equipment (like telescopes and electron microscopes, etc.) due to their excessive cost forces teachers, scientist and researchers to find other methods for the access. Internet may potentially fill the gap, as it has reached the maturity in many aspects. On top of this, Internet is on the edge of another revolution, where resources are globally networked and easily shared [2].

It was at CERN that Tim Berners-Lee, a British scientist, invented the World Wide Web (WWW) in 1989 [3]. The web was originally conceived and developed to meet the demand for an automatic information sharing between scientists at Universities and institutes around the world, expressed by *“The Internet has revolutionized the computer and communications world like nothing before. The invention of the telegraph, telephone, radio, and computer set the stage for this unprecedented integration of capabilities. The Internet immediately offers worldwide broadcasting capability, a mechanism for information dissemination, and a medium for collaboration and interaction between individuals and their computers without regard for geographic location”* [4].

With the occurrence of the Internet the situation was ripe for building remote laboratory (RL) from standalone hands-on equipment, which started two decades

ago. Soon emerged the idea of the remote control of real instruments [5] and a single remote experiment, using the identical laboratory equipment as hands-on, but shared by many, was born. The first documented e-experiment was built by PhD students in USA [6] (the whole history of e-experimentation is described in [7]).

Immediately, many problems, stemming from the new form of e-laboratories, have emerged. One of the early proponents of remote labs, Daniel Stancil (1996), outlined a rationale to create and operate e-laboratory [8]:

- Use of the lab when it is physically not open;
- Widening Access to equipment for students;
- Sharing Instruments among multiple Universities;
- Remote Access to expensive equipment the University cannot afford;
- Savings on travel time and expenses;
- Possibility of remote maintenance and support.

### **Why remote laboratories?**

In other words, in engineering education, a key activity to improve the learning process is hands-on experimentation, carried out by laboratory facilities or simulation tools [9]. Recent developments in information and communication technologies (ICT) during the last few decades resulted in new technologies like Internet based labs, we named remote laboratories (RLs) and simulated labs. These online labs allow remote access to a physical experimental system through Internet. The possibility of sharing resources with other institutes, hence gaining economic benefits, is considering an advantage for remote laboratories [10]. Some potential advantages of using RLs are:



- Reduce the number of student hours spending in the laboratory by increasing our self-paced learning offering,
- Achieving practical experiences with real equipment through Internet connection from home,
- Giving access to more learning materials, procedures and practical video presentations through implemented e-learning,
- Monitoring on real-time measuring system by using a web camera and storage of the acquired data.

Our University students (Tomas Bata University in Zlin) welcome RLs, because they increase access flexibility. According the last analyzes, RLs conception requires technical, pedagogical and computer science competencies. Due to these requirements, RLs appear to be more complex than other e-learning contexts such as on-line courses, virtual classrooms, e-projects, role-playing, etc. However, this kind of training is essential for scientific and technical disciplines and fits real needs.

More compatible strategy to the present state of the society is that used in the scientific method of cognition of real world or the method of e-LTR (e-Learning, e-Teaching and e-Research) [11]. Many real RLs across the Internet have been published that provide experiments on real world objects, supplying the client with the view of the experiment, interactive environment for the experiment control and resulting data for evaluation.

The benefits of RLs are predominantly in engineering education. They are:

- Relax time constraints – adapting to pace of each student, if there was insufficient time in lab,

- Relax geographical constraints – disregarding the physical locality of the student,
- Economies of scale – as sharing labs allows sharing of large fixed costs of traditional buildings,
- Improve quality of experiment – as it can be repeated to clarify doubtful measurements in lab,
- Improve effectiveness – as student may improve effectiveness of time spent at lab by rehearsal,
- Improved safety and security – as no risk of catastrophic failure.

Researchers from the Labshare (Australia) [12] describe the advantages as being:

- Increasing accessibility to laboratories by a factor of 4 within 3 years, since current lab utilization is less than 10%,
- Decrease fixed and variable expenditure by 50%, since faculty budget spends between 15-40% on lab infrastructure and personnel, around AUD 400 million per year,
- Improve learning objectives and outcomes to support better learning,
- Enhance sharing of knowledge, expertise and experience,
- Reduce start-up costs of laboratories.

This allows for economies of scale production. Another benefit is that the RLs technology can be integrating into several Learning Management Systems (LMSs) around the world, federalized into one global system. This will be described below.

On the contrary, everything has disadvantages and drawbacks. The disadvantages in remote experimentation differ depending on the type of RLs and the topic area. The general disadvantages compared to a hands-on laboratory are:

- Lack of hands on trouble shooting and debugging experience,
- Lack of equipment setup experience.

To build the RL requires as the first step to set up the computer-controlled experiment. In our laboratory, the user-friendly hardware (HW) and software (SW) for building experiments – Internet School Experimental System (ISES) – has been used [13]. The system has been constructed at the Charles University in Prague, Faculty of Mathematics and Physics, Department of Physics in 90<sup>th</sup> and is has been improved till now. The measuring system ISES has been supplied to the teaching institutions in the Czech Republic currently being used by more than 500 installations and teaching laboratories. It forms the basis of our approach to the simple RLs building. Here we will mention only few important facts in relation to the RLs building using ISES technology.

The ISES and its HW and SW comes from the Charles´ University in Prague [14] [9] as a complex tool for real time acquisition, data processing and control of hands on experiments. It is an open system consisting of a basic ISES HW (see Figure 1) with the controlling SW ISES WIN. The physical HW is composed of the ISES panel and the set of modules. The sensing ISES modules are easily replaceable, their presence and adjusted range are automatically sensed by the computer. The service SW enables the measurement simultaneously of 10 different channels (8 analogues and 2 binary) and capability to use 4 programmable output channels. All these are fully programmable, using the programming panel. More details about the ISES and how to build computer – oriented hands on experiments

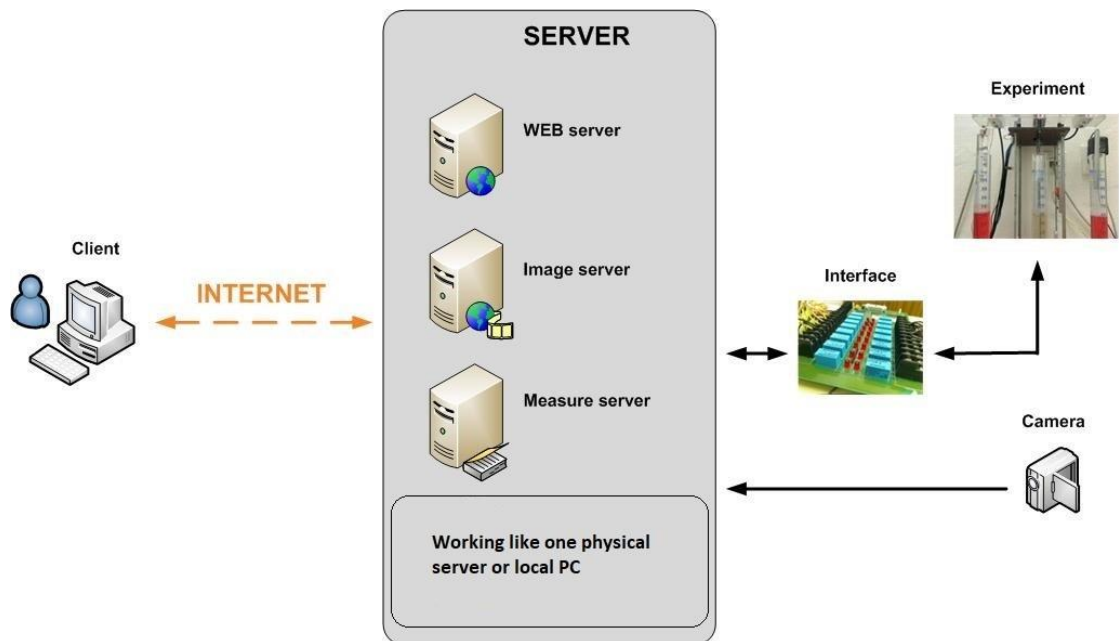
are to be found in the recent monographs [10] [15]. Such hands-on experiment is to be transformed into its remote counterpart, spread across Internet.



*Figure 1 System ISES, general view of the available physical HW [16]*

Let us briefly describe the transformation of any hands-on experiment to its remote counterpart, named Remote laboratory (RL). Technically, any RL runs at a location different from the client. Consequently, it consists of two parts, one is the physical HW (for a phenomenon to be examined), as with hands-on experiment and the second is the SW for transferring instructions from the client to the experimental setup, and resulting measured data to the client. All communication is across the Internet, using web services, and a corresponding communication interface. The general scheme of RL, using the client-server communication is shown in Figure 2. The physical HW is composed of a set of ISES measuring modules and sensing elements and the ISES transducer card (analog-digital digital-analog (ADDA)), whereas ISES service graphics and evaluation program belong to physical SW.

Let us explain the way of creating RL using ISES system in more details. The first step is to change the controlling SW of hands-on experiment to the remote one. The result is depicted in Figure 2 [17] with all installed necessary SW servers for remote experiments (WEB, Image and Measure) functioning as a finite-state machine (FSM). FSM is in fact a mathematical model of computation used to design both computer programs and sequential logic circuits. RL is conceived as an FSM that can be in one of a finite number of states [18].



*Figure 2 Basic scheme of the server-client communication in RL*

The set of depicted servers create connectivity with the client (WEB server), creates controlling web page (Image server), starting and executing measurements and providing measured data (Measure server). On the client side, a standard browser (Internet Explorer, Mozilla, Opera, etc.) and implicit Java Script (JS) support is used, without any additional modifications [19]. The WEB server provides the web services to the client, based on the Nginx, an open source reverse proxy, as well as a Hyper Text Transfer Protocol (HTTP) cache and a load balancer. The communication is realized by standard protocols via the Internet. The Image server transfers image information to the clients connected to RL. Image server

makes periodically adjustable snapshots acquired by the camera, which is displayed on the client's screen. We are storing the snapshots in two resolutions, depending on the Internet speed rate. The Measure server (MS) is a heart of every RL taking care of its running, processing of client's commands and corresponding responses and transfer (manipulation) of data. It is the middleware located between the physical HW (RL) and the client. The Core of MS [20] is designed as a deterministic FSM [21] to perform the instructions for running and solving the prescribed activities. Its exclusive functioning is controlled by the program script file (psc) loaded before the MS operation [22]. MS communicates with physical HW via the ADDA transducers card, by direct reading and writing of data from/to particular pins of the physical sensors and modules [23]. By this way we have the access to any connected physical device and corresponding physical signals and enabling controlling of RL. All bidirectional data and commands communication between the client and MS are basis on the end-to-end communication.

The maximum number of RLs of the Consortium Tomas Bata University in Zlin (TBU), Charles University in Prague (CHU) and Trnava University in Trnava (TU) reached 40 RLs, all with the ISES architecture [24] with the identical setup as depicted in Figure 2. The present list of running RLs is:

- Energy in RLC
- Characteristic of DC source
- Phase in RLC
- Photovoltaics
- Transient in RLC
- Wave Laboratory
- Induction

- Radioactivity
- Solar energy
- Rectifier
- Series RLC circuit
- Diffraction on micro objects
- Heisenberg uncertainty principle

The main output of our activities in building RLs was the set of RLs covering the curricula of natural science subjects and the design and building of the management system REMLABNET [25], enabling the access, management and exploitation of the set of 40 RLs easier. Simultaneously the RLs were introduced into the teaching courses of Physics in Zlin University I- III (Mechanics, Electricity and magnetism, Oscillation and waves and Quantum physics) via MOODLE and in Trnava University in courses of Electricity and Magnetism and Quantum Physics. Introductory description of the REMLABNET management system follows in the next chapter.

On top of those activities, to make building of new RLs easier, a new environment for transferring ISES hands-on experiments into their remote counterparts (RL) - EASY REMOTE ISES (ER ISES) [26] [27] was built. It is basically an expert system, working with the screen questionnaire and with photos of available ISES versions (Figure 3), which generates the control psc file and the web page code for a new RL. For practical reasons the newly generated remote experiments are divided into three categories according to their complexity- starting level (set of precompiled typical RLs), basic level (the most used RL with a variability and logics) and advanced level (very complicated RL) (more details in [28]).

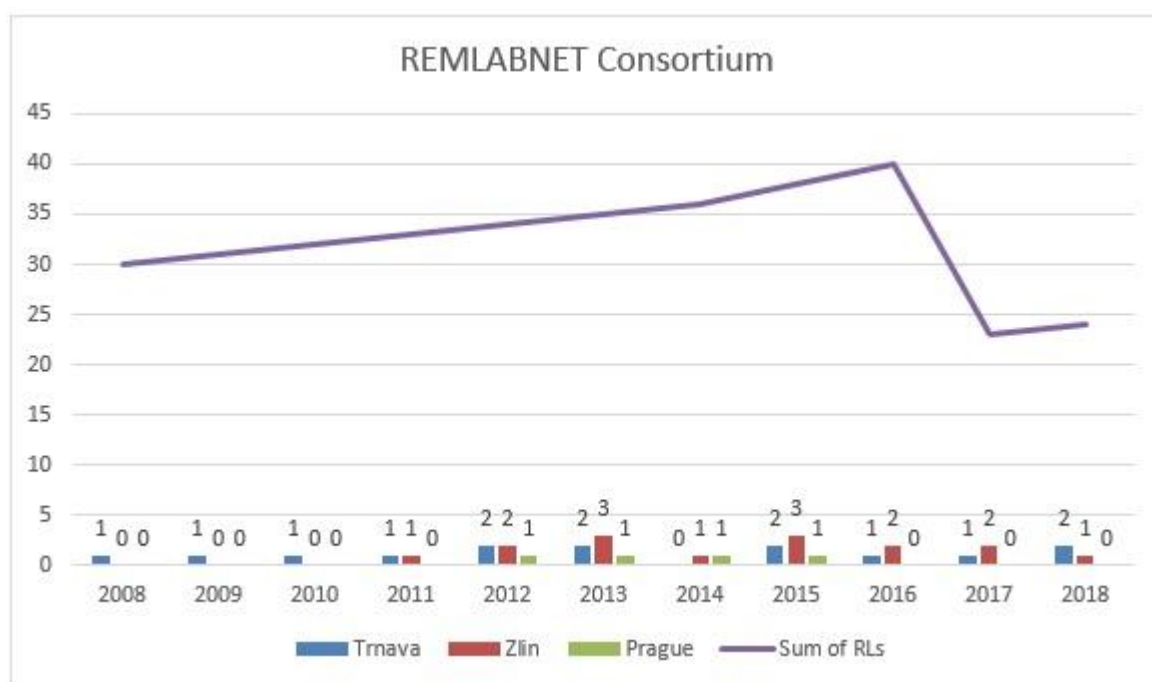


*Figure 3 Welcome panel of ER ISES graphical expert development environment*



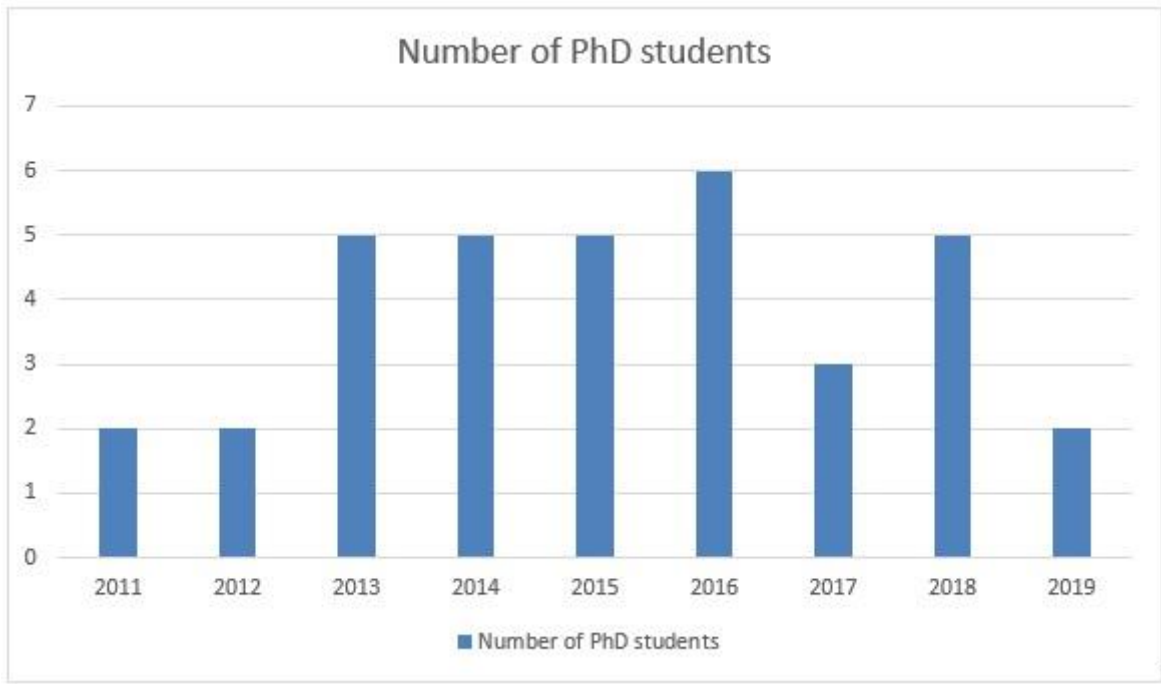
## 2. INTRODUCTION TO REMOTE LABORATORIES MANAGEMENT SYSTEM REMLABNET

The growing total No of RLs of Consortium workplaces is depicted in Figure 4. The graph shows evolution of RLs in Consortium, gradual adding of RLs and their whole summary in single years.

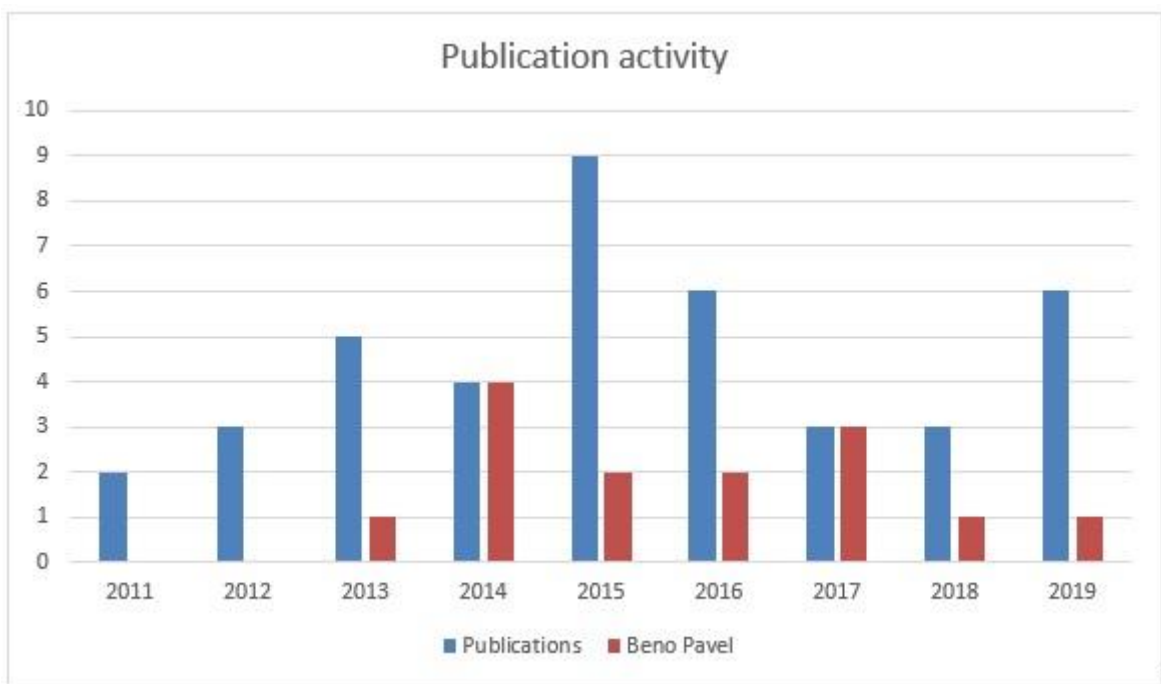


*Figure 4 Building of new RLs of the Consortium workplaces of Trnava, Zlin and Prague per years and total No of RLs of the Consortium in individual years*

Figure 5 shows the number of PhD students involved in activities of RLs in individual years reaching 6 PhD students, where the activities in building REMLABNET were running. Concurrently, the scientific output of the RLs group grew, as depicted in Figure 6.



*Figure 5 Number of PhD students in FAI group of RLs in individual years*



*Figure 6 Publication activity of RLs FAI group in individual years*

Present thesis was the part of the rather complicated and demanding development of the RLs group at FAI TBU in Zlin. In order to make clear the role of the present thesis in the activities of the RLs group, let us present the stages of its development in Zlin and Trnava with denoting the participation of the present thesis (denoted by color):

2005 – Habilitation thesis “RLs in Physics” (F. Lustig, in Prague)

2008 – 2010 – Starting and preparation steps for the 1st thesis in Trnava, - “Remote Electrochemical cell” (L. Valkova in Trnava),

2010 – First doctoral thesis defense “Remote Electrochemical cell” (L. Valkova in Trnava),

2011 – First doctoral students (M. Krbecek, P. Beno in Zlin),

2012 – Doctoral thesis defense “RLs in teaching electronics” (L. Tkac in Trnava)

2012 – Content Management System as basis of RLMS (P. Beno and M. Krbecek),

2012 – Easy Remote ISES – Java, (M. Krbeček),

2012 – REMLABNET – first design (P. Beno and M. Krbecek),

2013 – New doctoral students (L. Palka, P. Spilakova, M. Gerza) in Zlin,

2013 – RLMS named REMLABNET occurred (ALL),

2013 – REMLABNET moved to classical server of DTC Trnava, (P. Beno)

2013 – Consortium REMLABNET (Charles University in Prague, Tomas Bata University in Zlin and Trnava University in Trnava) established (ALL),

2013 – BigData, data warehouse (L. Palka in Zlin)

2014 – Easy Remote ISES – JavaScript, (M. Krbeček in Zlin),

2015 – REMLABNET official start in Trnava cloud (P. Beno in Zlin),

2015 – REMLABNET & Graasp & GoLab Federalization (M. Krbecek)

2015 – Swiss SCOPES project start (2015-2019) (F. Schauer, P. Beno)

2015 – Two levels remote experiments diagnostics (M. Gerza in Zlin)

2016 – Extension of REMLABNET for mobile devices (M. Krbeček in Zlin)

2016 – New services in cloud (P. Beno in Zlin)

2016 – New doctoral student (T. Komenda in Zlin)

2017 - Habilitation thesis “Remote Electrochemical Cell”, (Ž. Gerhatova2017 in Trnava) Doctoral thesis defense (“RLs and their administration in EU”, “RLs with embedded simulations and diagnostics”) (M. Krbecek, M. Gerza in Zlin)

2017 – New instalation of cloud, because old was compromised (P. Beno)

2017 – New students (M.Archibong -Nigeria, Shayan Dash - India)

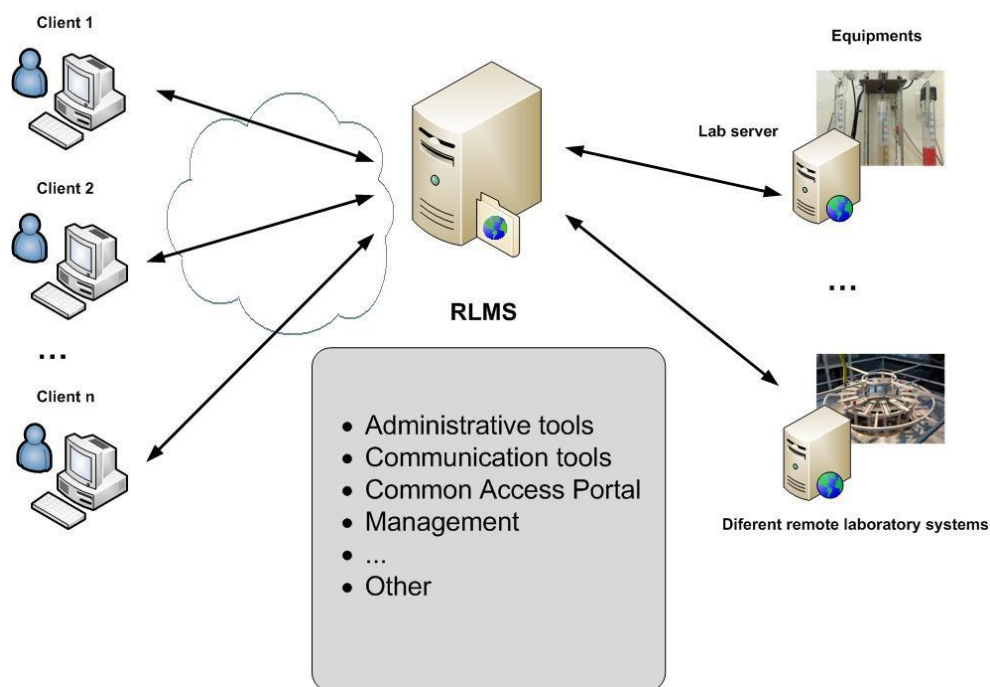
2017 – Inauguration thesis “INTEL and RLs in science education” M. Ozvoldova

2018 – Start of REMLABGRAB as new services of cloud (P. Beno in Zlin)

2018 – New students (J. Opalka, R.Spigel in Zlin)

### **Remote laboratories and their management systems**

To spread and provide to the interested public RLs is followed by many difficulties. Primary difficulty is the platform dependence. Each RL may be built on a different HW and SW platform. Web portal of RLs may differ and may be tagged to various languages. Also, it is questionable, if the client’s web browser is supporting all used languages and platforms. These simple unifying criteria are stimuli for the building Remote Laboratory Management Systems (RLMS). RLMS caused the end of the individual and thus separated RLs. The general trend is the connecting of standalone RLs into one management system, where it was possible to connect different laboratories under one unified layout. System like this is generally denoted Remote Laboratory Management System (see Figure 7) [29].



*Figure 7 Remote laboratory management system (RLMS) – the example of arrangement*

Every RLMS has to manage at least a subset of the following features: authentication, authorization, scheduling users to ensure exclusive accesses - typically through a queue or calendar-based booking-, user tracking and administration tools. These features are common to most remote laboratories and are actually independent of the particular remote laboratory settings [30].

Later, one of the features was that RLMSs started to support the federating of the RLMS. For example, if two Universities install RLMS, and they support federation protocols they share a laboratory with students of the second University without knowing these students, and even without any need to register particular students. It is the consumer system, which defines that a set of local users can access a particular laboratory of the provider system [31].

In the concept of individual RL rest several problems and drawbacks, especially, when every RL is operated with different standardization of interfaces, SW and HW. The clients, when searching for proper RL, are then facing a difficult

task to find proper RL for his/her needs and connectivity. On top of this there is a need for many IP addresses, DNS records and a lot of administration. The client was overwhelmed with searching and complete absence of reliability and diagnostics. That is why we had proposed a next step of the RLs building by designing RLMS.

Trend of nowadays is connecting standalone experiments to one management system, via which it is possible connect different laboratories under one unified layout and provide central management system on needed services. RLMS and whose main features are depicted in Figure 7.

### REMLABNET - Remote Laboratory Management System

Tomas Bata University in Zlin (TBU), Trnava University in Trnava (TU), and Charles University in Prague (CHU) as partners of the Consortium started to build the common management system REMLABNET in 2013 for their RLs. REMLABNET provides RLs via Internet and portal [www.remlabnet.eu](http://www.remlabnet.eu) (Figure 8).

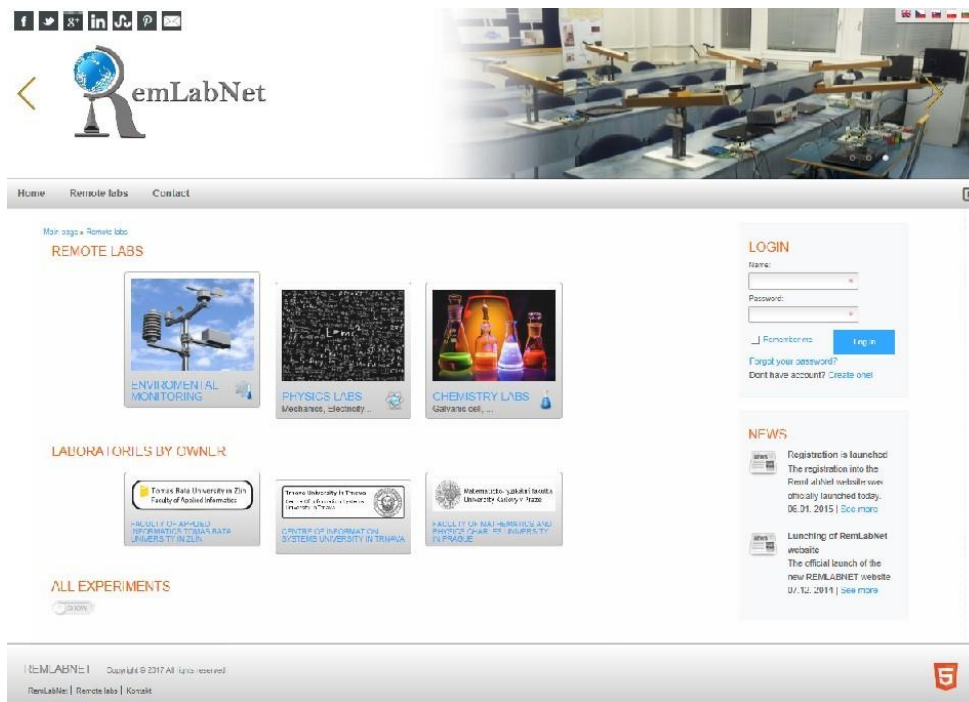


Figure 8 Remote laboratory management system REMLABNET – example of RLs offer

RLMS REMLABNET provides three types of communication among physical HW and clients (Figure 9). The first communication is with RL servers (brown color). This communication is among datacenters (DTCs) and each RL. The second channel of communication is transfer of information between the management and MS of the RL (blue color). This channel of communication will also provide diagnostics of individual experiments, remote repair of their malfunctioning and scheduling of the experiments as well. The third and the last channel of communication is communication with the client. The clients proceed to the experiment via the communication server (light brown color). Important parts of the whole communication network of the University are individual DTCs and their mutual communication (green color).

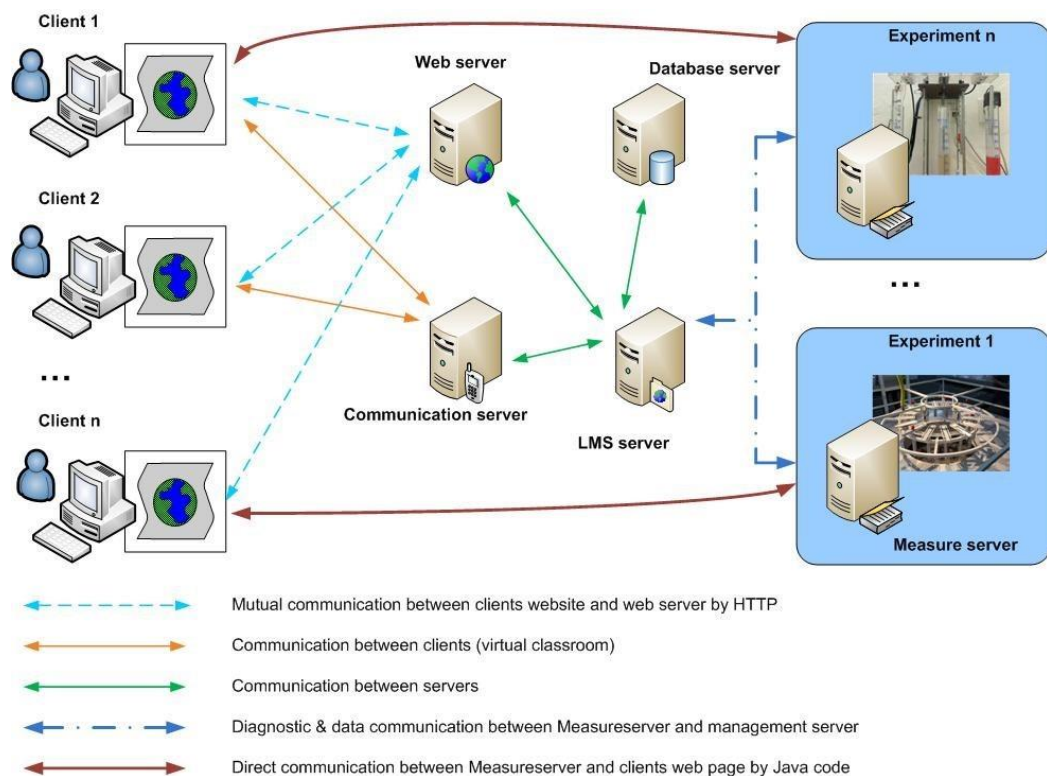


Figure 9 Communication scheme of the RLMS REMLABNET

In general, three methods for the access to RL are available [32]:

- Direct access through standalone authentication system of single laboratory instance,
- The Access provided by supervisory and management system like LMS or Content Management System (CMS),
- Access provided by platforms for interconnection and laboratory sharing.



### **3. GOALS OF THE THESIS**

Based on the status of the subject matter of virtualized cloud solutions and remote laboratory technologies here are goals of the thesis: **“Cloud computing solutions and security of EU remote interactive laboratories network”**

1. Create virtualized cloud environment, using progressive cloud solutions for hosting Remote Laboratories Management System – REMLABNET.
2. Design and provide the virtualized cloud environment with corresponding security precautions. For this purpose, carry out software security penetrating test of REMLABNET to ascertain its overall security resistance.
3. Model the University network failure and ascertain the limit of its spreading and ways for its effective suppressing and elimination.
4. Design the virtualized cloud interface environment for easier building, servicing and maintenance of remote laboratories embedded in the cloud.
5. Make full use of the participation as partner of group B level in the Swiss National Scientific Foundation project SCOPES NoIZ74Z0\_160454 “Enabling Web-based Remote Laboratory Community and Infrastructure” provide planned information and help to the partners of group level C.

## **4. USED METHODS, PERTINENT TO CLOUD COMPUTING OF REMOTE LABORATORIES**

The thesis deals with the general **applications of cloud technologies** in branch of RLs, which calls for a special approach. In following we will describe the methods, used for RLMS embedded in the virtualized cloud. In Chapter 4.1 we will present peculiarities of the system REMLABNET, at present hosting the set of 13 RLs (see the list on p. 14-15). Then, in Chapter 4.2 follow Security precautions for REMLABNET and proving security effectiveness by penetration tests and its modelling. The next Chapters 4.3 and 4.4 describe the used cloud services, as the solution for better communication with individual RLs, hosted in the cloud. The last Chapter 4.5 is the Federalization of individual management systems, concentrating on the sharing of know-how and data exchange.

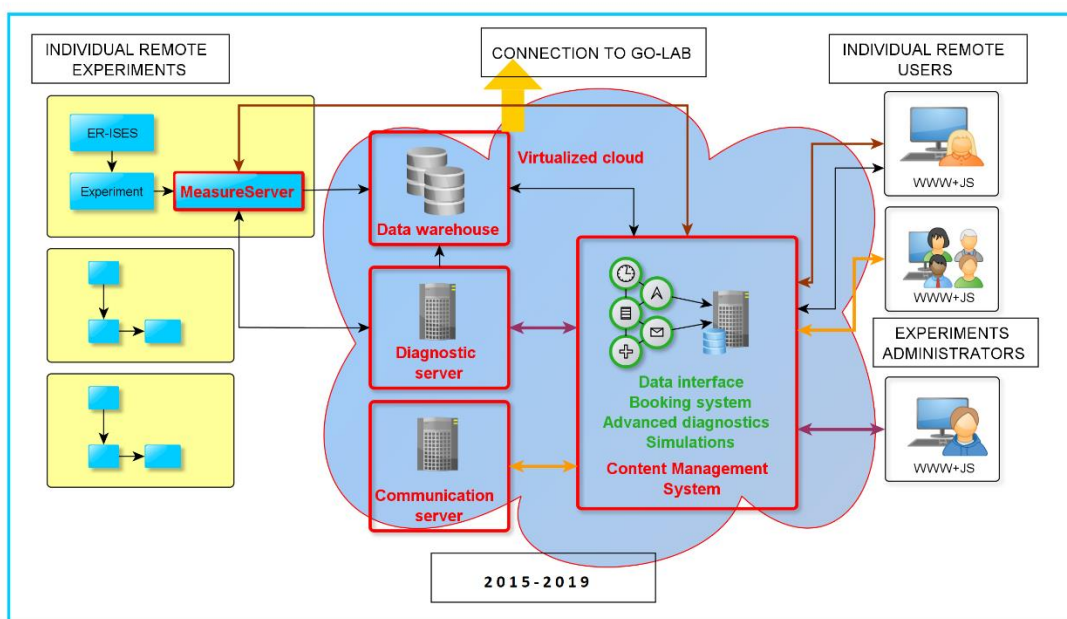
### **4.1 REMLABNET as a working method and cloud implications**

The system REMLABNET was the subject of the previous thesis (more detailed description of REMLABNET system is to be found in thesis of M. Krbeček, PhD. [27]). The schematic arrangement of RLMS REMLABNET is in Figure 10, with virtualized cloud (shaded area), physical experiments (on the left) and community of clients (on the right). Let us present the RLMS system in the extent, used in the present thesis, as the object of embedding in virtualized cloud and its functioning.

Every physical experiment and its input and output data are connected to its server via ADDA transducers to the central unit of MS and are coded for the Internet transmission.

To assure the sophisticated and complex functions of any RLs there is Content Management System (CMS) (Figure 10), forming the heart of any management system with multiple functions. To the general functions of CMS belong modules

as booking system, client's identification and rights allocation, virtual classes establishment, etc. Further, for the teaching purposes belong tools like various whiteboards, calculators, voice and stream services. CMS system organizes data storing and recovering for the subsequent processing, educational and research purposes. For this purpose, there are primary servers for communication, sharing data, publishing sites for individual experiments, publishing information about each experiment, laboratory and class, etc. These services provide Data warehouse (Figure 10) as the primary database for data storing and its mining. It constitutes of two parts, the former one is MSSQL database for the saving of measured data and for their mining for the research. The latter part of the Data warehouse database is based on the MYSQL, where all data from CMS and of the modules are stored.



*Figure 10 Idea of the representation of the Remote Laboratory Management System REMLABNET schematically embedded in a virtualized cloud (shaded area) Mind the "federalization" connection to the RLMS Go-Lab, also serving to Graasp interface*

The Diagnostic server (Figure 10), used for the diagnostics and administration of the remote laboratories. With every experiment, there is defined the diagnostic

status of each experiment and the deflections from those are sent to CMS system and clients can see the present status of every experiment (online, in use, offline). Next part of this server is the working management of each experiment, where administrator can force some steering functions on every experiment (restart, load data, load configuration, etc.). The Communication server, for communication intercourse among users of RL, e.g. within virtual classes. Connection to Go-Lab served for federalization of two RLMS REMLABNET and GO-LAB [33].

Summarizing, the functions of REMLABNET are:

- To embed individual RLs and provide their functioning,
- Enable Diagnostics of RLs,
- Enable communication in the virtual classes,
- Enable connectivity with another RLMS,
- Provide connectivity of clients from arbitrary locality,
- Provide unification of interfaces,
- Provide booking system,
- Ensure storing of measured data.

Thus, we recapitulated the basic properties of REMLABNET, pertinent to the cooperation with the cloud technologies, without addressing details of its realization. The practical steps necessary to take in cloud SW choice, peculiarities of SW installation, embedding of REMLABNET in cloud structures and its optimal alignment are to be found in Chapter 5 Results, mainly in 5.1 REMLABNET functions – choice of cloud SW and its optimization and partially distributed in subsequent Subchapters of Chapter 5.

## **4.2 Security and reliability of REMLABNET**

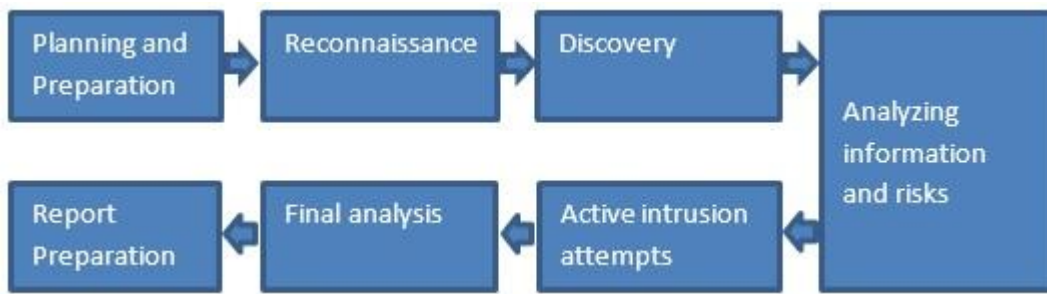
Cloud computing security is an evolving subdomain of general computer and network security. It refers to a broad set of policies, technologies, and controls deployed to protect data, applications and the associated infrastructure of virtualized CC.

We used for installing the virtualized cloud the SW package of the firm VMWare (USA). In all materials we have not found any references to special hazards for RLs. Thus, we had to execute SW security audit first on several mentioned items by penetrating tests using RLs connected to REMLABNET in Zlin.

### **4.2.1 Software security by Penetration testing**

General experimental method for security evaluation Penetration testing (PT) is used. PT normally evaluates a system ability to protect its networks, applications, endpoints and users from external or internal threats. It is oriented to find the security risk, which might be present in the system. If a system is not secure, then any attacker can disrupt it or take authorized access to that. Specifically, the goal of PT is to find the speed of the spreading of the fault caused by the perturbation of any sort and its depth. The subsequent steps are then aimed at finding the flaws or back doors in the system.

PT is a combination of techniques that considers various issues of the systems and tests, analyzes, and gives solutions. It is based on a structured procedure that performs penetration testing step-by-step in seven steps (Figure 11).



*Figure 11 Seven steps of Penetration Testing*

In our case we strived to evaluate and increase safety and security of the system REMLABNET and for this we had to:

- Identify REMLABNET environment and its functionality,
- Find weak areas where an intruder can attack either with the legal or illegal access to REMLABNET,
- The main parts of REMLABNET deserving protection are remote laboratories themselves, all stored data both experimental and for communication and misuse of the management system,
- For execution of the PT for REMLABNET we choose the Social engineering test (how access is safety), the Web application test (how REMLABNET app is secured) and the Network service test (how network with REMLABNET is safety),
- For evaluation of above-mentioned tests, we used standard mathematical methods,
- For disclosing the flaws or back doors in the system responsible for unacceptable results of PT we have to use exclusion, substitution, superposition or replacement methods of the individual parts of the system. A great deal of orientation in the problem of finding flaws or back doors is modelling method described in the next paragraphs.

## 4.2.2 General cloud security issues and inspections

Cloud computing solutions provide the clients and organizations (including universities) with various capabilities to store and process their data in third-party data centers. Organizations use the Cloud in a variety of different service models (IaaS, PaaS and SaaS) and deployment models (Private, Public, Hybrid and Community) [34]. There are a number of security concerns associated with cloud computing [35]. These issues fall into two broad categories:

- Security issues faced by cloud providers (organizations providing infrastructure, platform, or software as a service via the cloud),
- Security issues faced by their customers (companies or organizations who host applications or store data on the cloud).

The provider must ensure that their infrastructure is secure and that their clients' data and applications are protected, while the user must take measures to fortify their application and use strong passwords and authentication measures. We must protect in first place all RLs connected to our cloud (via REMLABNET system) and our clients must accept our password and security rules. Additionally, data centers must be frequently monitored for suspicious activity. Our cloud is provided by TU's DTCs, and this part is treated by Security manual of TU.

In order to conserve resources and maintain efficiency, we must store more than one customer's data on the same server. As a result, there is a chance that one the client's private data can be viewed by another client. To handle such sensitive situations, we, as the cloud service provider, should ensure proper data isolation and logical storage segregation.

Cloud security architecture is effective only if the correct defensive implementations are in effective. An efficient cloud security architecture should

recognize the issues that will arise with security management. The security management addresses these issues with security controls. These controls are put in operation to safeguard any weaknesses in the system and reduce the effect of an attack. While there are many types of controls behind a cloud security architecture, they can usually be found in one of the following categories:

- Deterrent inspections,
- Preventive inspections,
- Detective inspections,
- Corrective measures.

#### **4.2.3 Monitoring of communication network losses**

In our environment, we use single mode (SM) fiber made within the norm 652D, unshifted single mode optical fiber. What is the most important for our work is shown in Figure 12, namely the relation of attenuation on fiber optic in relationship with used radius and wavelength (bending loss). In Figure 12, we depict 3 options of attenuation of optical fiber within the radius of 10mm, 15mm and 20 and more mm on frequency used. In direct usage within the frame of REMLABNET we use mostly the wave lengths 1310nm, 1490nm and 1550 nm.



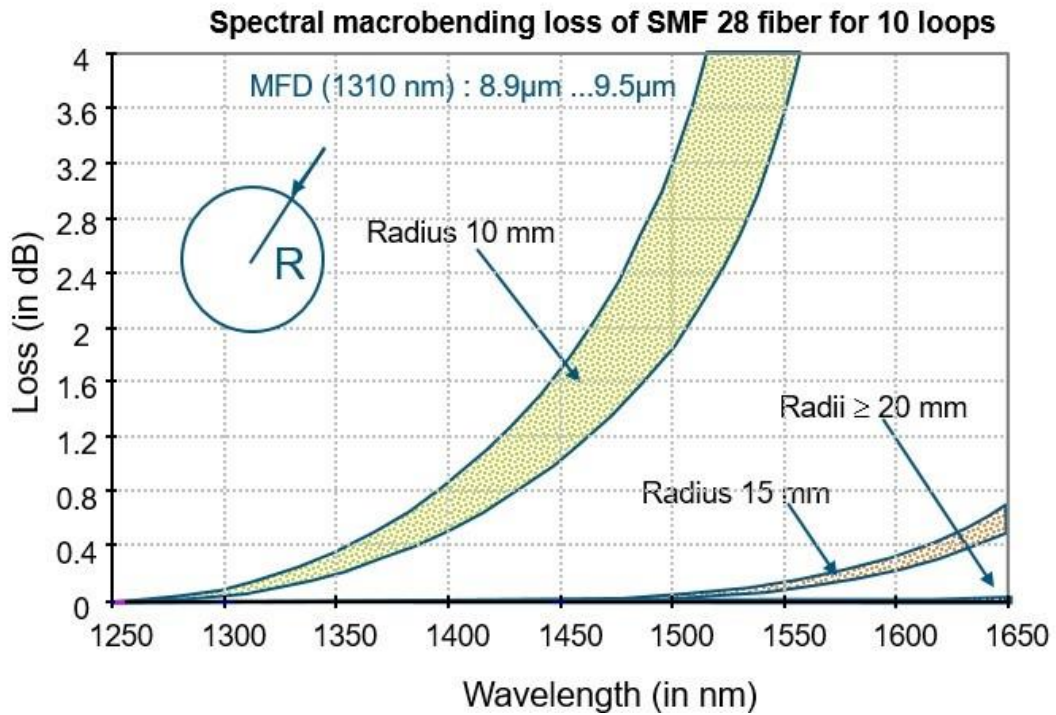


Figure 12 Bending loss of performance of standard SM fiber (ITU-T G. 652D)

The bending loss becomes important once bending radius becomes smaller than 20mm. Measurements were on 28 fiber cord with 10 loops in cartridge. For our mostly used wavelength 1310nm is the value of Mode field diameter (MFD) in scale from 8,9μm to 9,5μm. MFD is important because, as a measure of the size of the optical field itself, it enables to design launch-optics to match the mode of the source to that of the fiber and so maximize launching-efficiency.

#### 4.2.4 General Security

Embedding the system REMLABNET into cloud, we have to deal with its security. Speaking about security, we must consider many aspects of its complicated and acute constituents, which are outside of the scope of the thesis, nevertheless, we have specified in more details some of its constituents in Appendix G, which are here only enumerated:

## **Security and privacy:**

- Identity management,
- Physical security,
- Personal security,
- Privacy.

## **Data security**

- Data Confidentiality,
- Data Access Controllability,
- Data Integrity,
- Data encryption.

### **4.2.5 Modeling of the University network failure spreading**

A stochastic model is a tool for estimating probability distributions of potential outcomes by allowing for random variation in one or more inputs with time. The random variation is usually based on fluctuations observed in historical data on the network for a selected period using standard time-series techniques. Distributions of potential outcomes are derived from a large number of simulations (called stochastic projections) which reflect the random variation in the input.

A stochastic model represents a situation where an uncertainty is present. In other words, it is a model for a process that has some kind of randomness [36]. All stochastic models have the following in common:

- They reflect all aspects of the problem being considered,
- Probabilities are assigned to events within the model,
- Those probabilities can be used to make predictions or supply other relevant information about the process.

To analyze the performance of computer networks is a challenging task. It requires an intimate knowledge of the network system which is analyzed, and a careful selection of the methodology and tools [37]. Statistical modeling tools such as variable distributions, queueing models and Markov models [38] are commonly used for characterizing the behavior of computer networks. Stochastic models are first set up and the performance metrics are then determined. The mostly concerned performance metrics include:

- Throughput refers to the average rate of successful data or message delivery over a communication link or system. It is usually measured in bits per second (bit/s or bps),
- Latency (time) refers to the time delay experienced in a system. The definition may vary depending on the system. It is usually measured in millisecond (ms),
- Delay (time) in a general sense refers to a lapse of time. It is usually measured in millisecond (ms).
- Packet delay (time) variation (PDV) refers to the difference in end to-end delay between selected packets in a flow with any lost packets being ignored,
- Bandwidth metric contains four sub-metrics:
  - Bandwidth capacity,
  - Achievable bandwidth,

-Available bandwidth,

-Bandwidth utilization.

Network failures can occur for a variety of reasons. In most cases, the cause of a failure is accidental. However, network failure caused by deliberate acts or sabotage should not be ignored when planning for all contingencies. Deliberate acts of harm could come from either an external or an internal source, and a disgruntled employee could easily do much harm. The hardware could malfunction causing a network failure, although most key network hardware is duplicated, and this redundancy greatly reduces hardware failure as a source of network failure. Switching devices are operated by computer programs, or software, that is subject to a wide variety of errors, or bugs, when the software was written, ultimately by a human. Thus, even though hardware might be duplicated, usually the same software controls the hardware and thus a single software error could collapse the duplicated hardware. Hardware malfunctions can also affect software and lead ultimately to network failure.

## **Reliability**

Informally, the reliability of a system is the probability, over a given period of time, that the system will correctly deliver service as expected by the user. The term reliability may be applied to almost any item of the system - any device, equipment or component. Network reliability can be defined as the probability that a network will perform its required function over a specific period of time. A network component is said to fail when it ceases to perform its intended functions. Component reliability  $R(t)$  can be expressed as:

$$R(t) = e^{-\lambda t} = e^{-t/\theta} \quad (1)$$

where  $R(t)$  is the reliability or probability of success at time  $t$ ,  $\lambda$  is the expected failure rate per unit time,  $t$  is time and  $\Theta$  is often called MTTF or MTBF is the expected Mean Time To Failure or Mean Time Between Failure for the component. If the time period of interest is reasonably short, MTTF is assumed to be constant [39].

### **Reparability**

System failures are inevitable, but the disruption caused by failure can be minimized if the system can be repaired quickly.

### **Maintainability**

It is important to maintain the usefulness of a system by changing it to accommodate these new requirements. Maintainable software is software that can be adapted economically to cope with new requirements and where there is a low probability that making changes will introduce new errors into the system.

### **Survivability**

It is the ability of a system to continue to deliver service while it is under attack and, potentially, while part of the system is disabled.

### **Error Tolerance**

When errors occur, the system should, as far as possible, detect these errors and either fix them automatically or request the user to re-input their data and solve the problem.

## **Performability**

The perform ability  $P(L, t)$  of a system is a function of time, defined as the probability that the system performance will be at, or above, some level  $L$  at the instant of time  $t$  [40].

## **Testability**

Testability is the ability to test for certain attributes within a system. Measures of the testability will allow assessing the ease with which certain test can be automated and provided as an integral part of the system to improve the testability. Many of the techniques that are so vital to achieving fault tolerance can be used to detect and locate problems in a system.

Reliable communication between some nodes (such as servers, hosts, switches, routers, remote laboratories, etc.) within a maximum permissible cost is a basic consideration in the design of a computer network [34]. The quality of a designed network can be judged by its reliability. The reliability of a network depends upon the reliability of its nodes with stochastic in nature; reliability of the link (transmission media such as cables) used the network topology are assumed to be of high reliability. Redundancy increases the reliability but how many redundant components to be placed is of high important and it is required to product against malicious faults.

Redundancy improves system reliability and availability because it provides alternate paths through the system so that if one fails, there is another that continues operation. However, to achieve the improved reliability, maintainability, or avoiding the degradation in the system may contain an excessive amount or

redundancy. The cost of the extra redundancy will appear in the weight, size, power consumption, volume, and financial costs of the improved system [34].

### **Modeling of perturbation spreading**

A multitude of Internet applications, such as the world wide web, file transfer and remote login, have opted Transmission Control Protocol (TCP) as the transport mechanism. The same mechanism is used in data transfer of REMLABNET. We are using a model of TCP for REMLABNET, it has been proposed for predicting its performance in terms of latency and throughput. Understanding the impact of TCP dynamics on its performance is critical for the optimizing of the network.

For a better understanding of what is happening, we need to clarify the terms Latency (time needed for a packet transfer), Throughput (quantity of data can be sent and received within a unit of time - is how much data successfully travel through the channel), Round-Trip Time (RTT - the time it takes for the traffic to cover both ways) and Bandwidth (is the maximum amount of data that can travel through a channel).

In the Figure 13 is schematically plotted how both latency and throughput work. The network latency expresses how long it takes for the packet sent from a source server to reach a destination server. There are many contributions to the latency, and the latency can actually be different on different directions A to B and B to A. It is necessary to point out what is different between latency and RTT. The round-trip time is how long it takes for a request to be sent from a source to a destination and for the response to get back to the original source. Basically, the latency in each direction, plus the processing time. Processing time is the time from the last packet of the request to the first packet of the response.

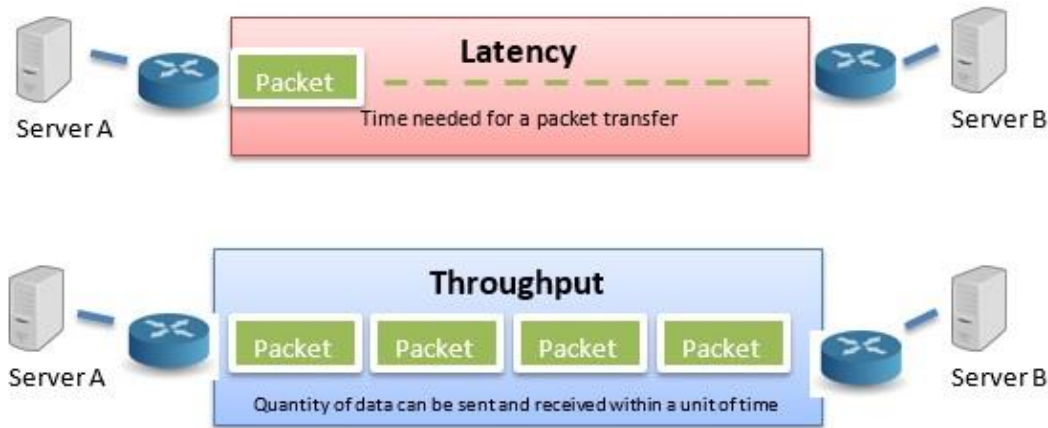


Figure 13 Schematically representation of quantities throughput vs. latency

### *A simple model for TCP Throughput in REMLABNET*

Sometimes, we are experiencing a slow Internet connection, but do not know how we can express its speed, what is the right speed, the download speed and the TCP throughput. This requires the measurement and calculating TCP throughput, which is the speed that the data is successfully delivered over a TCP connection. TCP throughput is bounded by two mechanisms:

- Flow control, where receiving hosts can limit the rate of incoming data to what they are able to process,
- Congestion control, where transmitting hosts limit their outgoing data rate to moderate their negative impact on the network.

Next, the window size ( $W$ ) of the packets of the server A to server B indicates, how many buffer space is available on A for receiving packets. So, when B receives a packet with window size 1, it would tell B how many bytes it is allowed to send to A. For more information you can read in Appendix F.



Throughput formula is:

$$Throughput = \frac{W}{RTT} [\text{bit/sec}] \quad (2)$$

Where Window Size, denoted as RCV buffer size, is the amount of data the receiving host is prepared to accept without explicit acknowledgment and RTT is the round-trip-time for the end-to-end network path. Some literature replace latency for RTT. Formula looks like this now:

$$Throughput = \frac{\text{WindowSize}}{\text{Latency}} [\text{bit/sec}], \quad (3)$$

which gives a slightly different value, because network latency is defined how long it takes for something to be sent from a source host to reach a destination host. There are many components to latency, and the latency can actually be different for A to B direction and B to A. The round-trip time is how long it takes for a request sent from a source to a destination, and for the response to get back to the original source. Basically, to the latency in each direction must be added the processing time.

TCP optimal window size for network bandwidth can be calculated:

$$\begin{aligned} \text{Bandwidth} * \text{Round Trip Time} [\text{bits}] &= \frac{\text{TCP window size}}{8} \\ &= \text{TCP window size} [\text{Bytes}] \end{aligned} \quad (4)$$

An example is in Figure 14.



*Figure 14 Example of calculate bandwidth*

In our example of a 1GE (Giga Ethernet) between two DTCs with 30ms RTT we used and therefore, if we configured our servers for a 3750KB TCP Window size, our connection would be able to fill the pipe and achieve 1Gbps throughput.

#### **4.2.6 Optimization of data collection, saving, backup and archiving**

Cloud backup, or cloud computing backup, refers to backing up the data to a remote, cloud-based server. As a form of cloud storage, cloud backup data are stored in and accessible from multiple distributed and connected resources that comprise a cloud [41].

Cloud backup must enable enterprises or individuals to store data and computer files on the Internet using a storage service provider, rather than storing the data locally on a physical disk, such as a hard drive or tape backup. To update or restore a cloud backup, the clients need to use our services specific to the client application or a Web browser interface. Files and data can be automatically saved to the cloud backup service on a regular, scheduled basis or information can be automatically backed up anytime changes are made.

Creating and storing a backup of data is an important component of a disaster recovery strategy of REMLABNET. It is also important to keep a backup in a remote location (not in the same physical location as the live copy).

An additional option is for the university to use a cloud-based service for offsite backup or data storage. The data would typically be transmitted over the Internet and stored on a remote server managed by itself or the third-party cloud provider. Use of a secure transfer protocol (e.g. Transport Layer Security (TLS)) will ensure that data cannot be intercepted in transit.

To increase chances of recovering lost or corrupted data, disaster recovery of REMLABNET, we follow the 3-2-1 rule [42]:

- 3 – Keep 3 copies of any important file: 1 primary (live) and 2 backups,
- 2 – Keep the files on 2 different media types to protect against different types of hazards,
- 1 – Store 1 copy offsite (e.g., outside home or business facility).

### **4.3 Cloud computing solutions**

The choice of suitable Cloud computing (CC) system serving for REMLABNET and remote laboratories is an important task. The selection of this kind of system is not simple, though in the early stages of the cloud introduction into our systems we were quite advanced in solution of this this problem. All progress of combination of system with RLs into cloud operation may be schematically represented by Figure 15.

Let us describe first the necessary steps in transformation from the system of RLs in its management system (Panel 1) to its embedded form in cloud (Panel 2). Here arise five major questions, when choosing proper CC system.

#### **1. Decide what we want out of a cloud**

Our Consortium is focused on organizational changes, duplication of services, security and management of services. Lucky enough, our cloud is in university environment, but it is otherwise separated from it. At present, the whole cloud setup is separated from the existing RLs, which are connected to the cloud via Internet and proper interface.

## **2. Have realistic expectations**

The trajectory of the designing of the CC is both about technological challenges and also about personnel challenges, as computational processes must be accommodated to the needs of the embedded system, routine tasks must be automated, and standardization introduced.

## **3. Understand workloads and services**

Documentation is the key, without it the relationship among systems is hard to formulate, service-level agreements are unknown, and it is easy to make false assumptions. The needs of the people using REMLABNET should also be documented so that new cloud services can be built to meet those needs

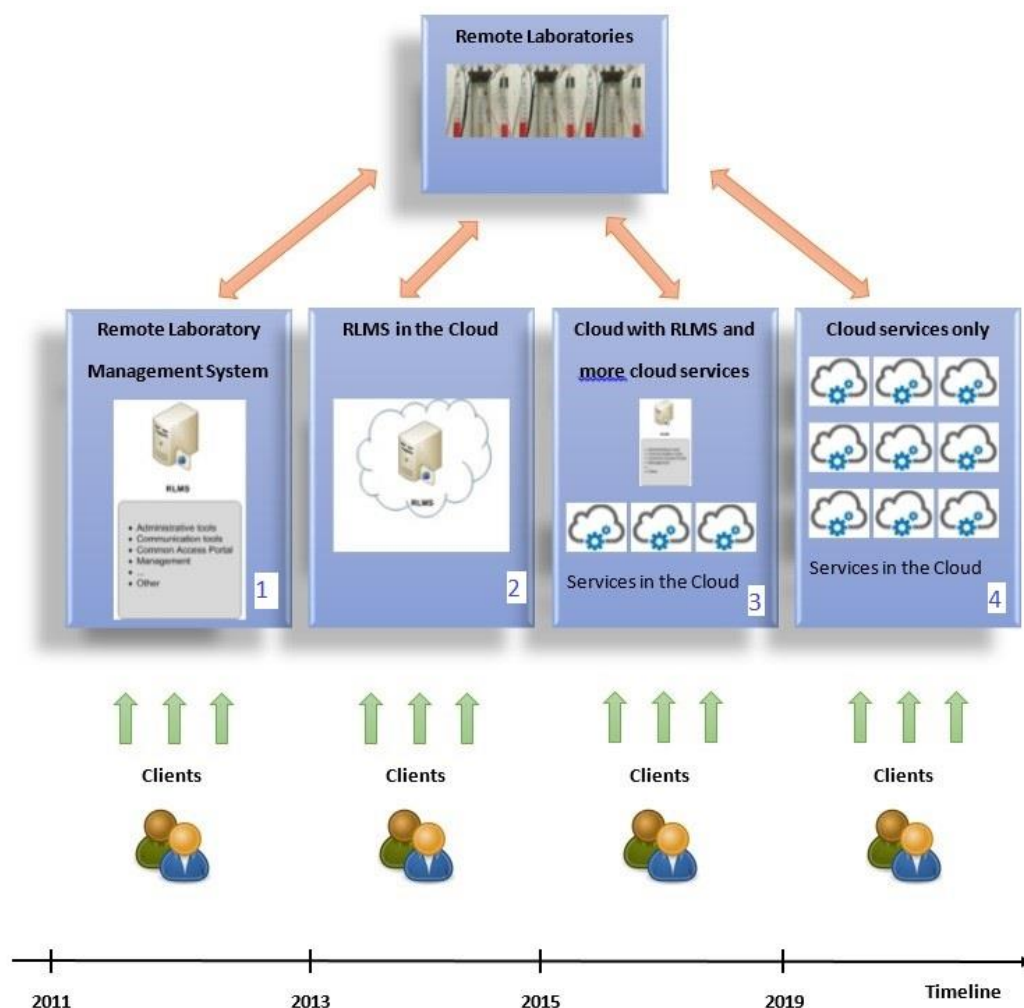
## **4. Get on the path to virtualization**

Virtualization usually drives certain knowledge and behaviors within REMLABNET. For example, centralized data storage should be a building block for REMLABNET cloud, so the knowledge gained in implementing virtualization is very beneficial to our private cloud.

## **5. Understand that standardization and unification go hand in hand**

In the RLs it is very difficult to talk about standardization of RLs systems also as their management systems are based on different platforms. It will be great to accomplish the standardization even on the EU level. Standardization can be also difficult for some organizations that has not practiced it. But once if we take on standardization, the time savings can be enormous.

When we succeed in coping with these five points, we have arrived at the Panel 2 in Figure 15 with embedded RLs and we thus had the ready management system in providing RLs in easy, automated, cheap, scalable system for future application at school and science. Next progress aimed at the services that CC may provide, represented by the transition of the Panel 2 to Panel 3 in Figure 15. They are services, pertinent to creation of infrastructure (IaaS), platform (PaaS) and software providing (SaaS). These are in detail described in chapters 4.4 and 5.4 In Panel 4 there is the scope of services, forced by the improvement of RLs functioning, designed by the team of CC providers. Those services needed for better functioning of RLs are described in chapter 5.5 of results.



*Figure 15 Steps and timeline of REMLABNET and RLs embedding into the cloud*

When we look at the timeline of what was built, we can see the progress in RLs. In the first place, it is obvious that the main functionalities of individual RLs are not changing, but some functionalities, ensured by the cloud, are added. According to the Figure 15 and taken into consideration Figure 16, it is clear, that by alone embedding RLMS into the cloud, we did not gain much and functionalities of the system himself did not change. What was changed substantially, was the security of the whole system, stability and of course the speed of response, which was too slow. This all was caused by the speed of clouds' HW and the way how it was configured and connected to the network.

In Figure 16, there is the timeline development of the individual design steps of the cloud. First, of all, REMLABNET (without cloud) provided functionalities, summarized in chapter 4.1 (Panel/Block 1). In 2013, we started installing cloud computing and placed our REMLABNET in a virtual cloud (Panel/Block 2), providing basic IaaS, PaaS and SaaS (red line) services (Panel/Block 3). Later, we begun creating additional services and options that our cloud might provide, and we built 19 extended options (Table 1, see below in chapter 4.4), of which 15-16 services (green line) are actually usable within RLs. According to our experience, the real interest is only in three, the most commonly used: Remote Laboratory as a Service (RLaaS), Simulation as a Service (SIaaS) and Storage as a Service (STaaS). In total, however, it is possible to launch 26 services within REMLABNET, which clients could use (purple line).

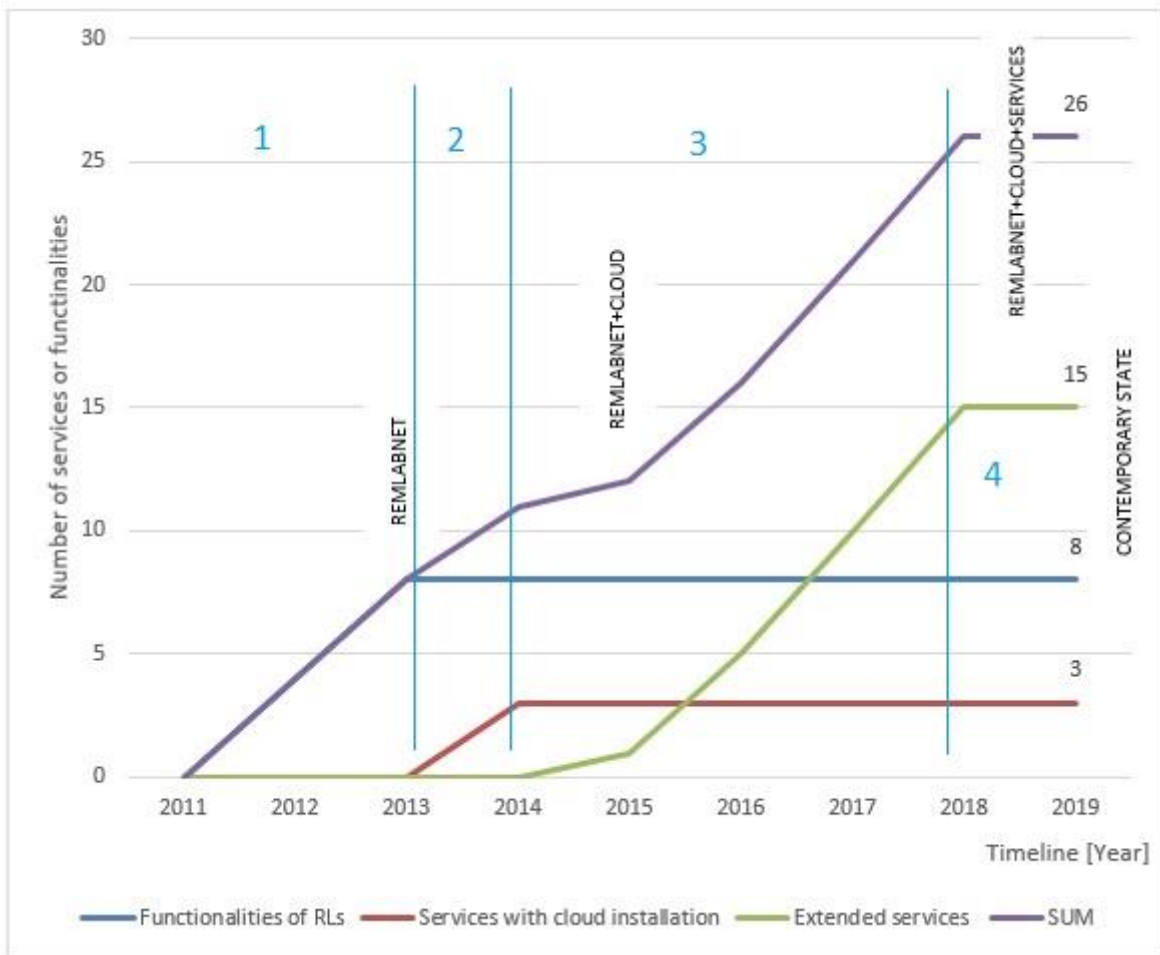


Figure 16 Timeline of introduction of functionalities and services depicted in Figure 15 into REMLABNET

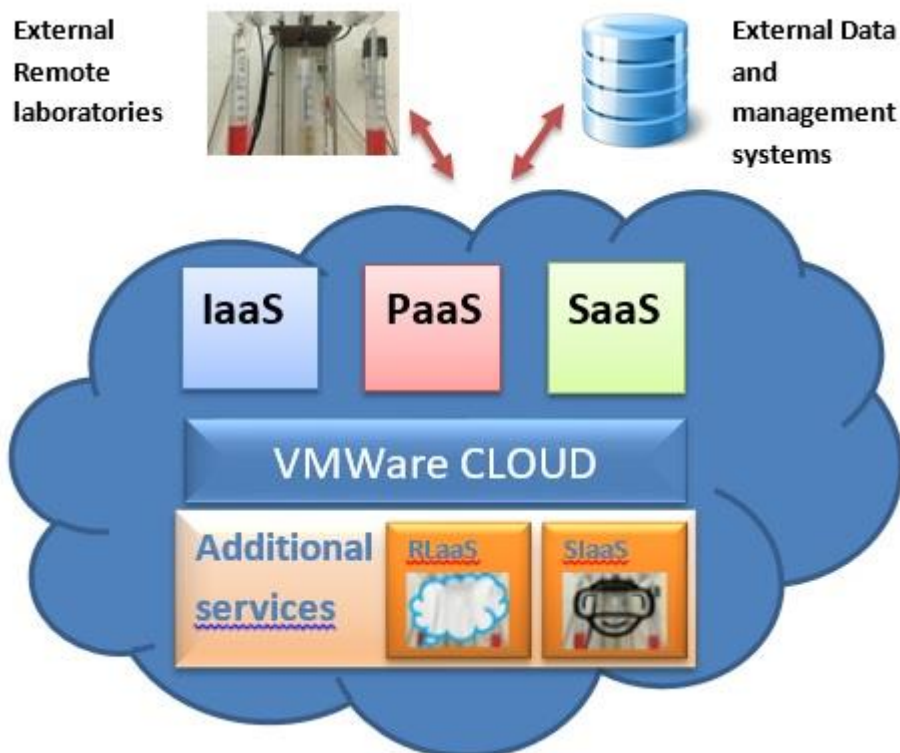
The virtualization and cloud solutions are the main topic of IT technologies nowadays, when servers, networks, disk arrays, individual luns on the storages are being virtualized. The trend touches also the field of RLs (Panel/Block 4 in Figure 16). We have to conclude that at present, the approaches in RLs world community, takes similar trajectory of building RLs, to provide RLs as service [43] - [44].



## 4.4 Remote laboratories and cloud computing services

Let us next describe the basic functions of CC (see Figure 17):

- **IaaS** – Infrastructure as a service is a standard service for providing all infrastructures (services such as storage, networking, servers, virtualization),
- **PaaS** – Platform as a service is a standard service for providing VMs with operating systems (operating systems, middleware, runtime),
- **SaaS** – Software as a service is a software licensing and delivering model in which software is usually licensed on a subscription basis and is centrally hosted. (Data and Applications).



*Figure 17 Cloud Computing concept and Cloud computing services*

Besides, we introduced and designed special services, specific to RLs:

- **RaaS or RLaaS** – Rig or Remote Laboratory as a Service. It is our new concept, where a new service is formed for the cloud computing and for providing a RL called Laboratory as a service (LaaS).
- **SIaaS** – Simulation as a service is a concept for providing science simulations.

Around 2015, there was a tendency to create as much of services for the cloud as possible. This trend has diminished at present, but there are still excessive efforts not only to virtualize everything to get the proper bandwidth, better management and security, as well as to embed Application Programming Interface (API) into clouds. The trend of present era is to utilize cloud solutions whether private, public or hybrid. CC services are summarized in (Table 1), partially present in the last version of Cloud Computing REMLABNET (CC-R). The table shows the services, their examples, and our exploitation in services of CC-R.

Table 1 Possible services in CC

	<b>Service</b>	<b>Abbreviation</b>	<b>Functions</b>	<b>Source</b>	<b>Where we are</b>
<b>Traditional CC services</b>					
1	Infrastructure as a Service	IaaS	Provision virtual machines, allocate storage, set up load balancers and allocate IP addresses.	Catherine, Edwin – A survey on Recent trends in Cloud computing and its application for Multimedia; IJARCET, Vol 2, Issue 1, Jan 2013; ISSN 2278-1323 [45]	Fully implemented
2	Platform as a Service	PaaS	Offer services higher up the application stack with an emphasis	Catherine, Edwin – A survey on Recent trends in Cloud computing and its application for	Fully implemented

			on databases, application servers, Web servers.	Multimedia; IJARCET, Vol 2, Issue 1, Jan 2013; ISSN 2278-1323 [45]	
3	Software as a Service	SaaS	General term for end clients and enterprise software made available to customers over the Web.	Vaile, Kalinich, Fair, Lawrence – Data Sovereignty and the Cloud; UNSW Faculty of Law, July 2013 [46]	Fully implemented
Newly introduced CC services					
1	Storage as a Service	STaaS	Model in which third-party providers rent space on their storage to end users that lack the capital budget and/or technical personnel to implement and maintain their own storage infrastructure.	Joshi, Tikar – Cloud-Computing its Services and Resent Trends; IJCSMC, Vol 4, Issue 2, Feb 2015, pg 136-143; ISSN 2320-088X [47]	Possible, until the level of HW
2	Security as a Service	SECaaS	Specialized SaaS for security, like email server anti-virus, anti-vulnerability scanner, encryption.	Vaile, Kalinich, Fair, Lawrence – Data Sovereignty and the Cloud; UNSW Faculty of Law, July 2013 [46]	We do not provide as service, but is possible to adjust some security services
3	Data as a Service	DTaaS	Provide collect and make available data on a wide range of topic, from economics and finance to social media to climate science	Apurva – Cloud Acronyms Explained; Peoples Soft Tutorial; July 28, 2013 [48]	We provide data through GaaS (see below)
4	Business process as a Service	BPaaS	Providing comprehensive solutions to business processes, such as personnel management, financial management or other forms of	Vaile, Kalinich, Fair, Lawrence – Data Sovereignty and the Cloud; UNSW Faculty of Law, July 2013 [46]	We do not resolve business processes

			operational support.		
5	Test Environment as a Service	TEaaS	Require properly configured servers, multiple client configurations, and well defined test cases run through testing support SW.	Apurva – Cloud Acronyms Explained; Peoples Soft Tutorial; July 28, 2013 [48]	We can adjust ASAP
6	Desktop as a Service	DaaS or TCaaS	Virtual desktop infrastructure (VDI) solutions are available for business that want to implement their own virtual desktops.	Apurva – Cloud Acronyms Explained; Peoples Soft Tutorial; July 28, 2013 [48]	Fully implemented
7	API as a Service	APIaaS	Cross-platform APIs allow cloud tenants the ability to access resources not just from their primary cloud provider, but from others as well.	Joshi, Tikar – Cloud-Computing its Services and Resent Trends; IJCSMC, Vol 4, Issue 2, Feb 2015, pg 136-143; ISSN 2320-088X [47]	Partly implemented, low attention-seeking
8	Rig as a Service	RaaS	New service is formed for the cloud computing and for providing a remote laboratory.	Beňo, Schauer, Vlček. University network with Remlabnet and communication among individual datacenters. Varna, Bulgaria: IEEE Computer Society's Conference Publishing Services, 2014. ISBN 978-1-61804-246-0 [34]	Resolved until the level of creating the core of system, necessary to do the switch between clients and HW of RLs
9	Laboratory as a Service	LaaS	Aims to tackle the common concurrent challenges in remote laboratories developing and implementation such as inter-institutional sharing, interoperability with other	Tawfik, Salzmann, Gillet, Lowe – A model for developing implementing remote laboratories as modular components; REV 2014, Portugal [49]	For now is this form not worked out

			heterogeneous systems, coupling with heterogeneous services and learning objects, difficulty of developing, and standardization.		
10	Remote Laboratory as a Service	RLaaS	New service is formed for the cloud computing and for providing a remote laboratory.	Beño, Schauer, Vlček. University network with Remlabnet and communication among individual datacenters. Varna, Bulgaria: IEEE Computer Society's Conference Publishing Services, 2014. ISBN 978-1-61804-246-0 [34]	Implemented
11	Simulation as a Service	SIaaS	Concept for providing science simulations.	Beño, Schauer, Vlček. University network with Remlabnet and communication among individual datacenters. Varna, Bulgaria: IEEE Computer Society's Conference Publishing Services, 2014. ISBN 978-1-61804-246-0 [34]	Fully implemented
12	Warehouse as a Service	WHaaS	Part of our researched and elaborated data from REMLABNET.	Not publicized before – Beno will work in future	Partly solved, low attention-seeking
13	Network as a Service	NaaS	Out networking, firewalls, related security, etc. from IaaS are listed as a separate Cloud providing – NaaS.	<a href="http://www.service-architecture.com/articles/cloud-computing/network_as_a_service_naas.html">www.service-architecture.com/articles/cloud-computing/network_as_a_service_naas.html</a> [50]	Not solved because of low attention-seeking
14	Big Data as a Service	BDaaS	Can include some of the features of data as well as analytic services to cull information from large volumes of diverse data.	Apurva – Cloud Acronyms Explained; Peoples Soft Tutorial; July 28, 2013 [48]	Not solved because of low attention-seeking

15	Hadoop as a Service	HDaaS	Provide a jump start on big data analysis	Apurva – Cloud Acronyms Explained; Peoples Soft Tutorial; July 28, 2013 [48]	Not solved because of low attention-seeking
16	Grab as a Service	GaaS	Grab system allow us the capture of data, what would not be possible with alone RL. In this way, it is possible to connect onto system, share the measured data	Lecture Beno, Schauer, Komenda - REMLABGRAB – data providing system for remote laboratories extensions building; REV conferences 2019, Bengaluru, India (sadly, the article had not been given to almanac, because of changes we send it after the deadline)	Fully implemented
17	Unified Communication as a Service	UCaaS	Assist clients and remote laboratories in exchanging ideas as well as to effectively	Not publicized before – Beno will work in future	Implemented
18	Diagnostic as a Service	DIAGaaS	Possibility of providing diagnostic tools especially for ISES system	We never published it anywhere	We do not provide, but it is possible to establish diagnostics over RLs
19	Anything as a Service	XaaS	Refers to any feature provided to customers through cloud rather than depending on in-house technologies.	Joshi, Tikar – Cloud-Computing its Services and Resent Trends; IJCSMC, Vol 4, Issue 2, Feb 2015, pg. 136-143; ISSN 2320-088X [47]	Fully implemented

#### **4.5 Remote Laboratories Management Systems federalization in frame of EU**

With time, the trend of RLMSs changed, as Information and Communication Technology (ICT) have evolved. The idea of building individual RLMS changed to

the integration of many RLMS into one, which could serve for the most RLs across the Europe or even World. The reason of this change came from the diversity of individual RLs and the approaches of their owners. Most of RLs and their RLMSs are focused on the specific HW. They allow inclusion of another HW types but in most cases it means limitation of provided features. This situation created ultimate barriers and halted possible integration tendency. Another problem was intention of administrators of RLs, where many of them want to build only their own RLMS.

Also, the definition of the federalization differs from one expert to another. However, the term basically describes a new technological architecture that integrates communication tools so as to allow both individuals and business people to manage all their communication in a single entity rather than separately. We can speak about standardized Unified communications technology (UCT) [51] [52], which integrates communication tools to assist people and remote laboratories in exchanging ideas as well as to effectively do their jobs. The ultimate aim of federalization of remote laboratories is to integrate the SW which supports different communication of RLs, so that at the end the client has an easy access to each of them. With Cloud at the center, we deliver an innovative and secure Unified Communications as a Service (UCaaS) experience, with solutions that unify multiple video from RLs, RLs data, devices and applications networks in one single, easy-to-use platform that allows RLs providers to collaborate efficiently – anytime, anywhere.

REMLABNET provide global "principles" of federalization using cloud technologies. In relationship to the clients' interests they form the core component of our philosophy of building RLs. Federalization is bringing a globalization, conducting RLs within and across diverse cultural and social settings, with diverse values, morals and ethics of Countries of EU.

## **5. RESULTS OF THE THESIS**

In the following chapter we present the findings and results obtained from the thesis research. All results are organized to subchapters 5.1 -5.5, corresponding to those 4.1-4.5 in the Chapter 4 - Methods used. In 5.1 we describe obligatory steps, taken with respect to our main object of interest, management system for RLs REMLABNET, when embedding it into the Cloud. In 5.2, devoted to Security, we deal with all the steps taken to achieve the required for the REMLABNET needed state of the security. We have to take the steps to increase security in few areas, like main REMLABNET, servers, network, communication lines and Users (or the clients), their personnel records and privacy, and, last but not least, we must cope with the corresponding legislative in the European Union (EU) and in the Czech and Slovak Republics. In 5.3, devoted to cloud computing solutions, we deal with the necessary and obligatory steps taken for embedding the REMLABNET into the Cloud. In 5. 4, devoted to the introduction of new cloud computing services, induced by the special features of RLs and their management. In 5. 5, devoted to Federalization, especially with the work, towards mutual binding of RLMS systems of Go-Lab and REMLABNET.

### **5.1 REMLABNET functions – choice of cloud SW and its optimization**

Besides general requirements on both management system of RLs and cloud given in paragraph 4.1 and 4.3, we have an extensive list of points to be fulfilled for proper functioning. Next, we summarize our results of changes on the REMLABNET running on standalone server in Zlin in 2012 when transferred to its cloud version running in Trnava network.



### 5.1.1 Cloud and the RL functions

Each Cloud Computing API project has its own peculiarities, and our REMLABNET as well. Here are five essential characteristics of our cloud:

- **On-demand self-service:** The client of REMLABNET expects he/she can unilaterally obtain computing capabilities, such as server time or network storage, and the results of data mining from RLs, automatically, without requiring human interaction,
- **Unhampered network access:** The facilities are available over the Internet and accessed through standard mechanisms,
- **Resource pooling:** The resources are pooled to serve multiple consumers, with different physical and virtual resources, dynamically assigned and reassigned according to clients' demand. The client generally has no control or knowledge over the exact location of the provided resources (geographically separated DTC),
- **Rapid elasticity:** Facilities can be elastically provisioned and released, in some cases automatically, to scale rapidly outward and inward commensurate with demand. To the consumer, the facilities available for provisioning often appear to be unlimited and can be appropriated in any quantity at any time.
- **Measured service:** Cloud system REMLABNET is automatically controlling and optimizing resources, uses metering facility at some level of abstraction appropriate to the type of service. Resource usage can be monitored, controlled and reported, providing transparency for the administrator and consumer.

### 5.1.2 Suitability of cloud software for the Remote Laboratories

Cloud computing helps to be more efficient and save on SW and HW, compared to standalone version, important for its proper functioning [53]. The private cloud and its infrastructure requires the existence of the hypervisor, which is the part of the private cloud that manages the virtual machines, i.e. it is the unit (program) that enables multiple operating systems to share the same hardware. Each operating system could use all the hardware (processor, memory) if no other operating system is on.

There are two types of hypervisors (Figure 18):

- Type 1 hypervisors run directly on the system hardware – A “bare metal” embedded hypervisor,
- Type 2: hypervisors run on a host operating system that provides virtualization services, such as I/O device support and memory management.

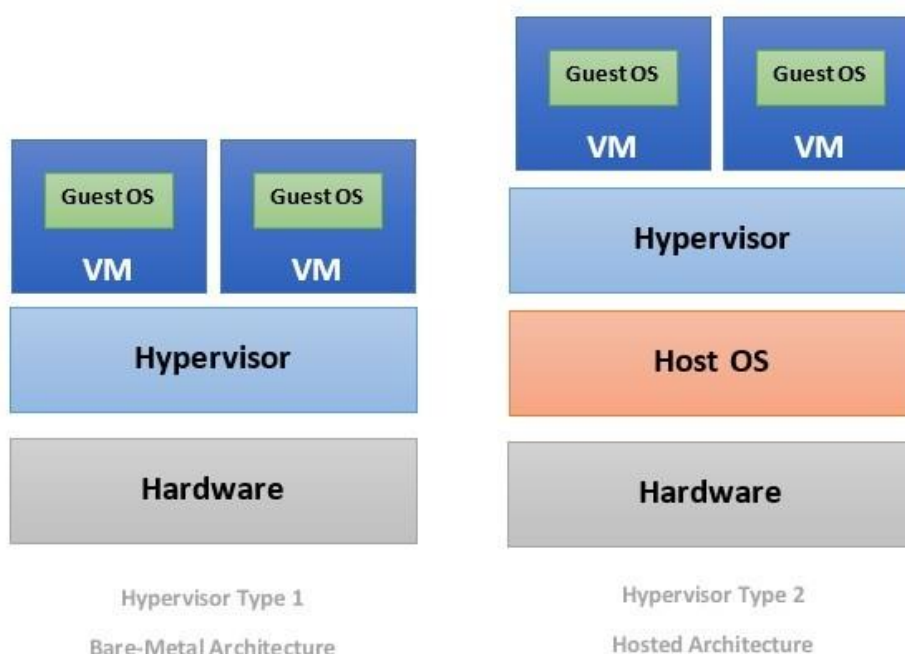


Figure 18 Two types of hypervisors

We had to carry out the comparison of suitable cloud SWs on the basis of their features and hardware requirements. First, we had to decide what kind of cloud solution to choose. There are several options that vary in more than just the kind of hypervisor they use. First of all, we had to decide whether to use the paid version or to use the free version. Within the university environment, this is more difficult question, since the paid versions for the university sector are substantially cheaper than the commercially provided versions. However, since we did not have any funding at the time, we decided to test the free versions of Citrix and later OpenStack. Open Stack seemed to be a better solution for REMLABNET embedding, but it deterred us for the enormous amount of coding and scripting for proper functionality. It was not about quality of SW, but we quit the SW because it was time consuming for us especially when our environment was built during full time job. So, we get our hands on, at that time not paid, version from Huawei, Fusion server. Around this time the Trnava University in Trnava had bought data stores by named company and so in frame of that, they can install SW free. It was more elegant and better functioning environment as OpenStack. As the licensing policy Huawei had then changed, we had to reconsider our decision, consider paid version and search for funding. The help came from the framework of the European Structural Funds, we became a part of the OPVaV-2013 / 5.1 / 05-SORO project with a total of about 2 mil EUR from which we could buy servers, disk arrays, required SW and other necessary infrastructure. The project was tied to Trnava University in Trnava, but since we already possessed virtual servers there, I became the manager of it all. This opened the way for a well-built cloud solution, where we could also buy paid SW versions. Therefore, before the purchase we made an evaluation on fully-valued versions, and we tested Microsoft HyperV and VMWare ESXi Server whose comparison is in Table 2.




Table 2 MS HyperV and VMWare comparison







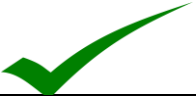
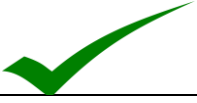
	<b>Maximum number of realization and accessibility</b>	<b>HyperV 2012 R2</b>	<b>VMWare 5.5</b>
<b>Host</b>	Logical Processors	320	320
	Physical Memory	4TB	4TB
	Virtual CPUs Per Host	2048	4096
<b>VM</b>	Virtual CPUs Per VM	64	64
	Memory Per VM	1TB	1TB
	Active VMs Per Host	1024	512
<b>Cluster</b>	Maximum Nodes	64	32
	Maximum VM	8000	4000
<b>Security</b>	Includes Anti-virus / Anti-malware protection	YES	YES

<b>Capability</b>	iSCSI/FC Support	YES	YES
	Network File System Support	YES (SMB 3.0)	YES (NFS)
	Virtual Fiber Channel	YES	YES
	Storage Virtualization	Yes (Spaces)	Yes (vSAN)
	Storage Tiering	YES	YES

It was rather difficult decision according these parameters. But when we compared harmonization and block-by-block conditions comparison (Table 3), the choice was clear.

Table 3 Harmonization choice and block-by block comparison of vCloud Suite vs. MS Windows Private Cloud

<b>Accessibility</b>		VMWare vCloud Suite	MS Private Cloud
Core Cloud Platform	Core virtualization		FT servers or SW
	Director and Connector		

	Automated DTC level DR planning, testing and execution		3rd party e.g. Weeam Backup and Replication
Cloud Networking and Security	SW defined networking, security		3rd party virtual distributed switch and load balancer
	Firewall and network availability		
Cloud Operations Management	Performance monitoring, Capacity planning and optimization		3rd party performance monitoring
	Chargeback management		3rd party chargeback
	Infrastructure navigator		

According to all criteria, VMware was a better solution for x86 server virtualization. Also, VMware feature set, reputation, and pricing all reflected that choice. As already mentioned, the REMLABNET Consortium was oriented on participation in projects that provided the HW and SW needed to build cloud technology. It is necessary to point out that REMLABNET and all its parts, even if they are located at Trnava University. However, both of them are positional/separately distributed. REMLABNET possesses a decent computing power with plenty of storage space and should have well-secured security. For this reason, the situation allowed to concentrate exclusively on the proper choice of user friendly and technologically advanced SW. At that time the cloud HW was already available, compiled after long consultations with the representatives of Cisco

Company both in the Bratislava branch and headquarters in USA. We concentrated on the middle price components of the series Unified Computing System™ (UCS). For this we will here concentrate only on the choice of the most suitable SW focused the only application – REMLABNET.

In the process of choice the proper SW, we went through a demanding process, testing several SW packages, both free and paid, with the Bare-metal hypervisor and Hosted architecture, and especially with various HW applications. After all this testing it turned out as a probably the most fitting SW a VMWare vCloud produced by VMWare (the details of the SW are to be found in [54]). Let us shortly present SW. The VMWare vCloud SW combines a vCloud Director server group with the vSphere platform. We set up a vCloud Director server group by installing vCloud Director SW on the first two dedicated servers, connecting the servers to a shared database, and integrating the vCloud Director server group with vSphere. Our cloud architecture contains a vCloud Director server group comprising of two servers. Each server can run the collection of services called a vCloud Director cell. Servers in the group share a single database. The group connects to multiple vCenter servers and the ESXi hosts that they manage. Each vCenter server connects to a vShield Manager server. The vSphere provides storage, compute, and networking capacity to vCloud Director, our starting information was the quality and capacity of vSphere and vCloud Director we needed and plan a configuration that can support it.

As to setup of the new Cloud, each server in a vCloud Director server group must meet certain HW and SW requirements and limitations. Each server group requires access to a vCenter server, a vShield Manager server, and one or more ESXi hosts.

Further, we will deal with individual steps of new cloud installation:

1. In the installation process itself we must first configure a network IP addresses - Each vCloud Director server requires two IP addresses, so that it can support two different SSL connections and one connection for the HTTP service, the second is for the console proxy service. Using command *#ip addr add*.
2. Next comes just alignment of the world time. Network Time Service – *ntp.truni.sk* to synchronize the clocks of all vCloud Director servers, including the database server, with the requirement of maximum allowable drift among the clocks of synchronized servers is 2 seconds.
3. Then we must allocate hostname to the new cloud. The hostname must be resolvable by DNS using forward and reverse lookup of the fully qualified domain name or the unqualified hostname. *#nslookup remlabgrab.truni.sk 193.87.54.10*.
4. Transfer Server Storage - To provide temporary storage for uploads and downloads, an NFS or other shared storage volume we must create accessibility to all servers in a vCloud Director cluster. Real way is: */opt/vmware/vcloud-director/data/transfer*
5. Next, we had to install Microsoft SQL Server Database for vCloud Director. A database server is configured with 12GB of memory, 80GB storage, and 4 vCPUs.



*Ex.: CREATE DATABASE [remlabgrab] ON PRIMARY(NAME = N'remlabgrab', FILENAME = N'C:\remlabgrab.mdf', SIZE = 100MB, FILEGROWTH = 10% )LOG ON*

We set the transaction isolation level, created user account and assign permissions to the vCloud Director database user account.

6. Create SSL certificates – system is configured to use SSL coding to secure communication among clients and servers. For example here is untrusted certificate: *#keytool -keystore certificates.ks -storetype JCEKS -storepass passwd -genkey -keyalg RSA -alias http*
7. Next step is in creating a vCloud director server group and connect it to the database.
8. The last installation step was to solve the database connection. We used to use Microsoft SQL Express edition at the beginning, but later, because of the capacity and absence of tools, we bought Microsoft SQL Standard edition, which solved most of the problems.

Also, every installation was not without problems and we met the following:

1. *Timed out while connecting to the cloud* – the problem was in DHCP server. Problem was removed by admin after restart DHCP server.
2. *An error occurred in the cloud: createVapp: The operation failed because VirtualCenter "vCenter-5.0" is not connected* –. We connected the virtual center to the vCloud Director instance.
3. *Error in vCloud: The parameter is not supported in the current context: AdminPassword* - The administrator password was replaced with a randomly

generated password. The solution was, we had to shut down VM and click the Guest Customization tab in *Properties*. Deselect Allow local administrator password helped as well.

## **5.2 Security and reliability optimization of REMLABNET**

With the increasing cyber-attacks in recent years, we started focusing on security features of SW RLs and REMLABNET applications. Despite attentive efforts towards the development of safe and secure SW applications our and commercial SW products did not possess necessary security aspect or features. Thus, it has become essential to explore each and every vulnerable area present in the application which may invite and provide opportunity to hackers and crackers in exploiting the REMLABNET.

The following chapter of Security of our CC for embedding of REMLABNET complies with the chapter 4 of working methods. Because Security is both a wide branch, we distributed results of Security into both specific steps taken and general precautions common to all IT applications. For that reason, we omit next general steps towards increased Security and will devote to Security steps pertinent to RLs and their management system REMLABNET.

The layout of the chapter is following. First, in 5.2.1 we undertook several sorts of Penetration testing that brought information about the ability of the system to suppress illegal intrusions. Second, in 5.2.2 we tested stability influence of embedded REMLABNET. Then, in 5.2.3 we deal with the utmost important issue of RLs' data protection. Then in 5.2.4 we optimized the Cloud system for the embedding of the REMLABNET and its optimal function with the result of the reasonable HW. In the last subchapter 5.2.5, we present optimization results of the data collection, saving, backup and archiving.

### 5.2.1 Penetration testing

With reference to Methods used in chapter 4.2.1, PT is one of the useful testing methodologies to identify and reveal vulnerable areas of each system, which may provide free passage to number of unauthorized and malicious users or entities for intruding, attacking and compromising the REMLABNET integrity and veracity. Penetration testing of any system may be carried out using any of the following approaches:

- Manual Penetration Testing,
- Automated Penetration Testing,
- Mixed Penetration Testing.

Each of the approaches can be used and is the choice is only up to the tester, so we choose Mixed PT. The reason was, another approach appeared as dictated by someone who created the test application and because the human factor is completely decisive in discovering the vulnerability. We decided to use the following methods for PT (due to excessive length of the text in the main part of the thesis is published only test 1 and remaining test are in Appendixes B, C, D and E):

- Network service penetration test (see next text and Appendix B),
- Social engineering penetration test: it examines the confidence of clients to provide personal data by phishing (Appendix C),
- Web application penetration test: it examines vulnerability of the application (Appendix D),
- Cloud penetration testing: it examines the reliability of the special features of cloud (Appendix E).

Next, let us present a simple example of network services testing, using the *nmap* utility, while it is excessively used.

We use the *-PS* switch which customizes the TCP pings send by *nmap*. Then we selected a range of my popular ports which are usually open on remote hosts (Figure 19)

```
root@kali:~# nmap -PS21,22,23,80,443,3306,3389 remlabgrab.truni.sk
Starting Nmap 7.70 ( https://nmap.org ) at 2019-08-05 10:36 CEST
Nmap scan report for remlabgrab.truni.sk (10.33.16.250)
Host is up (0.00062s latency).
Not shown: 966 filtered ports, 30 closed ports
PORT      STATE SERVICE
21/tcp    open  ftp
22/tcp    open  ssh
80/tcp    open  http
443/tcp   open  https
MAC Address: 00:50:56:90:57:2B (VMware)

Nmap done: 1 IP address (1 host up) scanned in 4.11 seconds
```

*Figure 19 nmap test of ports*

The command above will do host discovery by sending TCP SYN packets to ports 21, 22, 23, 80, 443, 3306 and 3389.

We always sent the results of the scan to a file in the following form

```
#nmap -PS 21,22,23,80,443,3306,3389 remlabgrab.truni.sk-oA
discoveredhosts remlabgrab.truni.sk
```

The above will create 3 files (with name “discoveredhosts”) in TEXT format, XML format and GNMAP (Grepable) format. Next, I use a linux command (awk) to create a clean list of live IP addresses from the gnmmap file created above (figure 20).

```
root@kali:~# awk '/open/{print $2}' discoveredhosts.gnmap > liveIPAddress.txt
root@kali:~#
root@kali:~# cat liveIPAddress.txt
10.33.16.250
root@kali:~#
```

*Figure 20 awk command to create list of IP*

The awk command will search through the gnmap file for “open” ports (which means the host is alive) and send the IP address of live host to the text file “liveIPAddress.txt”. The switch {print \$2} sends the 2<sup>nd</sup> field in the gnmap file which is the IP address of the live host. The result is a list of live IP addresses (one per line, only one in our case, but we use it later). Now we will use the list above to perform full port and service scanning.

We can replace remlabgrab.truni.sk with its IP address and assuming that it uses Class C of IP addresses, commands can look:

```
#nmap -PS21,22,23,80,443,3306,3389 remlabgrab.truni.sk -oA  
discoveredhosts 10.33.16.0/24
```

```
#awk '/open/{print $2}' discoveredhosts.gnmap > liveIPAddresses.txt
```

```
# cat liveIPAddresses.txt
```

Where we found 115 live addresses. Which of the safety reasons we do not mention. These IPs are stored in the text file liveIPAddresses.txt one by one. Our next task is to execute full port scan and service scan to the live hosts (we use REMLABGRAB only). The full scan now will run on ALL ports of the hosts so that we’ll discover additional services running on the targets. The complete command is:

```
#nmap -p- -Pn -sS -A -iL liveIPaddresses.txt -oX fullscan.xml -oN fullscan.txt
```

Of course, if we used the live IPaddresses.txt file, we would scan all live IP addresses in the list. The switches I used mean:

-p- = This switch scans all 65535 ports.

-Pn = Disable host discovery. Port scan only.

-sS = TCP SYN port scan.

-A = Detect both Operating Systems and Services.

-iL = Scan from the list of IP addresses in the text file.

-oX = write results of scan to XML file (useful for importing into NESSUS).

-oN = write results of scan to normal TXT file.

Up to here we will have a good idea of the target network, services running, operating systems etc. Depending on the results we might perform further analysis using NMAP scripts. The XML file of the scan results above (-oX) can be imported into NESSUS which is another excellent tool for vulnerability analysis and much more.

Although NESSUS has its own port scanning functionality, importing NMAP results might be better since nmap is dedicated to port scanning and does a better job in this area in my opinion. But this exceeds the scope of the present work.

### **5.2.2 Communication quality of REMLABNET**

One of the important aims of the present thesis was to create from RLMS REMLABNET and clients on one hand and remote laboratories on the other, the informatics system with the least possible communication failures. Our efforts then were to interconnect more Remote Laboratories and clients in a reliable way to

support calm and flawless educational and research process. The main need was to eliminate the failure immediately after it occurred and do not allow its spreading into cooperating systems (see chapter 4.2.5). For this purpose, categorization and elimination of the failure is very important to be defined first, especially in the context of the connectivity globally. It should be strictly prohibited to allow the failure to move within one system from one node to the other, described in [55] [56] [57]. In this respect, research and educational institutions are especially vulnerable, requiring following measures:

- Categorization of the failure,
- Improve communication among users and RLMS,
- Improve communication among remote laboratories and RLMS,
- Identification of the failure in the network interfaces and possibilities of their spread,
- Elimination of generate and spread failures.

Mentioned requirements call for several subsequent steps to be introduced. First, it is the introduction of the verification of the communication rights between client and RLMS. This will be accomplished by SW authentication and authorization server. Second, of the utmost importance is a fast identification and categorization of the failure in system. This step, enormously important, is difficult to be solved by one precaution, due to the wide range of failure sources and their inborn properties, spanning from the grid failure to a human attack on the system. Third, it is necessary to introduce solutions preventing excessive failure spreading, not limiting the flux of working data. Fourth, to find for every category of failures its optimum healing method, automatized if possible. All four steps mentioned must be carefully predesigned and discussed with the specialists in the security and communication field and inserted into the system project. On top of this, all these

steps should be continuously supervised during the system functioning and even online modelling.

Simulation of the university network, as another tool, is very time demanding and very long time is spent to achieve significant results. For our requirement we simulate communication between DTCs and DTCs to remote laboratory because this part is a key component of this work. Communication with each experiment is important but failure on this part of the network aborts only one from few RLs.

Very good program for the simulation of possible problems is Packet Tracer (PTR) from Cisco Company [58]. This was an ideal tool for us (we were trying more), because we were working with Cisco technology in our network and PTR has a database with devices, technologies and resources similar to ours. Every device has configuration wizard or my favorite command line interface (CLI). For this moment we specified two parts for simulation

- Failure of the physical link
- Failure of the network devices

### **Failure of the physical link choice and configuration of the transfer protocol**

Main simulation rests in unplugging active port from connectivity and waiting for network responses. One of the aspects of availability is the ability of the network in quick adaptation process on the failure of the transmission line. This quick convergence of the network is result of the work of the routing protocols. We were testing two of these protocols, suitable for our network from the point of view of (format) size and structure: Open Shortest Path First (OSPF), and Routing Information Protocol (RIP).



For our measurement (Table 4) we were intrigued mainly with comparison of behaviour of throughput (Figure 21, Graph 1), end-to-end delay (Figure 21, Graph 2), packet loss (Figure 21, Graph 3) and convergence time (Figure 21, Graph 4).

Table 4 Comparison of the routing protocols

		Rip v2	OSPF
Throughput	Packet Size		
	2048	1200Mbps	1190Mbps
	1024	860Mbps	840Mbps
	512	320Mbps	350Mbps
End-to-end delay [s]	Bandwidth		
	2Gbps	0.024	0.028
	1Gbps	0.041	0.057
	100Mbps	0.048	0.063
Packet loss [%]		0.24	0.29
Convergence time [s]	No. of nodes		
	3	39	57
	4	42	64

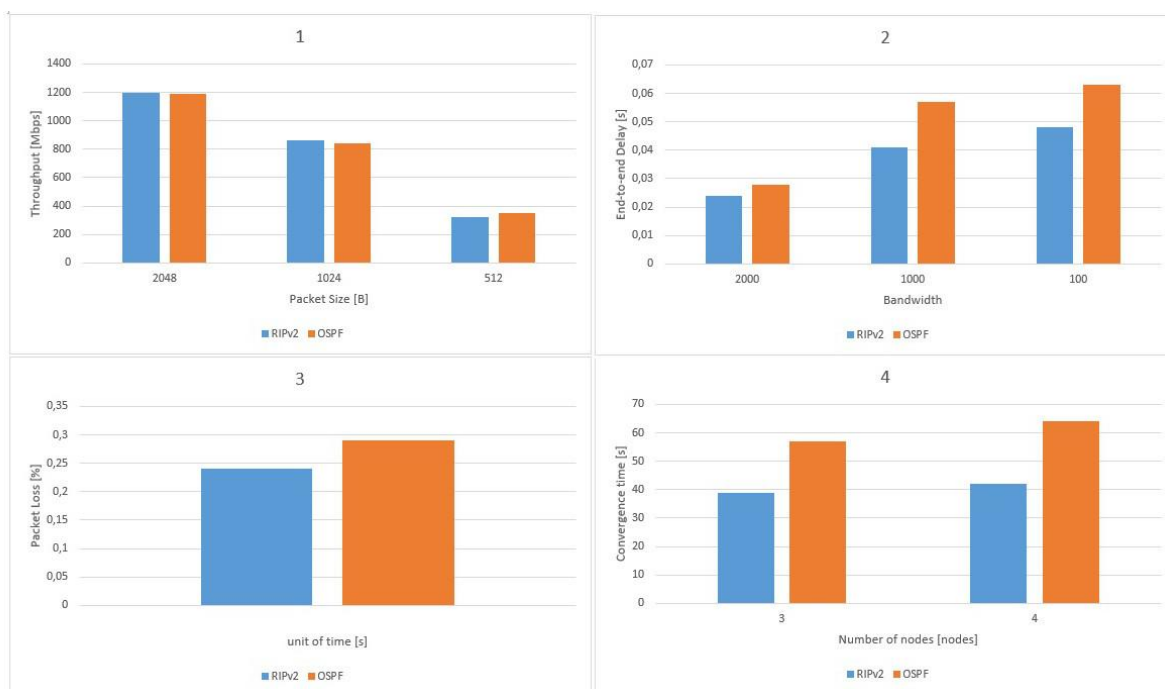


Figure 21 Compare of the routing protocols RIP and OSPF

We came to the conclusion that RIP v2 is better for sensitivity for the failure and so we are using it. In the Table 5, there is a segment of the configuration of our routers.

Table 5 Segments of routers configuration of the RIP protocol (left side is CORE, right side is AA distribution switch)

<pre>interface GigabitEthernet2/5 description Adalbertinum switchport trunk encapsulation dot1q switchport trunk allowed vlan 2,8,16-18 switchport mode trunk udld port disable channel-group 8 mode active ! interface GigabitEthernet2/6 description Adalbertinum switchport trunk encapsulation dot1q switchport trunk allowed vlan 2,8,16-18 switchport mode trunk udld port disable channel-group 8 mode active ! router rip</pre>	<pre>interface Port-channel8 description truni-ff-s1-rck2-c4503 switchport switchport trunk allowed vlan 2,8,15-18 switchport mode trunk ! interface GigabitEthernet3/3 description truni-ff-s1-rck2-c4503 switchport trunk allowed vlan 2,8,15-18 switchport mode trunk channel-group 8 mode active ! interface GigabitEthernet4/3 description truni-ff-s1-rck2-c4503 switchport trunk allowed vlan 2,8,15-18 switchport mode trunk channel-group 8 mode active</pre>
---	--

<pre> version 2 redistribute connected passive-interface default no passive-interface Vlan5 no passive-interface Vlan6 no passive-interface Vlan7 no passive-interface Vlan8 no passive-interface Vlan9 network 10.0.0.0 no auto-summary !</pre>	<pre> ! router rip version 2 redistribute connected passive-interface default no passive-interface Vlan8 network 10.0.0.0 no auto-summary !</pre>
--	---

### **Failure of the network devices**

Next step in the simulation of failure of our network with RLs is a failure of at least one of the network devices. For this purpose, we can use our redundant connectivity on the gateway. Cisco has a protocol HSRP (Hot Standby Router protocol), which serves for connectivity of all nodes on the network, if default gateway is down. This technology was standardized by the IETF organization with the name VRRP (Virtual Router Redundancy Protocol) similarly to the standard technology in the router redundancy. We have two default routers. The first one is active, while the second is passive in standby mode. Passive router monitors current functionality of the active router with the use of hello packets. If functionality of the active router goes down, passive router compensates this functionality. Passive router has the same virtual IP address and responds with Media Access Control (MAC) address on Address Resolution Protocol (ARP) query. Connectivity is renewed with converge of the protocol STP (Spanning Tree Protocol). This is displayed in the Figure 22, where we are using Packet Tracer, simulation tool by Cisco. We can also separate end nodes into two groups. Each group will have different active and passive default gateway. This was a good way for load balancing between both routers.

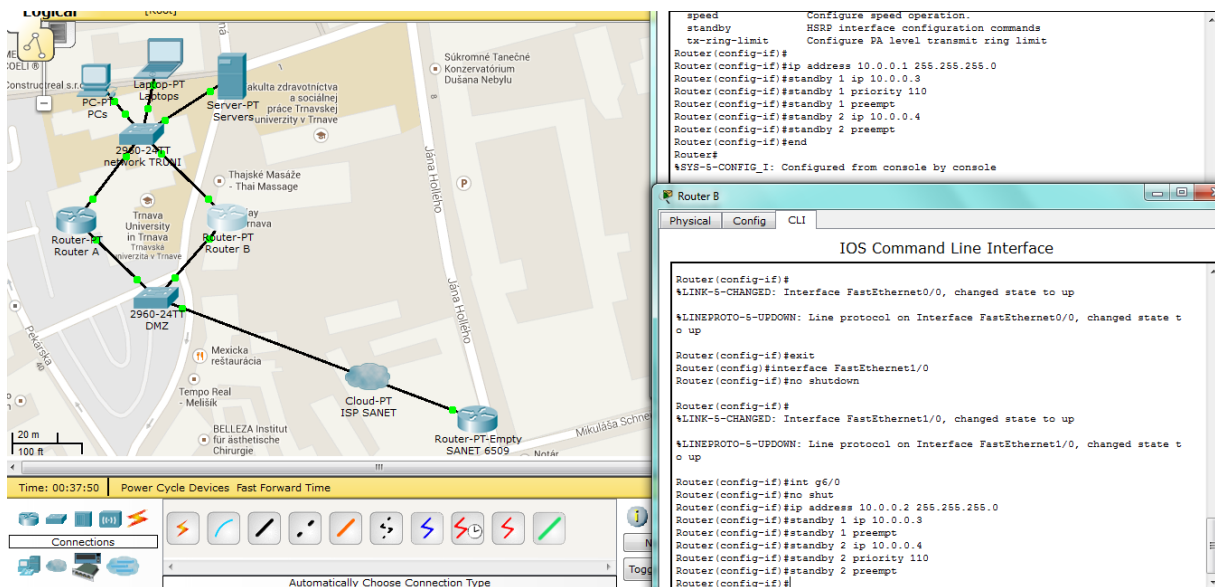
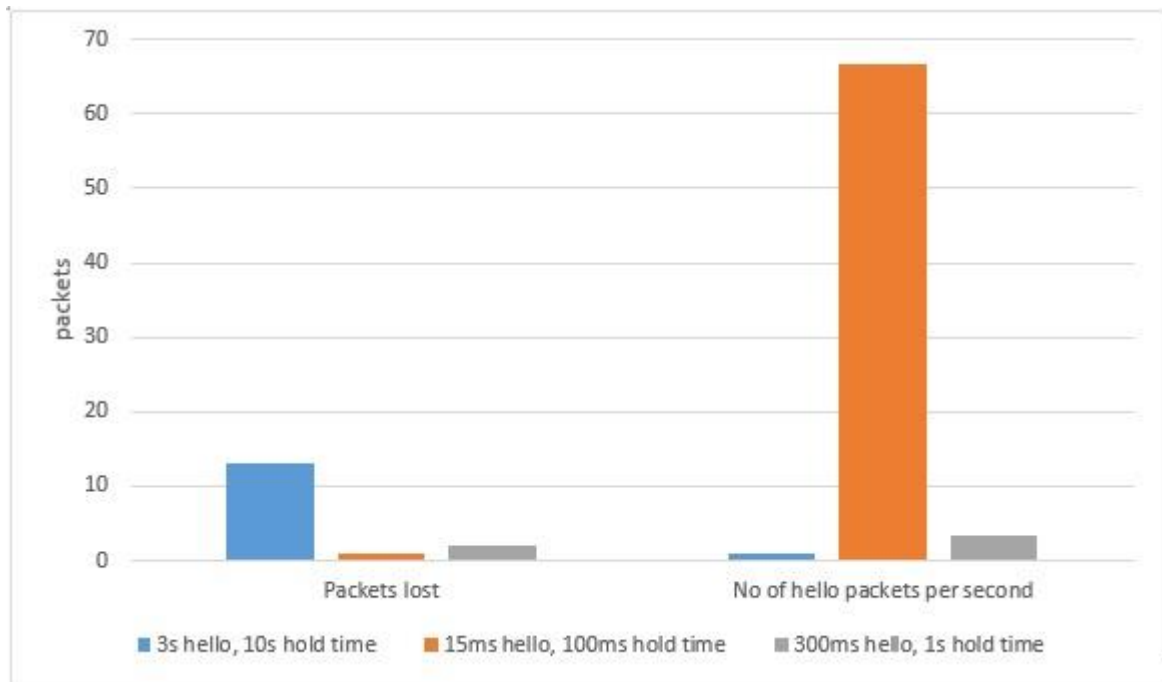


Figure 22 Gateway redundancy and configuration with command line interface (CLI)

A ping tool test is sufficient to verify HSRP. In the first step, we verified the client PC in the network, which is connected through a common switch and trying to fix the gateway ping. The router shutdown is currently in use during the test. This was one with the default HSRP timer settings (3 sec hello packet and 10 sec hold time). Using this timer results in a long downtime, but low link load (Figure 23). Now let's try to achieve a minimum down time. We will use exactly the same method but set the timers to 15ms hello packet and 100ms hold time. Here we managed to achieve a single packet loss. But the problem was that more than 60 hello packets were sent every second, with 92Bytes each. In the third step we set the timer to 300ms hello packet and 1 second hold timer. The loss went around to two lost packets, sending about 3 hello packets per second.



*Figure 23 Test of the HSRP - use different value of timers*

Our simulations on the PTR showed possibilities with using gateway redundancy. Without simulating parts how it was, we could never try this on the real network, because all configurations had to be without failures. PTR is great simulating tools, because it has possibility with real configuration how is on the real routers.

### **Monitoring of the communication**

Communication monitoring was accomplished by the help of four systems for measurement and evaluation of the failure and attenuation:

- EXFO FTB 931 – this is a direct method for the measurement of attenuation change,
- EXFO FTB 200 + net blazer – for the measurement of transmissivity of the transmission lines,

- MLS-50A – this is a permanent measurement of the network for the attenuation and evaluation of fiber optic lines,
- Reflectometer DRB 200 + FT7300 – this is a distance measurement of the attenuation point on the transmission lines.

The failure measurements were the key point of our work with the cloud, because it was crucial for monitoring, finding, analyzing, evaluating and providing communication for REMLABNET system. In the Figure 24 is schematically shown, how the experiment was designed. After installation of CC-R the communication was flawless, but after the installation of the REMLABNET we found enormous power cuts on network interface between two DTCs, which subsequently caused instability of communication processes. Subsequently the communication dropouts, well observed on the active parts and visible on CLI of the routers, were discovered. Thus, the problem was on the network level, and it constituted a remarkable problem. With a hired instrumentation (EXFO FTB 200 + net blazer, producer EXFO) we started the measurement as shown in Figure 24a. We discovered, that the attenuation of communication is on the level of 4.11dB (Figure 24b), which is too much for communication bandwidth 1Gbps FO fiber. With the help of FTB 200, we discovered following problem, which rested in the SFP modules used, built for greater power (distance coverage). Then, in our configuration overload and the attenuation occurred, caused the excess attenuation. For checking the hypothesis, we made the attenuator by ourselves from the patch cord, we simply wrapping the optical fiber in a coil, to create the attenuator. The hypothesis was affirmed, increasing the excess attenuation, the total attenuation of optical path has decreased to 1.11 dB (Figure 24c).

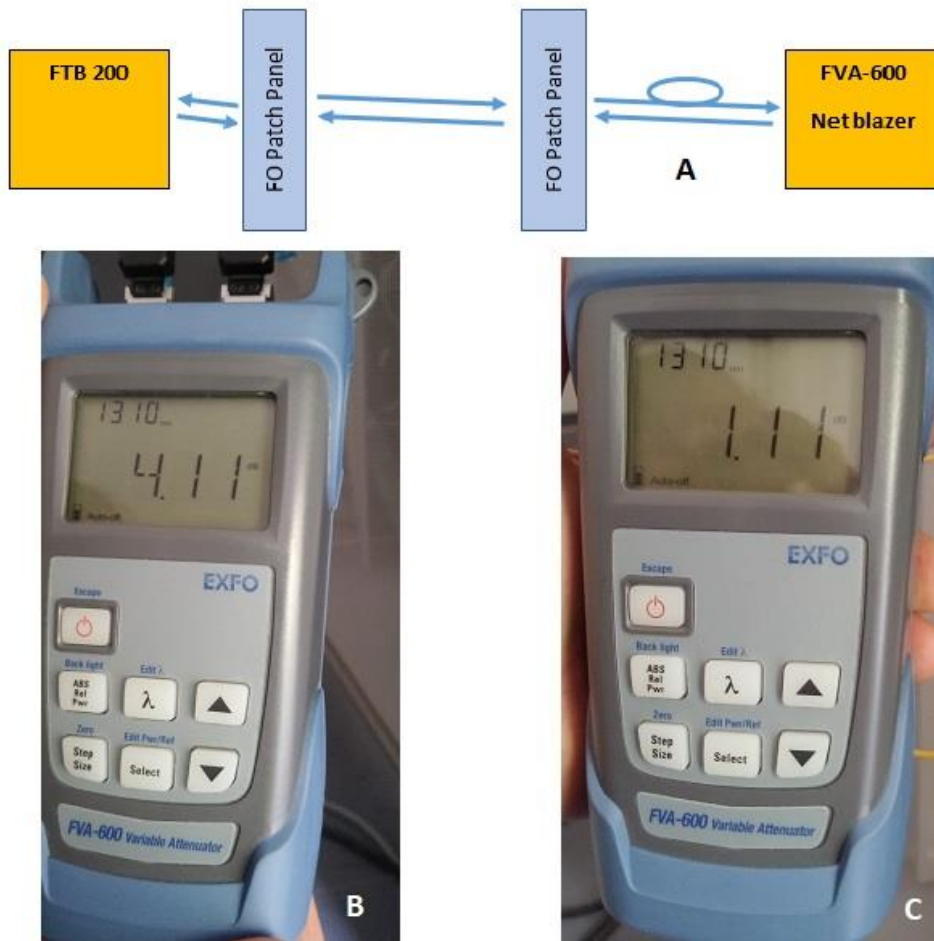
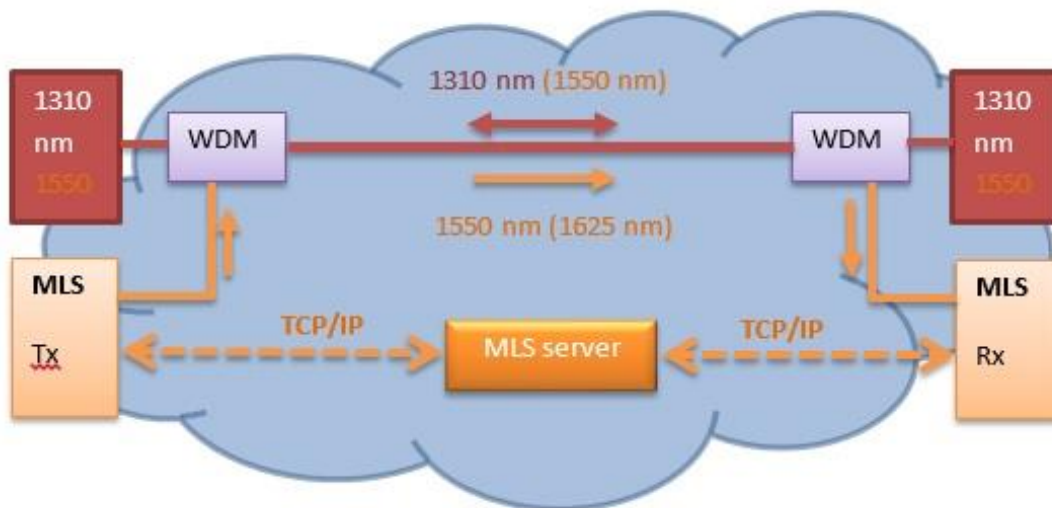


Figure 24 Overload measurements of the SFP modules, a) arrangement of measurements with additional attenuator b) attenuation measurements by EXFO FTB 200 without additional attenuation c) the same as b) with additional attenuation

The next measurement was aimed at identification of security violation into the optical fiber between DTCs, which can be activated by mechanic effects, forced or unforced violation of fibers, or illegal monitoring of communication on optical fibers. For the reason we introduced continuous monitoring - MLS-50A, whose schematical arrangement is in Figure 25. The setup consists of the couple transmitter-receiver of the optical signal for two cases – for communication with the wavelengths 1310nm and 1550nm and for monitoring 1550 and 1625 nm. The functioning of the setup is following: Let us suppose that the communication traffic is on 1310nm between two DTCs. Monitoring Line System (MLS) server sends measured impulses on 1550 nm through Wavelength Division Multiplexing

(WDM), where the signal is connected to other communication and both wavelengths (1310 and 1550 nm) travel together on one monitoring fiber. On the other side the WDM separates both signals again into communication and monitoring signals. Monitoring signal travels to the receiver MLS. Both Tx and Rx signals from MLS communicate via TCP protocol with MLS server, which evaluates the power and delay of both (communication and monitoring) signals and may send info to the administrators' e-mail. Thus, monitoring is feasible even without the interruption of the fiber.



*Figure 25 Schematical arrangement of on line delay and attenuation measurements on the optical network*

System MLS allows also the measurement of Transient Optical Loss (TOL), which may occur during the full traffic and usually reports about a more serious damage on the transition line. This is the reason, why it was monitored during the full traffic and continuously reported. Result of our example measurements of TOL



of duration of 0.2 s is in Figure 26, where significant loss of packets at the level of 3dB is followed by the residual loss of about 0.5dB.

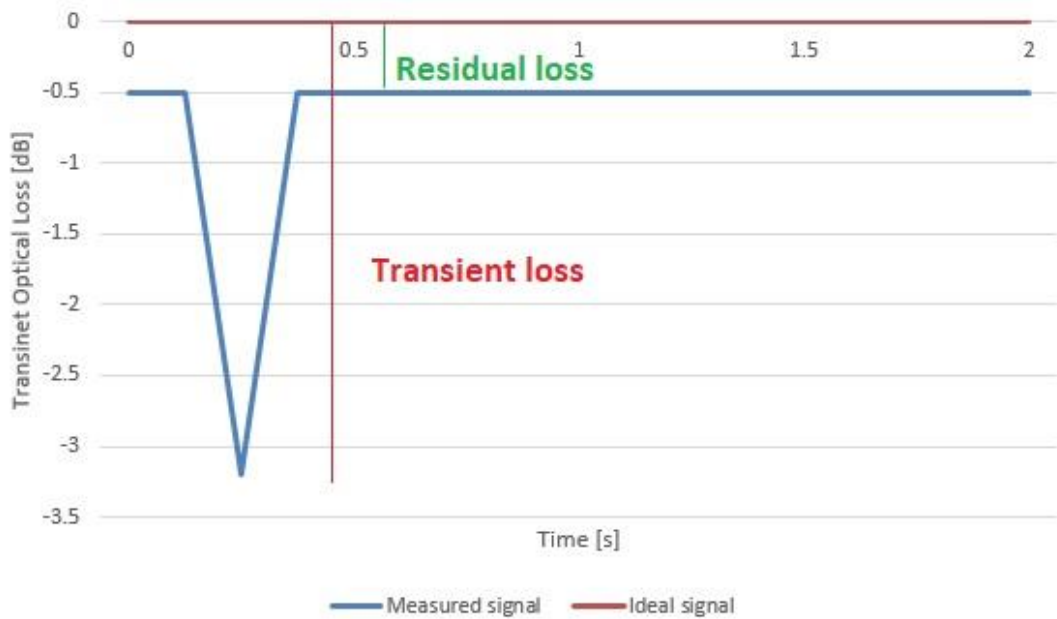


Figure 26 Example of transient optical loss between two DTCs

For illustration, the instrumentation sources of TOL for individual bit errors, are gathered in Table 6.

Table 6 Transient loss vs. bit errors

Transient loss (dB)	Bit error	Note
0.6	B1	Differences indicate the occurrence of section-level bit errors
1	B1+B2	Differences indicate the occurrence of line-level bit errors.
3.5	B1+B2+B3	Differences indicate the occurrence of path-level bit errors.

4.5	B1+B2+B3+ REI	Remote Error Identification
5	B1+B2+B3+ REI+TIM	Trace Identifier Mismatch
5.5	B1+B2+B3+ REI+ TIM+ SYNC	Synchronization loss
6.5	B1+B2+B3+ REI+ TIM+ SYNC+ OOF	Out of Frame
8	B1+B2+B3+REI+ TIM+ SYNC+ OOF+ LOF	Loss of Frame
8.5	B1+B2+B3+ REI+TIM+SYNC+OOF+ LOF+ LOS	Loss of Signal

The measurement of TOL was important to discover the excess attenuation, caused during installing cloud, due to bending of FO fiber. Then, based on the measured distance of error, we discover immediately the place of the accident, which might be removed. The principle of the distance of the fault finding is depicted in Figure 27.

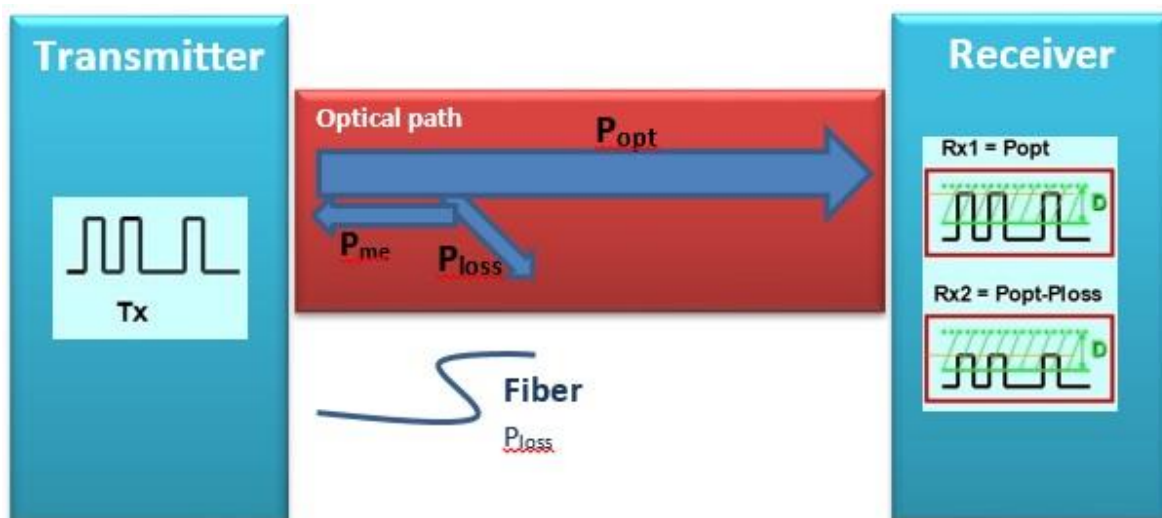


Figure 27 Scheme of the measurement by MLS method of the source and position of the optical power attenuation

### 5.2.3 Remote laboratories data protection

By 25.5.2018 the General Data Protection Regulation (GDPR) of European Union came into force. It is a regulation of the European Union, which edits and replaces existing law about personal data protection [59]. As to the REMLABNET, which we started to operate in the frame of the law 69/2018 Z.z. “Law about cyber security” of the Slovak Republic, which was even more stringent than one of the EU. Because of the mentioned regulations, we were obliged to create set of documents, related to the services of the information system, where it was expressed, how to process personal data of clients, accumulated during system functioning. The part of the process is in Appendix A – Data Protection Act. Our efforts in this direction aimed at the strengthening of the REMLABNET security and within the striving we created couple of rules, as the recommendation for our clients. Mentioned rules can be found in Appendix H.

### 5.2.4 Optimization of the Cloud

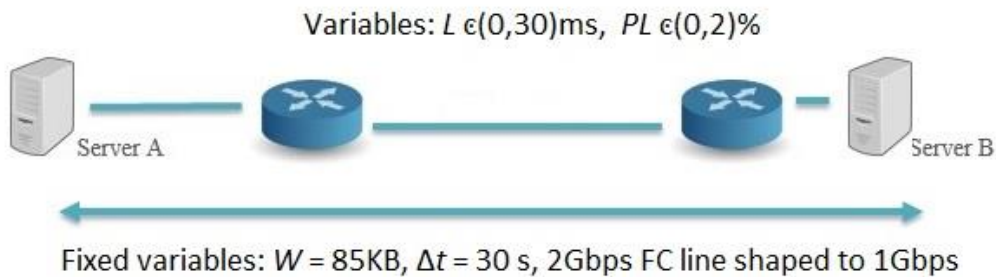
The following Subchapter deals with the crucial item of alignment of the demands on efficient functioning of embedded application and demands on cloud HW. Let us choose for the problem solving the criterion function of the necessary throughput for ensuring reliable functioning of the application

$$T = f(L, PL) \quad (5)$$

where two variables are latency  $L \in (0,30)$ ms, and loss of packets  $PL \in (0,2)\%$ , which we knew for REMLABNET from orientation measurements, whereas fixed variables were window size  $W = 85$ KB and  $\Delta t = 30$  s time span of measurement.

The problem was formulated for the communication between two hosts (host A - DTC Hornopotocna st. - sends traffic for 30 seconds to host B - DTC

AdAlbertinum, Holleho st. – see Figure 28) to find optimum of the criteria function for variable quantities latency  $L$  and loss of packets with fixed the other.



*Figure 28 Scheme of interconnection of two host for throughput  $T$  optimization*

Let us give practical example of the process of optimization, followed by the final results.

### **Example in three steps:**

1. For our purpose we use following applications:

- netem – (Network Emulator) was an enhancement of the Linux traffic control facilities that allowed to add delay, packet loss, duplication and more other characteristics to packets outgoing from a selected network interface,
- iperf – (Internet Performance), a tool for performing network throughput measurements,
- tc – (Traffic Control), the user-space utility program used to configure the Linux kernel packet scheduler.

2. The example of the detailed optimization procedure expressed in CLI:

- Select two random virtual servers (first in DTC on Holleho st., second in DTC on Hornopotocna st.)
- detect network server interfaces (command used **#ifconfig**, detection of interfaces and IP addresses)

Server 1: rlg-gw.truni.sk, 10.33.16.242 (ens32)

Server 2: sqlinjection.truni.sk, 10.33.23.201 (ens160)

- Detecting network interface status for packet trimming, etc. command:

**#tc qdisc show dev ens32 //for server 1**

**#tc qdisc show dev ens160 //for server 2**

- Server 2 has started a communication check with a command **#iperf -s** that is now waiting for the other server to communicate.
- Setting a 5ms latency on server 1 and packet loss of 0%

**#tc qdisc replace dev ens32 root netem latency 5ms loss 0%**

- Then I ran the command to check the iperf communication, using the **-c** switches to specify the IP address, **-t** to set the scan progress for 30 seconds, and **-Z** to set the cubic method for TCP communication

**#iperf -c 10.33.23.201 -t 30 -Z cubic**

- Now, points 5 and 6 were repeated for all values to fill Table 5. That is, the latency values changed between 0, 5, 10, 15, 20, 25, and 30 ms for a loss of 0, 0.25, 0.5, 1, and 2%.
- The last point was the release of network interfaces of both servers, where the latency was set by the command:

**#tc qdisc del dev ens32 root //for server 1**

**#tc qdisc del dev ens160 root //for server 2**

3. Resulting example of CLI record of the optimization procedure is in Figure 29.

```

root@sqlinjection:~# iperf -s
-----
Server listening on TCP port 5001
TCP window size: 85.3 KByte (default)
-----
[ 4] local 10.33.23.201 port 5001 connected with 10.33.16.242 port 41226
[ ID] Interval      Transfer    Bandwidth
[ 4] 0.0-30.0 sec  2.18 GBytes 623 Mbits/sec
root@rlg-gw:~# iperf -c 10.33.23.201 -t 30 -Z cubic
-----
Client connecting to 10.33.23.201, TCP port 5001
TCP window size: 85.0 KByte (default)
-----
[ 3] local 10.33.16.242 port 41226 connected with 10.33.23.201 port 5001
[ ID] Interval      Transfer    Bandwidth
[ 3] 0.0-30.0 sec  2.18 GBytes 623 Mbits/sec

```

Figure 29 Example of print screen of the optimization procedure of criterion function

The results of the optimization procedure are summarized in Table 7 and in detail in Figures 30 and 31. Table 7 presents the results of the criterion function (5) of the throughput  $T$  for variable latency  $L$  for three values of the packet loss  $PL$ , 0, 0.025, 0.1, 0.25, 0.5, 1, and 2%. In Figure 30 and Figure 31 are corresponding results in graphical form.

Table 7 Throughput  $T$  (and corresponding transferred data for 30s) as function of latency  $L$ , packet loss  $PL=0, 0.025, 0.1, 0.25, 0.5, 1, \text{ and } 2\%$

Measurement of throughput at latency and 0% packet loss		
Latency, $L$ (ms)	Throughput $T$ (Mbs <sup>-1</sup> )	Transferred data (Byte)
0	923	3.23G
5	825	2.88G
10	486	1.70G
15	605	2.11G
20	462	1.61G
25	488	1.71G
30	282	1010M

Measurement of throughput at latency and 0.025% packet loss		
Latency, $L$ (ms)	Throughput $T$ (Mbs <sup>-1</sup> )	Transferred data (Byte)
0	905	3.16G
5	622	2.17G
10	428	1.14G
15	233	834M
20	256	916M
25	153	547M
30	208	748M
Measurement of throughput at latency and 0.1% packet loss		
Latency, $L$ (ms)	Throughput $T$ (Mbs <sup>-1</sup> )	Transferred data (Byte)
0	903	3.15G
5	298	1.04G
10	158	565M
15	129	462M
20	41.1	147M
25	37.6	117M
30	25.7	92.1M
Measurement of throughput at latency and 0.25% packet loss		
Latency, $L$ (ms)	Throughput $T$ (Mbs <sup>-1</sup> )	Transferred data (Byte)
0	899	3.14G
5	146	523M
10	53.2	190M
15	27.8	99.4M
20	17.7	63.8M
25	15.2	54.4M
30	13.1	47.2M
Measurement of throughput at latency and 0.5% packet loss		
Latency, $L$ (ms)	Throughput $T$ (Mbs <sup>-1</sup> )	Transferred data (Byte)
0	875	3.06G
5	112	404M
10	28.1	101M
15	15.2	54.4M

20	12.4	44.4M
25	8.81	31.9M
30	8.62	31.0M
Measurement of throughput at latency and 1% packet loss		
Latency $L$ (ms)	Throughput (Mbs <sup>-1</sup> )	Transferred data (Byte)
0	643	2.25G
5	41.4	149M
10	17.5	62.9M
15	11.9	42.8M
20	8.24	29.6M
25	6.54	23.5M
30	5.53	20M
Measurement of throughput at latency and 2% packet loss		
Latency $L$ (ms)	Throughput (Mbs <sup>-1</sup> )	Transferred data (Byte)
0	281	1004M
5	19.8	71M
10	10	36M
15	6.59	23.8M
20	5.17	18.6M
25	4.55	16.5M
30	4.01	14.5M



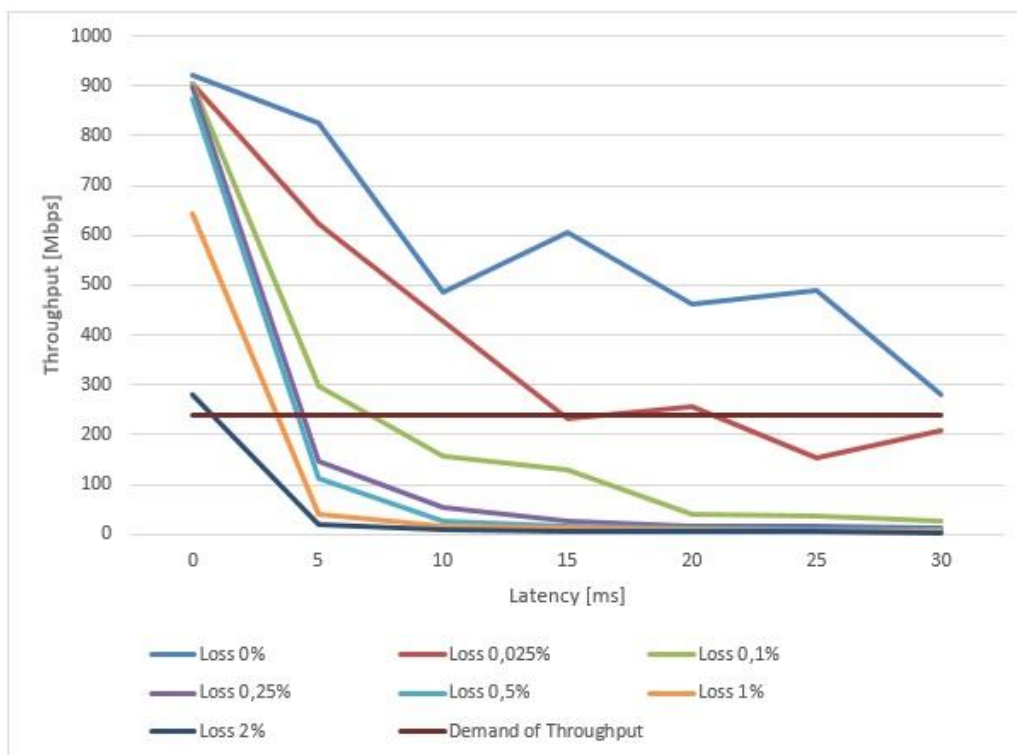


Figure 30 Network throughput  $T=f(L, PL)$  ( Eq.(5) ) for values of packet loss 0% (light blue), 0.025% (light brown), 0.1% (green), 0.25% (violet), 0.5% (cyan), 1% (orange), and 2% (dark blue);also denoted are the requirements of REMLABNET (dark brown).

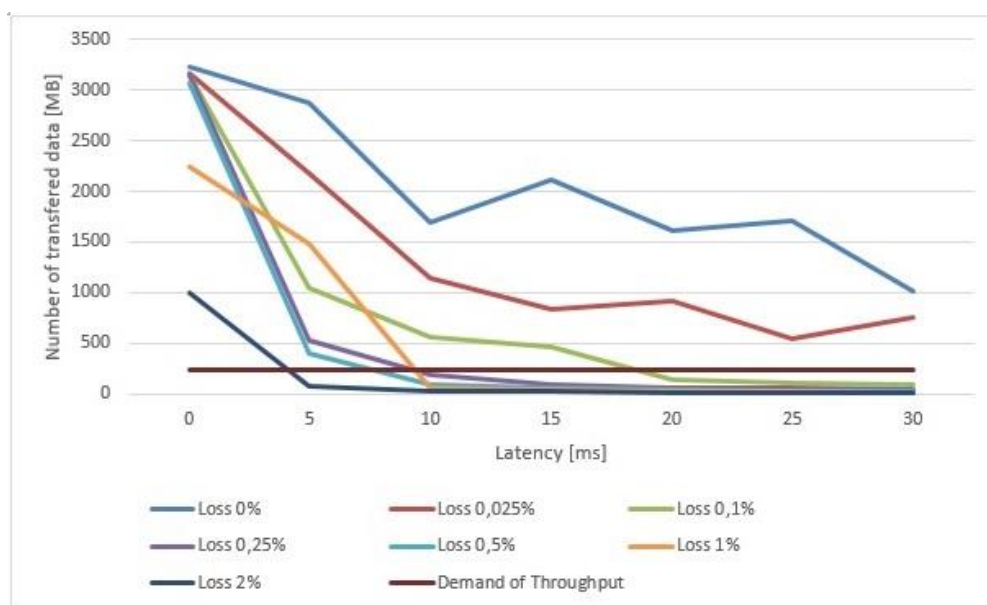


Figure 31 Number of transferred data for values of packet loss 0%(light blue), 0.025% (light brown), 0.1% (green), 0.25% (violet), 0.5% (cyan), 1% (orange), and 2% (dark blue);also denoted are the requirements of REMLABNET (dark brown).

Comparing results in Figures 30 and 31 we can see immediately the results in Figure 30 (depicting Throughput  $T$ ) are more stringent as results in Figure 31 (depicting Number of transferred data), so discussion will be limited to the results of Figure 30.

The above presented results in Figure 30 were important for the choice of predominantly HW of the Cloud system. The optimized quantity, throughput  $T$ , is closely related to the quality and price of the CC HW and, on the other hand, it is closely related to the application requirements. As we established by measurements CC REMLABNET required the throughput  $T=250$  Mbps [60] in a wide range of latencies (in Figure 30 depicted by dark brown line), when the DTC with RLs was located in one destination (TBU Zlin). Then, we easily achieved the values of latency  $L\sim 15$ ms, achieve with moderate price of HW, allowing for packet loss 0.1% (brown curve in Figure 30). But, taking into consideration the foreseen development of the system, when we suppose extending to the location of several DTCs, which will definitely result in the latency  $L>18$  ms, we have to concentrate on the solution, increasing the throughput  $T$  and thus the price. The reasonable solution is, by improving the quality of HW, and thus by increasing the price of HW, to suppress the packet loss % (towards blue curve in Figure 30).

### **5.2.5 Optimization of data collection, saving, backup and archiving results**

Every day, internet users create trillions of bytes of information, an inconceivable mass of ones and zeros, that are then stored in the cloud computing farms run by the world's biggest companies [61]. In the REMLABNET is situation "little bit" better, but our clients are producing data every day and backup configuration files.

Data backup (see methods used in chapter 4.2.6) is a process of duplicating data to allow retrieval of the duplicate set after a data loss event. Backups have two distinct purposes. The primary purpose is to recover data after its loss by deletion or corruption. The secondary purpose of backups is to recover data from an earlier time, according to a user-defined data retention policy, typically configured within a backup application for how long copies of data are required. Though backups represent a simple form of disaster recovery and should be part of REMLABNET disaster recovery plan. There are two ways of backup data in REMLABNET:

- Backup on magnetic tape,
- Backup on cloud storage.

### **Backup on magnetic tape**

Within the framework of University LAN, we gained an older Oracle StorageTec SL48 Tape Library, which is library of 48 magnetic tapes for backuping data. As a part of this, we gained SW Netbackup. We are using this primary for backup of snapshots, databases and other cloud solutions. Advantages of magnetic tape backup are:

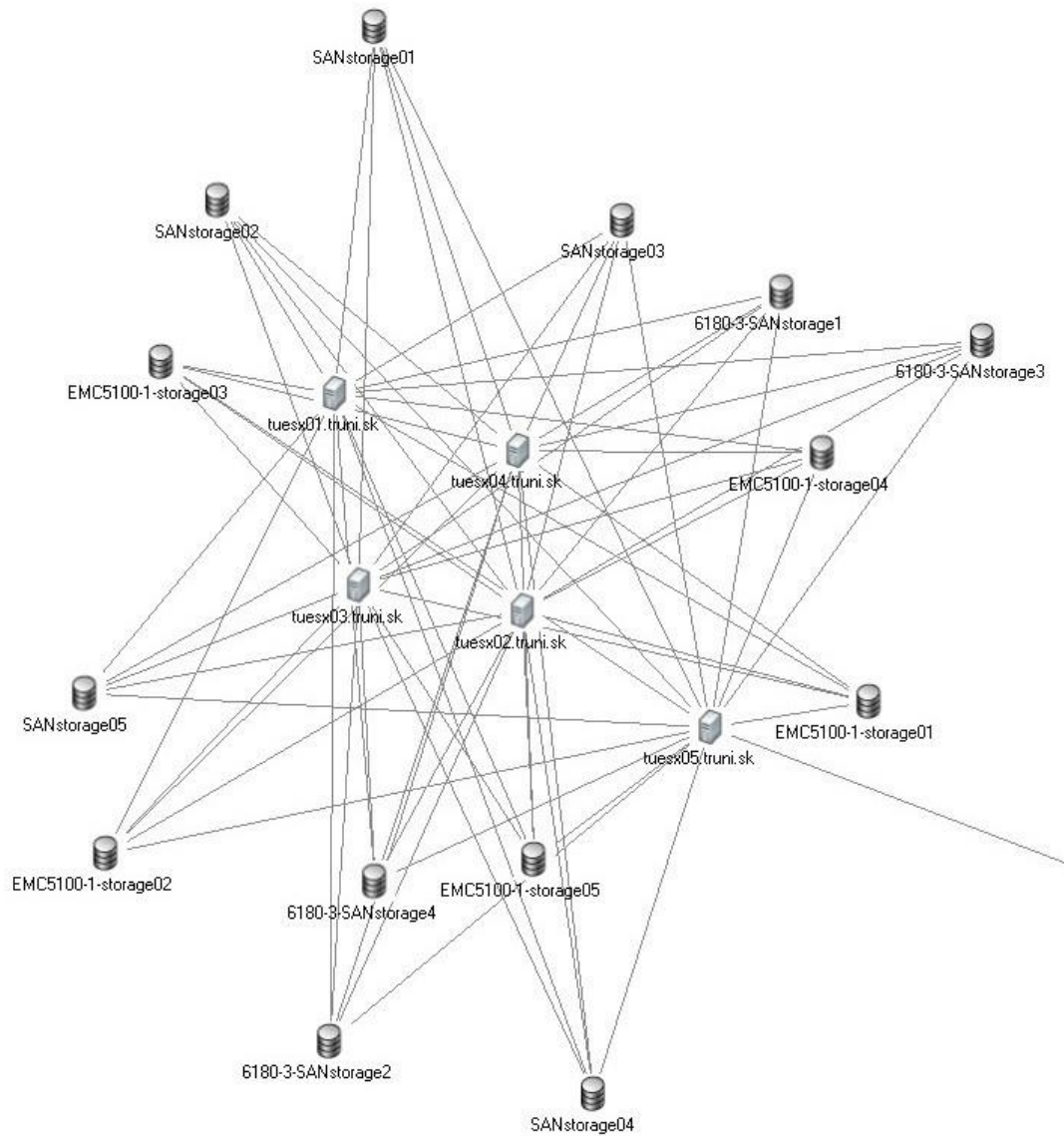
- High capacity,
- Fast performance,
- Lower cost per GB,
- Portability,
- Better longevity,
- Scalability.

## Backup on cloud storage

Using online backup cloud storage services makes backing up data easy, which is just one of the reasons cloud computing is ideal for small businesses like REMLABNET. A major benefit of using cloud backup is that it can make managing a backup system easier. Data moved offsite should be deduplicated to speed the backup and encrypted for protection. In our solution, we have a separate disk array for backing up data. Every cloud storage backup in REMLABNET are working like script, where it started from cron. Example of „tar“ archive is:

```
#!/bin/bash  
BCKDIR=/export/backups/named  
DATE=`date + "%d-%m-%y-%H:%M“`  
Cd /var/lib; tar cf $BCKDIR/named-$DATE.tar named - -exclude=proc - -  
exclude=dev
```

Figure 34 shows interconnection between each nod of cloud storage in one DTC, where we are backing up our systems and all data of REMLABNET.



*Figure 32 Part of cloud storage of REMLABGRAB service*

In forming the scheme of the storage we stick to the rule „2+1= Data backup best practice“, that means for critical data of all activities we should make two full copies, maintained on separate physical devices. In addition, a third copy should be kept offline, preferably situated at another location.

Let us look at how we archive the data of REMLABNET. Data archiving is the process of moving data that is no longer actively used to a separate storage device for long-term retention. Archive data consists of older data that remains important to the organization or must be retained for future reference or regulatory

compliance reasons. Data archives are indexed and have search capabilities, so needed files can be located and retrieved [62].

### **5.3 Cloud computing solutions**

If we intend to embed an application like REMLABNET (see chapter 4.1 of Methods used) to our cloud, we had to answer several vital questions. REMLABNET was created as the software package, consisting of several components (servers) working together. REMLABNET was running on servers for processing logic that was accessed through a web browser with Internet connection. The goal was to transfer REMLABNET with all its services into a remote DTCs providing cloud services infrastructure and operated by Trnava University in Trnava.

With the advancement of remote computing technology, clear similarities among the cloud and web applications have occurred. Cloud and web applications accessed the data, residing on distant storage. Both use server processing power that might be located on premises or in a distant data center. A key difference between cloud and web applications was their architecture. A web application (REMLABNET before) must have a continuous Internet connection to secure functioning. But, a cloud application (REMLABNET now) performs processing of tasks on a local computer or workstation. An Internet connection is required primarily for downloading or uploading data.

In our case, main issue of REMLABNET is provided like Software as a Service (see chapter 4.4 in Methods). When we were building REMLABNET application, no cloud was considered, but we were thinking primarily about scalability of our system in contrast to local server solutions. We were searching

for proper programming language and database and appropriate software tools. There were many questions then to be answered. Building a product for the cloud embedding means building a product with a modern programming language and progressive methods used. The choice of the programming language was influenced by the possibilities of each language. There were many and various (modern) programming languages and methods available, making the choice difficult. We ended up using PHP and Python programming language, influencing the choice of a document-oriented database. We decided to use the standard relational database, because it was free.

### **5.3.1 REMLABNET implementation in the cloud**

Let us now suppose the cloud provides necessary functionality and the step of embedding the application is possible. In our case the embedding problem API was the by us designed application REMLABNET. Because the VMWare SW represents the top of cloud computing technology, the embedding of any application was straightforward and did not constitute any major problem. In light of this we will touch next the functionality of our CC-REMLABNET and its peculiarity compared to standard REMLABNET.

Our CC planned concept and idea of Cloud Computing REMLABNET (CC-R) was documented in chapter 4.1 in Figure 10. Let us describe it more detail.

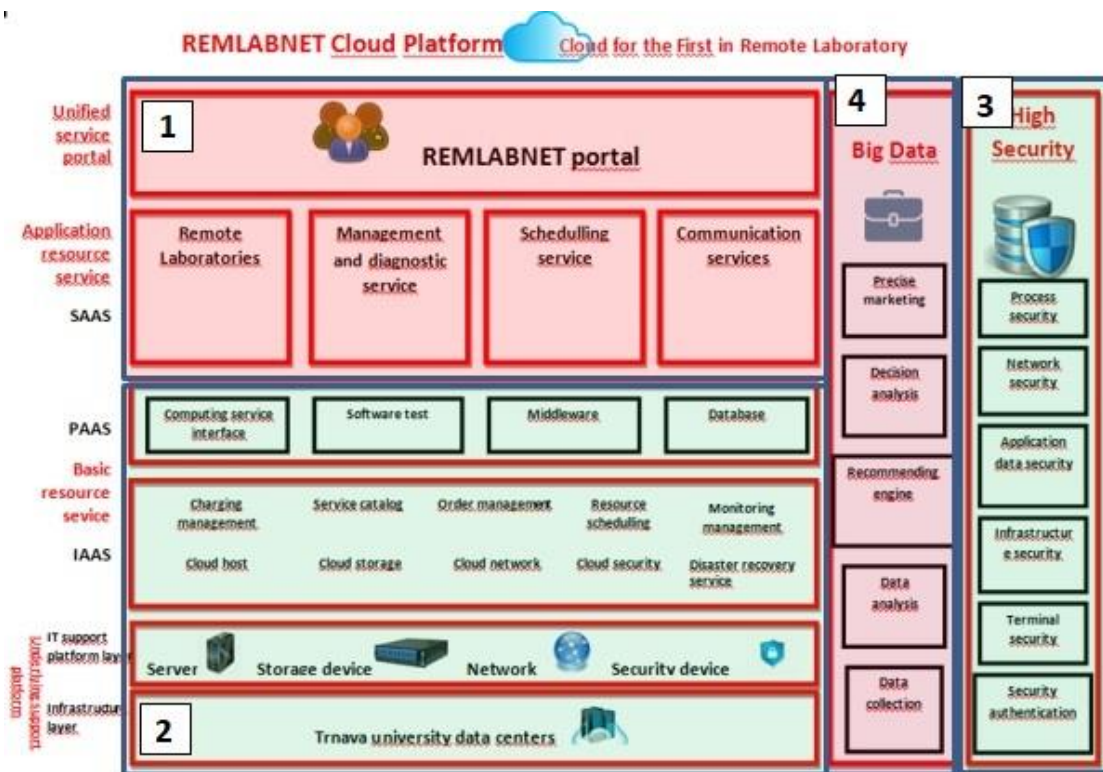


Figure 33 CC-REMLABNET - cloud implementation - detailed structure (version 2014)

In Figure 33 is the schematically arrangement of embedded REMLABNET, forming CC-R (version 2014) with its main blocks. Old REMLABNET (versions before 2013) is in blocks 1 and 2, CC-R as its embedded counterpart has new blocks 3 and 4.

Block 1 (in Figure 33) represents the standard and known functions of REMLBNET containing **Remote laboratories, Management and diagnostic service, Scheduling service and Communication services** [63]. All these modules are controlled by **Unified service portal**, enabling access to REMLABNET by clients and administrators. In block 2, there are platform services **Computing service interface, Software test, Middleware and Database**. There are also modules ensuring the functioning of both REMLABNET and CC-R, Basic resource service (BRS). These are platform **DTCs, Servers, Storage devices, Network, Security devices**, and **Charging management, Service catalog, Order**



**management, Resource scheduling, Monitoring management, Cloud host, Cloud storage, Cloud network, Cloud security and Disaster recovery service.**

Two new blocks, called High Security (3) and Big Data (4) were supposed to be an extension of the basic cloud solution REMLABNET forming CC-R. Nowadays, only High Security is in operation. The second Big Data block is under construction. Block High Security (3) contains the most important security components, where we define our main processes that require special security protection. **Process security** in CC-R is in fact the security of the individual RLs. **Network security** is managed from the University environment, but CC-R also uses the network settings above the University measures. **Application data security** assures security at the CC-R data level, their storage and individual accesses. **Infrastructure security** is a component securing the complete RLs CC-R portal, including its physical security. **Terminal security** is a component that ensures security on a thin client level. **Security authentication** is the last component ensuring correct and secure access of clients and administrators.

### **5.3.2 Advanced cloud computing services**

#### **New cloud services**

The new built cloud with CC-R embedded, induced the need of several specific services inserted after installation of the new cloud. They were **IaaS** - Infrastructure as a Service, **PaaS** – Platform as a Service and **SaaS** – Software as a Service. These services were both needed, and their functioning was conditioned by the cloud itself. Programmed and created by us services in CC-R are services of **RLaaS** – for grant RLs clients, **GaaS** – which serve to harvest the information from RLs, **TCaaS**

– where we use thin client instead of classic PC, **STaaS** - for sharing and storing measured values. Let us describe them next.

### **RLaaS – Unit REMLABGRAB**

Private cloud brings many advantages with respect to RLs. We are the owners of HW and SW and thus we have responsibility for their availability. One of the services in our CC-R (see details in chapter 4.3 and 4.4) is Remote Laboratory as a Service (**RLaaS**), which would make availability of RLs more straightforward. During the design of REMLABNET, we had to build a new API style interface in 2018, which we called REMLABGRAB (RLG). The function and properties of RLG, are closely related to the properties of RLMS REMLABNET [25] and by it operated RLs [11]. Basically, RLG serves for an easy access to all bidirectional data flux between **supervising personnel** and the RL. Supervising personnel has the approach to all the data, corresponding to proper functioning of a RL, but also possesses the possibility for changing its functioning. In schematical representation (Figure 34), are represented two kinds of connectivity, one by **measuring client** via REMLABNET (green line) and one via REMLABGRAB by the supervising personnel (orange line). The clients are connected via IP address, which enables connection to RLs, whereas supervising personnel needs also IP address and extra rights corresponding to their special rule, as demonstrated by the following example in JAVA code for RL experiment „Phase in RLC circuit“.

1 . This part of code establishes connection:

```
$( document ).ready(function() {  
    VL.Connect("ws://remlabgrab.truni.sk:8899/");  
    $("#connection").VLCConnection();
```

2 . Establishes connection for RLs „Phase in RLC circuit“ and enables adjustment of its parameters:

```
$("#button_freq_10").VLButton({  
  devices : [  
    { deviceName : "control_base_freq", value : 10 }  
  ],  
  description : "10 Hz",  
  autoDisable : true,  
});
```

3 . Adjusting measuring frequency of the RLs at 10Hz or read data from experiment (HTML output):

```
$("#data_output_html").VLDataOutput({  
  devices : [  
    { deviceName : "control_voltmeter", loadMethod : "Experiment", slot :  
      "experimentId"},  
    { deviceName : "control_ampermeter", loadMethod : "Experiment", slot :  
      "experimentId"},  
    { deviceName : "control_freq", loadMethod : "Experiment", slot :  
      "experimentId"}  
  ]  
});
```

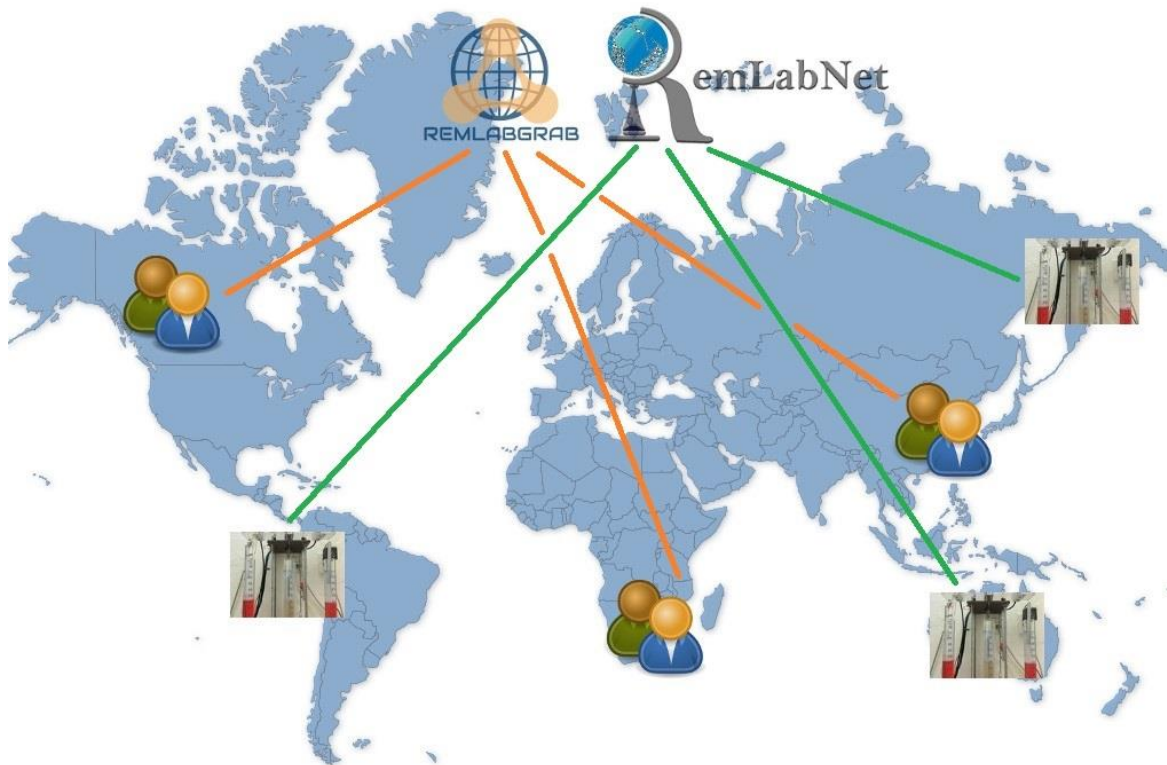


Figure 34 REMLABNET and REMLABGRAB: Possible connections in our system of RLs: **clients** via REMLABNET for the measurements on RLs (green line) and **supervising personnel** via REMLABGRAB to inspect measurements and control data (orange line)

Next lines describe two examples of the measurements with using RLG system. First one is the RL measurement of „Electromagnetic induction“, the second is the RL measurement of „Phase in RLC circuit“.

Example 1) **Measurement of „Electromagnetic induction“ with using RLG** (Figure 35):

Values of parameters adjusted to measurement:

Controlling voltage on electromotor:

$$indukce\_napeti = \{0, 2, 4, 6, 8, 10\} \text{ V}$$

Number of coils at time:

$$indukce\_sim\_windings\_count = 18 \text{ coil (for } 0 - 13.484 \text{ s)}$$

$$indukce\_sim\_windings\_count = 36 \text{ coil (for } 13.484 - 27.8 \text{ s)}$$

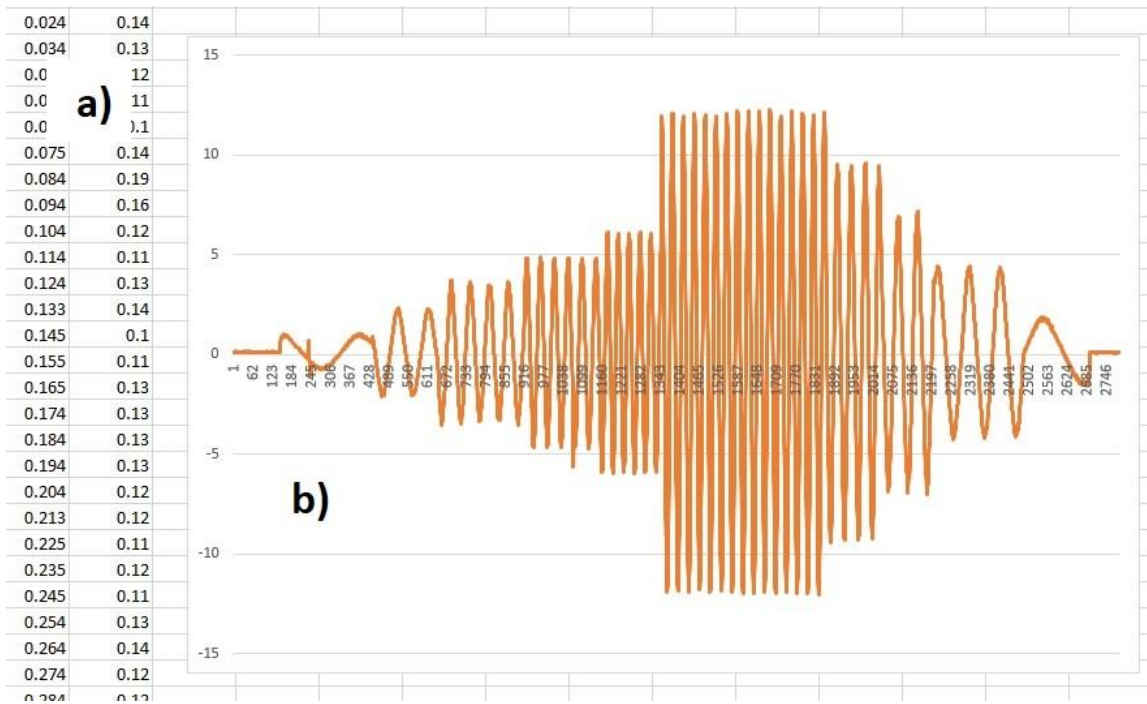


Figure 35 Measurement of „Electromagnetic induction“ via REMLABGRAB – a) part of the measured data, b) the graph of the measured induced electromotive voltage for controlling voltage on driving motor {0, 2, 4, 6, 8, 10, 9,7,5,3 } V

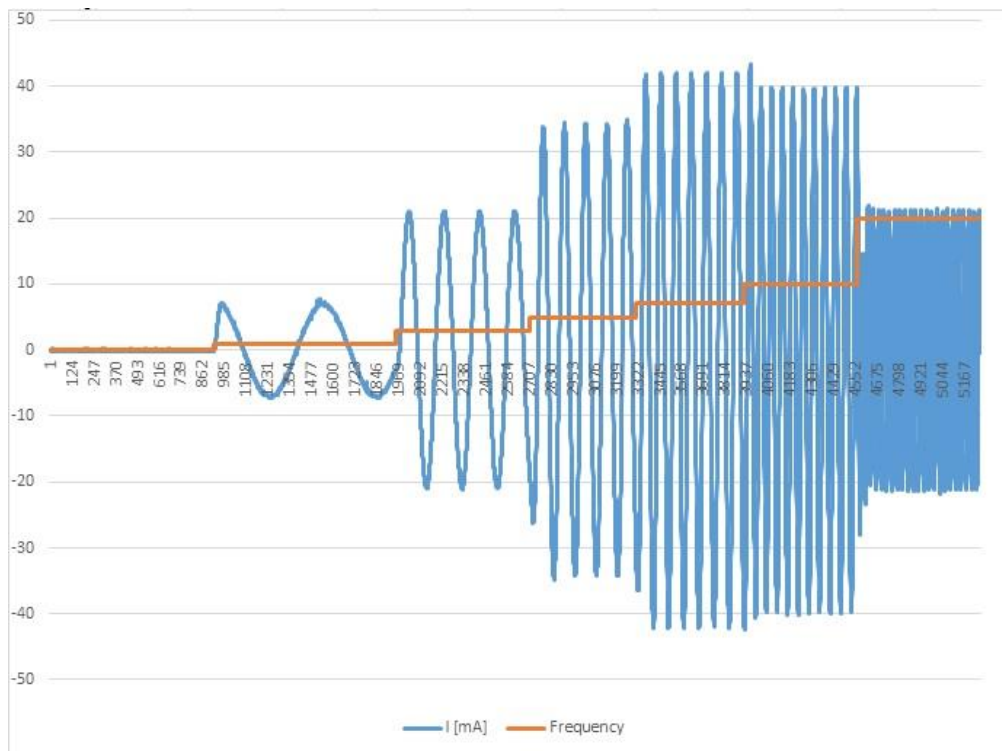


Figure 36 Example of configuration on line: the measurements via REMLABGRAB the measurement of „Electromagnetic induction“ via REMLABGRAB, the graph of the measured induced electromotive voltage (blue) and controlling voltage on driving motor (red otherwise not accessible in standard RL).

Example 2) Measurement RL „Phase in RLC circuit“, with using RLG:

Values of parameters adjusted to measurement:

Voltage of variable frequency source:  $U = 5 \text{ V}$ , Resistance:  $R = 20 \text{ } \Omega$ ,

Inductance:  $L = 250 \text{ mH}$ , Capacitance:  $C = 1,5 \text{ } \mu\text{F}$ .

Scheme of the measurement is depicted on Figure 37.

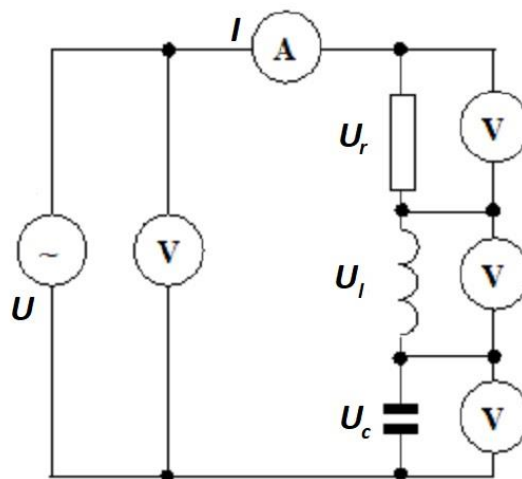


Figure 37 Scheme of the measurement on RL „Phase on RLC“

Next graphs show the measured data from RL specifically „Phase in RLC circuit“, (Figures 38-40).

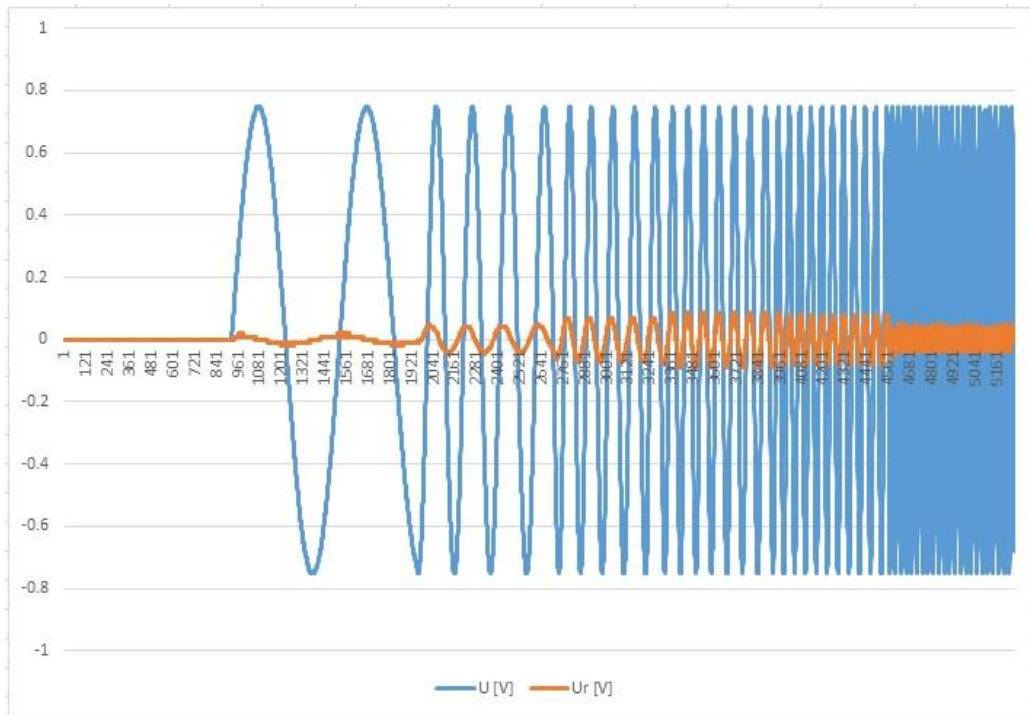


Figure 38 Result of measurement on RL „Phase in RLC circuit“, comparison of the source voltage and voltage on the resistor

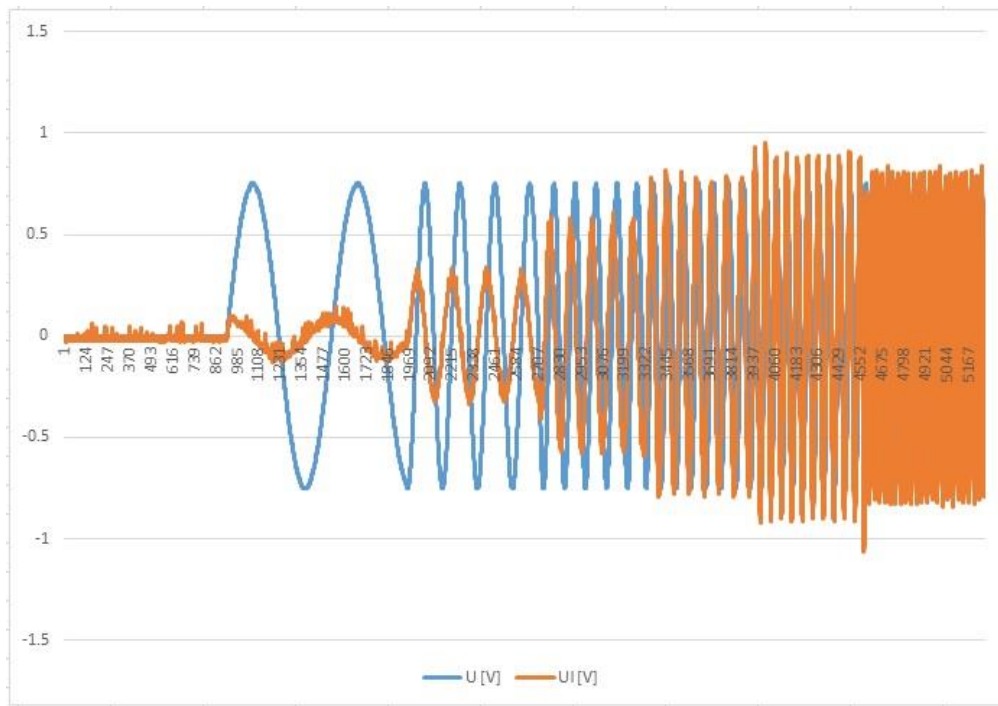


Figure 39 Result of the measurement on RL „Phase in RLC circuit“, comparison of the source voltage and voltage on the inductor

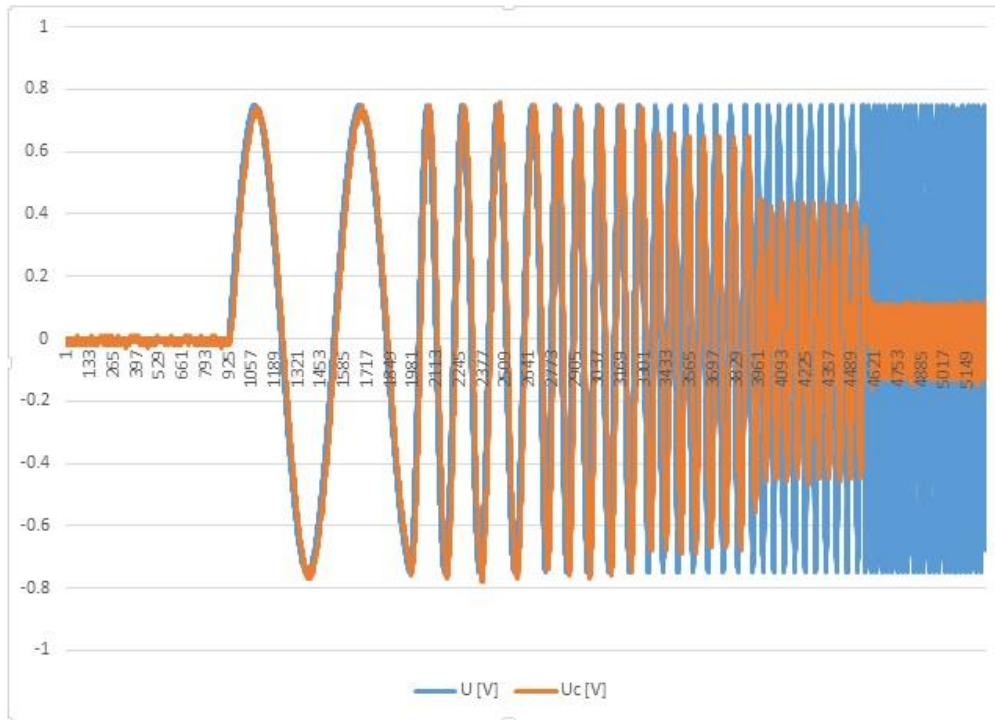


Figure 40 Result of the measurement on RL „Phase in RLC circuit“, comparison of the source voltage and voltage on the capacitor

### GaaS – REMLABGRAB as a Service, for new applications

GaaS service uses REMLABGRAB and goes beyond standard application in RLaaS. It uses available data in REMLABGRAB for following activities:

- Accessibility of complex data of every RL in REMLABNET system,
- Possibility of REMLABNET monitoring and its simplified supervising,
- General possibility of easy laboratories maintenance in computer oriented laboratory,

But the most important use of the GaaS service is:

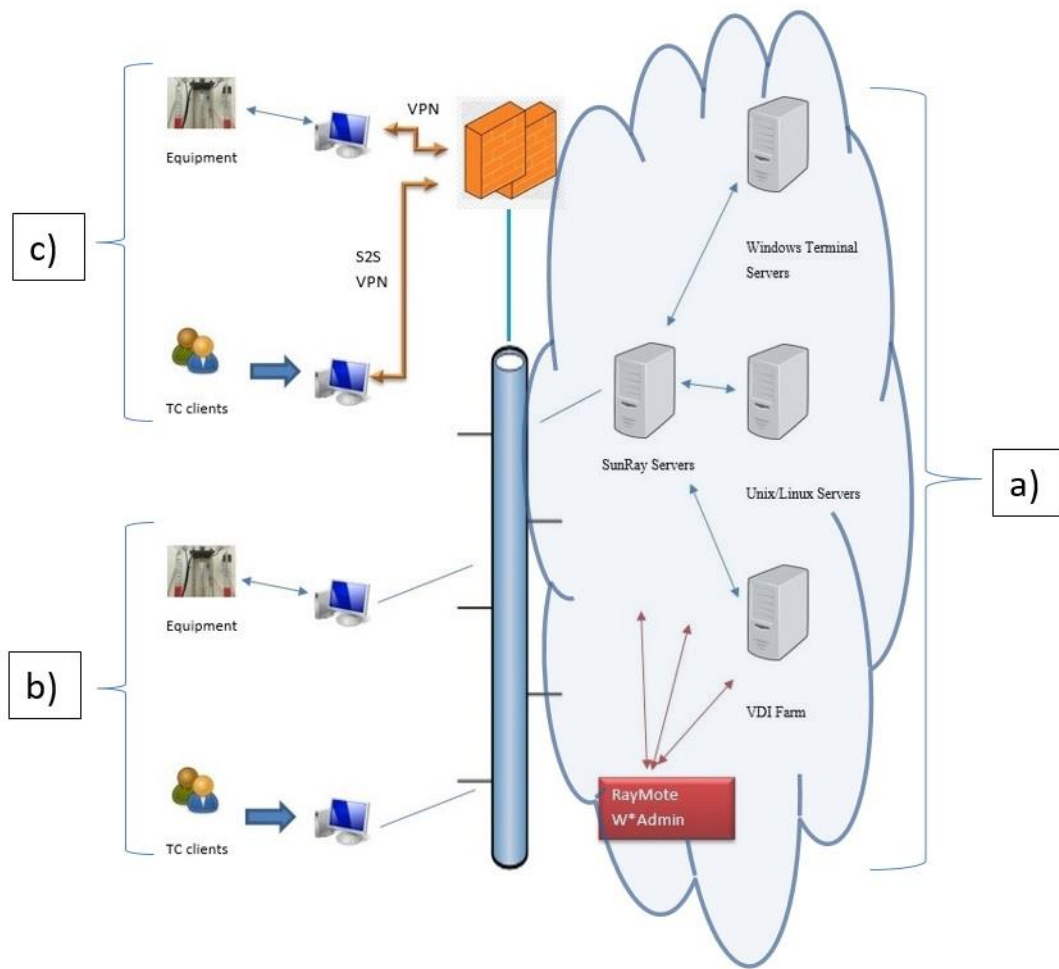
- Possibility of building extra sophisticated versions for specific RL bringing a wide range of additional applications.

For more information read Appendix I – Progressive applications of REMLABNET.



## **TCaaS – Thin Client REMLABNET**

In the next service Thin Client as a Service (**TCaaS**) TC-REMLABNET is in fact a new, highly economical and suitable for multiplying and scaling version of management system. The economical shortcuts rely on using the simple version of thin client both on the client working place and on the place of physical HW. Thin Client (TC) as an informatics tool comprises in a setup monitor, keyboard and mouse. All other components as graphic card, motherboard, HDD and extensive operation memory are absent, and all the data are immediately forwarded by the net connection to the cloud. It is obvious that all demanding and sophisticating services of REMLABNET must be given over to the cloud services. This is schematically depicted in Figure 41 a), where there must be embedded both virtualized servers for controlling RLs and clients communicating servers. The first ones are the group of Windows Terminal servers through RDP, assuring the sessions. The second ones are the Unix/Linux servers connected throughout the X protocol. These servers assure Unix/Linux interfaces. The last ones are VDI farm connected throughout the RDP and these servers assure the VDI sessions for the REMLABGRAB the clients, which using our cloud service Desktop as a Service. Special explanation requires SW unit RayMote W\*Admin. The unit helps with virtualization and coping with RLG TC infrastructure, executes central management of TC and ensures central administration of desktops. On top of this enables approach to infrastructure resources and monitoring and auditing. The last service of the unit RayMote W\*Admin provides integration of VDI and management of systems in one Graphic User Interface (GUI). In part b) and c) are communication possibilities for both clients and physical HW either by direct connection to Internet or via VPN.

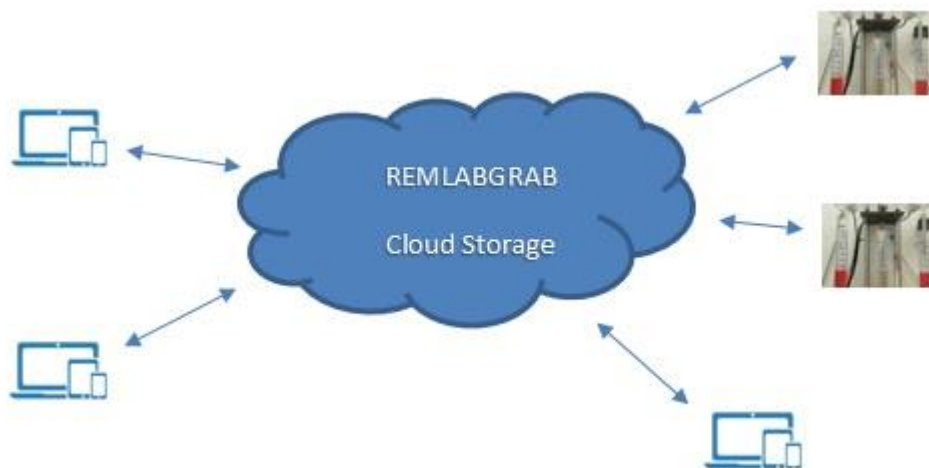


*Figure 41 TC-REMLABNET: General scheme of the combination of thin client and REMLABNET and REMLABGRAB a) cloud with the virtual servers for support thin client architecture of CC-R, with service administration of virtualized controlling servers by RayMote W\*Admin, b) more or less standard communication with RLs, c) VPN communication with RLs*

## **STaaS – Storage as a Service, Data cloud storage unit**

Advanced technology has also invited some severe security threats, like the cyber threat. Moving your data to the cloud is considered to achieve their maximum safety [64]. Cloud storage refers to the online space where data can be stored. This online space resides across multiple remote servers housed inside massive DTCs, built on virtualization technology, which means that storage space spans across

different servers and possibly even multiple and geographically different locations. The **STaaS** takes care about storing all generated data both by measurements, calculation and modelling on one side and control traffic data on the other. The added value is a possibility to distribute the cloud storage locally to even very remote localities and thus suppress vulnerability of the both storage HW and data stored. Idea of this is depicted on Figure 42.



*Figure 42 REMLABNET and REMLABGRAB: Cloud common storage with denoted both clients of REMLABNET and the measurements data storage of RLs.*

#### **5.4 Remote Laboratories Management Systems federalization in frame of EU**

In past two decades we may record the trend of general integration of resources in branch of remote laboratories. It is induced by two major trends, one is bridging the gap between individual technical solutions of RLs and the other is striving for easy access of RLs all over the World. We can formulate four levels of integration (Figure 43)

**a) Equipment level**, contains RLs to allow the distance measurement or observation by individual clients without limitation on time or location [65] [66],

**b) RLMS level**, this level is characteristic by plenty of management system, managing a great number of individual RLs and usually provide unification of interfaces, tools, outputs. On top of this many services like processing and teaching tools like reservation systems, whiteboards, sound communications, etc., as well as accessibility and authentication, are included [67],

**c) Federation level**, the federation is based on sharing of RLs between few management systems. The main goal of building federation is removing all barriers for accessibility, authentication, choice and sharing accompanying tools for clients and thus introduce higher level of user friendly environment [68] [69],

**d) Interoperability level**, this level allowing interoperability between different models, unifying their communication interface and opens the possibilities of sharing RLs despite these differences [70].



*Figure 43 Scheme of levels of federalization integration*

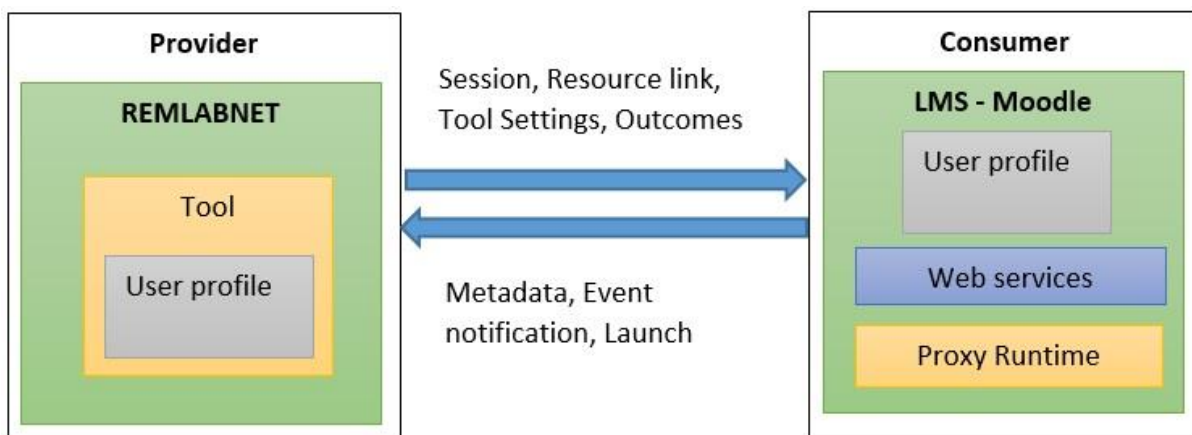
The European Union Commission is investing 60 million euros in research actions, projects and network of excellences in Technology-Enhanced Learning (TEL), under the objective ICT-2011.8.1 of the call FP7-ICT-2011-8. One of the target outcomes is precisely “Supporting European wide federation and use of remote laboratories and virtual experimentations for learning and teaching purposes”. Indeed, the IP project Go-Lab, funded by this call with 10 million euros, aims to support a wide federation of remote and virtual laboratories [71].

Additionally, the Go-Lab project aims to provide remote and virtual labs [72] for the large-scale use in education [73]. In the scope of this project [74], existing laboratories will be provided to schools free of charge, saving teachers the bother of registration processes [75], and through a technical solution based on OpenSocial. OpenSocial is a wide and complete standard that includes authorization, data storage or messaging mechanisms [76].

Federation of two RLMS with their RLs, aims at enabling at least two systems located in different entities (universities, secondary schools, research centers, etc.) can share laboratories. This means that a set of users of the client’s system, registered only in that system, will be using a set of RLs located in the provider system in an exclusive basis, without being registered there. This way, a federation could be considered a particular case of local scheduling. However, there are relevant differences, such as authentication, authorization or user tracking, and where each scheduling system is located. Most of them can be targeted by letting enough information from one system to another and with trust chains among systems [77].

In general, federalization requires deep changes in any RLMS structure. In our RLMS REMLABNET we had to design general criteria according the two new communication interfaces. First one is mainly intended for sharing RL with the

European project GoLab [78] and the associated knowledge management system Graasp [79]. Second interface is based on the Learning Tools Interoperability (LTI) [80] [81] protocol, which is primary designed to connect learning systems such as a learning management system (LMS) [82] with external service tools in a standardized way. The principal concept of LTI is to establish a standard way of integrating rich learning applications (often provided by third-party services) with platforms LMS, web portals, object repositories or other educational environments. This approach was adopted by many systems like Moodle, course builder and many more. In LTI these LMS are called Consumer and the source applications are called Provider (Figure 44).



*Figure 44 The general scheme of Interoperability between REMLABNET and Learning Management System*

REMLABNET was federated into Go-Lab project ecosystem with an HTTP plugin [83] for the Smart Gateway. HTTP plugin is used like web. Technical solution and used methods are fully described in [84]. Both of the interfaces (see above) are fully operable and are used for RL sharing.

SmartGateway interface is currently used for connection with knowledge management system (KMS) Graasp [85] which is an affiliated part of GoLab project [86]. Most of the RLs from REMLABNET were shared with Graasp. RL is

transformed into the specific block which is suitable for sharing. The OpenSocial gadgets link [87] is generated and provided to the administrator. Administrator is able to access RL at the Graasp system and adjust all information suitable for sharing. After that the RL is accessible for all Graasp users without any other registration at REMLABNET site.

#### **5.4.1 The SCOPES project**

The SCOPES [88] program of the Swiss National Science Foundation (SNSF) and The Swiss Agency for Development and Co-operation (SDC) [89] in the scheme of “Scientific co-operation between Eastern Europe and Switzerland” and the project was “Enabling Web-based Remote Laboratory Community and Infrastructure (IP)” with number IZ74Z0\_160454, was launched in 1990, came to an end on 31 December 2016 [90]. The project was oriented on spreading the modern technique of RL with participants of Switzerland (as steering participants A group), Slovak Republic (as participants B group) and Serbia (as participants C group). It was envisaged the scheme for transferring technologies for transfer from advanced participants A and B to the developing partners C. The participants in this project were:

- EPFL, School of Engineering, Switzerland (partner A),
- University of Trnava, Faculty of Education, Slovakia (partner B),
- University of Belgrade, Faculty of Mechanical Engineering, Serbia (partner C),
- University of Kragujevac, Faculty of Science, Serbia (partner C).

The system REMLABNET, as the main topic of the present thesis, was partially financed and supported by SCOPES project.

The main goal of the SCOPES program was to extend quality of scientific projects. We were the partner of SCOPES project during whole time. Financial cover helped me to realize this thesis. From this project we bought three laboratories which are situated in Tomas Bata University in Zlin: Wave laboratory [91] [92], Radioactivity [93] and Electromagnetic induction [94].

## 5.5 Summarization of Chapter 5 Results

*In the Subchapter 5.1 REMLABNET functions – choice of cloud SW and its optimization we had to align basic functionalities of standalone REMLABNET with to be functionalities of CC-R, namely, to embed individual RLs and provide their functioning, Enable Diagnostics of RLs, Enable communication in the virtual classes, Enable connectivity with another RLMS, Provide connectivity of clients from arbitrary locality, Provide unification of interfaces, Provide booking system, Ensure storing of measured data (see p. 28, Chapter 4.1 and p. 57, Subchapter 5.1.1 Cloud and the RL functions). For the purpose turned out after detailed inquiry and comparison to be the most suitable available SW VMWare v Cloud (see p. 60-62, Subchapter 5.1.2 Suitable of cloud software for the Remote Laboratories). Followed the multiparameter and sophisticated installation of the cloud SW and the system was ready for next API embedding. At this stage REMLABNET as API in question was installed.*

*In Chapter 5.2 Security and reliability optimization of REMLABNET we solved one of the major goals of the thesis security and reliability of API application in the cloud system. For this purpose, we used several acknowledged methods.*

*In Subchapter 5.2.1 Penetration testing (see p. 66) was used and applied in seven steps (see Figure 11 in Subchapter 4.2.1), specifically Social engineering penetration test: it examines the confidence of clients to provide personal data by phishing (Appendix C), Network service penetration test (see more in Appendix B), Web application penetration test: it examines vulnerability of the application (Appendix D), Cloud penetration testing: it examines the reliability of the special features of cloud (Appendix E). Especially surprising was the Social penetrating test dealing with approaches of clients to security sensitive steps, where corrective instructions of clients had to be introduced. Also, other PT revealed considerably leaks in Network, SW and HW and so may be considered as start of the improving steps in several directions. Worth mentioning is application and results of SQL Injection in Web application penetration tests.*

*In Subchapter 5.2.2 Fault stability influence in REMLABNET (see p. 70) we dealt this problem in integral stability of the network in Trnava with respect to REMLABNET functioning, especially with issues of transfer and redundancy protocols. Subsequent monitoring of the communication using EXFO FTB 200 (Fig 24) gave interesting results with the necessity of building of artificial attenuation for achieving optimal functioning of stability. Also, subsequent measurement of transient dropouts (in Figure 25 and 26) gave important hints on imperfections in optical fibre. And in Figure 27 is depicted the principal of anti-spy coordinate determination on optical fibre. In 5.2.3 alignment with general requirements on*



security and with corresponding laws of the Slovak Republic and GDPR of EU is reported.

In major Subchapter 5.2.4 Optimization of the Cloud (p. 83) we carry out alignment REMLABNET requirements with the cloud properties using Latency, Packet loss, Windows size and transferred data on output quantity throughput. This quantity turned out to be decisive for any API embedded in cloud and using the procedure for REMLABNET and its requirements we established cloud properties specified by two quantities Latency and Packet Loss (Table 7, Figure 30 and 31, p. 86-89). Taking in consideration of REMLABNET requirement of throughput  $T=250$  Mbps in a wide range of latencies, at the present state of the network, when the DTC with RLs is located in one destination (TBU Zlin). We reach the values of latency  $L>15$ ms, which is easy to achieve with moderate price of HW, allowing for packet loss 0.1%.

In Subchapter 5.2.5 we decided how to solve storing and recovering of data produced and needed for running of REMLABNET. Our choice was twofold, Backup on magnetic type and Backup on cloud storage.

**In Chapter 5.3 Cloud computing solutions** we must answer several vital questions. REMLABNET runs on servers for processing logic that is accessed through a web browser with Internet connection. The goal was to transfer REMLABNET with all its services into a remote DTCs providing cloud services infrastructure and operated by Trnava University in Trnava.

In Subchapter 5.3.1 REMLABNET implementation in the cloud, the result of our embedding activities, forming CC-R (version 2014) in Figure 33 (p. 96) with its main blocks 1 and 2, CC-R as its embedded counterpart has new blocks 3 and 4. On top of this by installation were created following services IaaS - Infrastructure as a Service, PaaS – Platform as a Service and SaaS – Software as a Service.

In Subchapter 5.3.2 Advanced cloud computing services were described in detail additional services, needed for running on advanced TC-REMLABNET, RLaaS – for grant RLs clients, GaaS – which serve to harvest the information from RLs, TCaaS – where we use thin client instead of classic PC, STaaS - for sharing and storing measured values.

**In Chapter 5.4 Remote Laboratories Management Systems federalization in frame of EU**, we described steps from individual RLs to Interoperability in four levels. Next, we showed Interoperability between REMLABNET and Learning Management System Moodle and discussed Learning Tools Interoperability with Go-Lab and Graasp.

In Subchapter 5.4.1 The SCOPES project, we described main idea and usage of this project for REMLABNET.

## 6. DISCUSSION OF RESULTS

Let us discuss the results of the thesis “Cloud computing solutions and security of EU remote interactive laboratories network” in light of the formulated goals in discussion style.

The main subject of the present thesis is the general problem of standalone API, created by programmers – PhD students of FAI TBU – Remote Laboratory Management System REMLABNET for administration and management of about 40 Remote laboratories (RLs) of the Consortium TBU, TU and CHU. This SW package was created in years 2012-2013 and worked successfully for those few RLs we then possessed. The problems occurred when number of RLs grew, highly involved in the teaching process. At that time REMLABNET provided inclusion of individual RLs and their functioning, enabled diagnostics of RLs, communication in the virtual classes, enabled connectivity of clients from arbitrary locality, enabled booking system, ensured storing of measured data and last, but not least enabled connectivity with another RLMS (Go-Lab and Graasp). All this was presented and described in Chapters *4.1 REMLABNET as a working method* and cloud implications and *5.1 REMLABNET functions – choice of cloud SW and its optimization*.

The first goal was to embed standalone REMLABNET to virtualized cloud with all its theoretical advantages and its cloud resulting SW, services and functions were described Chapter *4.1 REMLABNET as a working method and cloud implications* and Subchapter *5.1.1 Cloud and the RL functions*. For the purpose turned out after detailed inquiry and comparison to be the most suitable SW – VMWare vCloud with its advantages, disadvantages and peculiarities, described in Subchapter *5.1.2 Suitability of cloud software for the Remote Laboratories*. To ensure all existing functionality at the stage of installation the SW some obligatory services, IaaS (Infrastructure as a Service), PaaS (Platform as a Service) and SaaS

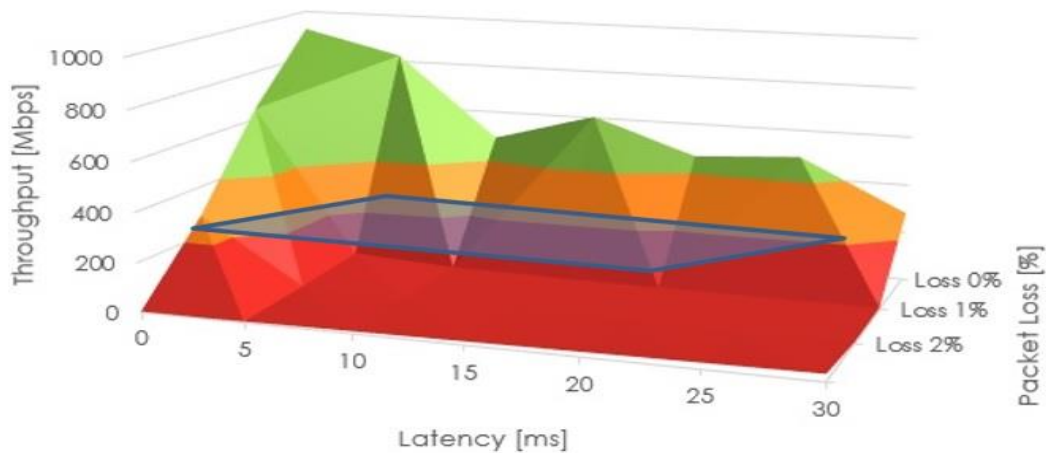
(Software as a Service) were installed for the purpose and explained in general in *Chapter 5.3 Cloud computing solutions* and especially in Subchapters *5.3.1 REMLABNET implementation in the cloud* and *5.3.2 Advanced cloud computing services*.

The second goal was all embracing Security problem, which was presented in *Chapter 4.2 Security and reliability of CC-REMLABNET* on a general level both with obvious and obligatory precautions and with special aiming at security of RLs. Then in *Chapter 5.2 Security and reliability optimization of REMLABNET* the problem is solved exclusively for RLs and CC-REMLABNET. For the purpose several test of security qualities was undertaken. In Subchapter *5.2.1 Penetration testing* was used and applied in seven steps (see Figure 11 in Subchapter *4.2.1 Penetration testing*) giving results of Social engineering penetration test. It examines the confidence of clients to provide personal data by phishing, also there are results of Network service penetration test, Web application penetration test, which examines vulnerability of the application and Cloud penetration testing, which examines the reliability of the special features of cloud. Especially surprising was the Social penetrating test dealing with approaches of clients to security sensitive steps, where corrective instructions of clients had to be introduced. In Subchapter *5.2.3 Remote laboratories data protection* alignment with general requirements on security and with corresponding laws of the Slovak Republic and GDPR of EU is presented. In Subchapter *5.2.5 Optimization of data collection, saving, backup and archiving results* we solved how to store and recover data in CC-REMLABNET.

The third goal deals with possible network failure, its cause, spreading and termination. In Subchapter *5.2.2 Communication quality of REMLABNET* (see p. 70) we dealt this problem in integral stability of the network in Trnava with respect to REMLABNET functioning, especially with issues of transfer and redundancy

protocols. Then, faults generation, their causes and position determination are described as the results of measurements using apparatus EXFO FTB 200 (Fig 24) gave interesting results with the necessity of building of artificial attenuation for achieving optimal functioning of stability. Also, subsequent measurement of transient dropouts (in Figure 25 and 26) gave important hints on imperfections in optical fibre and anti-spy coordinate determination on optical fibre.

In major Subchapter 5.2.4 *Optimization of the Cloud*, we carry out alignment REMLABNET requirements with the cloud properties using Latency, Packet loss, Windows size and Transferred data on output quantity throughput. This quantity turned out to be decisive for any API embedded in cloud and using the REMLABNET requirement of throughput  $T=250$  Mbps in a wide range of latencies, at the present state of the network, when the DTC with RLs is located in one destination (TBU Zlin). We reach the values of latency  $L>15$ ms, which is easy to achieve with moderate price of HW, allowing for packet loss 0.1%. The summarizing result of cloud optimization with respect to CC-REMLABNET needs is in Figure 45 depicting 3D view of Throughput  $T$  as function of both Latency  $L$  and Packet Loss  $PL$  (0, 1, 2 %), together with demands of REMLABNET on cloud qualities (blue plane).



*Figure 45 3D view of Throughput  $T$  as function of both Latency  $L$  and Packet Loss  $PL$  (0, 1, 2 %), together with demands of REMLABNET on cloud qualities (blue plane).*

The fourth goal, creating virtualized cloud interface environment is dealt with in Subchapter 5.3.1 *REMLABNET implementation in the cloud*, is summarized in Figure 33 with its main blocks both stemming from original standalone REMLABNET and added in designing CC-REMLABNET. Additional services created for the work with REMLABNET and RLs IaaS - Infrastructure as a Service, PaaS – Platform as a Service and SaaS – Software as a Service were designed as added value, their functioning is described in Subchapter 5.3.2 *Advanced cloud computing services*.

The fifth goal fulfillment was described in Subchapter 5.4.1 *The SCOPES project*. It was the participation in the SCOPES program of the Swiss National Science Foundation (SNSF) and The Swiss Agency for Development and Co-operation (SDC) in the scheme of “Scientific co-operation between Eastern Europe and Switzerland” and the project was “Enabling Web-based Remote Laboratory Community and Infrastructure (IP)” with number IZ74Z0\_160454. The project enabled partial financing of building CC-REMLABNET and REMLABGRAB. Also SCOPES supported the federalization activities towards Go-Lab, Graasp and LTI.

## **7. ASSETS OF THE THESIS FOR SCIENCE AND EXPERIENCE**

The assets of the thesis in the field of Remote Laboratories and their management system may be in general formulated as success in designing more efficient, secure, reliable system of management Remote Laboratories via its cloud counterpart CC-REMLABNET and TC-REMLABNET together with REMLABGRAB as a tool for scaling and designing of new generation of federalized management system.

Above this, to especial mentioning belong following assets

1. Describing the functionality of general cloud system by unified criterion function, enabling expressing the major measurable quantity of the cloud quality throughput as a function of quantity Latency, Packet Loss and Window size. This enables finding optimal setup of the cloud both SW and HW for a specific application and its demands.
2. Application of procedure describing in point 1, we, using demands of CC-REMLABNET, established corresponding cloud HW ensuring its functioning. Generally, the procedure resulted both in optimization of properties of CC-REMLABNET, but before all enabled price optimization of cloud setup.
3. The programming of cloud services RlaaS, GaaS, TCaaS and STaaS ensuring much greater deal of embedding of the system of Remote Laboratories into cloud services.
4. As a new idea for future is a complete embedding in to virtualized cloud is an idea of Thin Client virtualized cloud solution enabling to provide huge number of simulations and Remote laboratories exclusively by cloud technologies. For corresponding cloud technology solutions will serve new introduced tool REMLABGRAB, described in thesis.

## 8. CONCLUSIONS AND OUTLOOK

We may formulate following conclusions:

- Science, industry and education call for more intensive involvement of both remote sensing and remote interactive measurements,
- Cloud technologies turned out to be suitable tool and environment for massive spreading of remote interactive measurements, due to economical and safety arguments,
- In principle, all the split and not unified or standardized branch of remote measurements and experimentation may be transferred globally into few cloud-oriented datacenters with all the rich services hoped for by the community of pioneers and adherent to the field of Remote laboratories,
- For the outlined bright future of the branch of Remote laboratories remains to persuade the responsible and financing authorities as seemingly high investments into globally functioning activities or may bring back much higher assets and payback.

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## List of acronyms and abbreviations

### A

ADDA	-	Analog Digital Digital Analog
AI	-	Artificial Intelligence
API	-	Application Programming Interface
ARP	-	Address Resolution Protocol

### C

CC	-	Cloud Computing
CC-R	-	Cloud Computing REMLABNET
CLI	-	Command Line Interface
CMS	-	Content Management System

### D

DTaaS	-	Data as a Service
DTC	-	Datceneter
DTCs	-	Datacenters

### E

ER ISES	-	Easy Remote Internet School Experimentation System
EU	-	European Union

### F

FO	-	Fiber Optic
FSM	-	Finite State Machine

### G

GDPR	-	General Data Protection Regulation
GE	-	Gigabit Ethernet
Gbps	-	Gigabit per a second

### H

HSRP	-	Hot Standby Router Protocol
HTTP	-	Hyper Text Transfer Protocol
HW	-	Hardware

### I

- IaaS - Infrastructure as a Service
- ICT - Information and Communication Technologies
- IP - Internet Protocol
- IPs - Institutional Partnerships
- ISES - Internet School Experimental System

## **J**

- JS - Java Script

## **K**

- KMS - Knowledge Management System

## **L**

- L - Latency
- LaaS - Laboratory as a Service
- LAN - Local Area Network
- LMS - Learning Management System
- LMSs - Learning Management Systems

## **M**

- MAC - Media Access Control
- Mbps - Megabit per second
- MFD - Mode Field Diameter
- MLS - Monitoring Line System
- MS - Measure Server
- MTBF - Mean Time Between Failure
- MTTF - Mean Time To Failure

## **O**

- OS - Operating System
- OSPF - Open Shortest Path First

## **P**

- PaaS - Platform as a Service
- PL - Packet Loss
- PT - Penetration Testing
- PTR - Packet Tracer

## **R**

RaaS	-	Rig as a Service
RDP	-	Remote Desktop Protocol
RIP	-	Routing Information Protocol
RL	-	Remote Laboratory
RlaaS	-	Remote Laboratory as a Service
RLG	-	REMLABGRAB
RLs	-	Remote Laboratories
RLMS	-	Remote Laboratory Management System
RLMSs	-	Remote Laboratory Management Systems
RTT	-	Round Trip Time

## S

SaaS	-	Software as a Service
SDC	-	The Swiss Agency for Development and Co-operation
SIaaS	-	Simulation as a Service
SLA	-	Service Level Agreement
SM	-	Single Mode
SNSF	-	Swiss National Science Foundation
STaaS	-	Storage as a Service
STP	-	Spanning Tree Protocol
SW	-	Software

## T

T	-	Throughput
TBU	-	Tomas Bata University
TC	-	Thin Client
TCP	-	Transmission Control Protocol
TLS	-	Transport Layer Security
TOL	-	Transient Optical Loss

## U

UCaaS	-	Unified Communications as a Service
UCS	-	Unified Computing System™
UCT	-	Unified communications technology

## V

VRRP	-	Virtual Router Redundancy Protocol
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## W

- W - Window Size
- WDM - Wavelength Division Multiplexing
- WWW - World Wide Web

## Publication activities

1. ICTIC 2013, Security and risks in Cloud Computing for remote laboratories, 25.-29.March 2013, Žilina – Slovakia
2. ICTIC 2014, Neural Networks for Security Enhancement in Cloud Computing, 24.-28.March 2014, Žilina – Slovakia
3. Beňo, Schauer, Vlček. University network with Remlabnet and communication among individual datacenters. Varna, Bulgaria: IEEE Computer Society's Conference Publishing Services, 2014. ISBN 978-1-61804-246-0
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9. ICTIC 2017, Remote laboratory management centre REMLABNET embedded in University network - security and redundancy aspects, 26.-30.March 2017, Žilina – Slovakia
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11. Schauer F., M. Krbeček, P. Beňo, M. Gerža, L. Pálka, P. Špilakova, T. Komenda, M. Ožvoldová, Ž. Gerháťová and L. Tkáč. REMLABNET IV — LTI federated laboratory management system with embedded multiparameter simulations. 2017 14th International Conference on Remote Engineering and Virtual Instrumentation (REV). 15.-17 March 2017, Columbia University, New York, USA. Pg. 340-350.
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13. SIT 2018 – International Scientific Days, Cloud Computing concept for digital consumers, 16.-17. May.2018, Nitra – Slovakia, DOI: 10.15414/isd2018.s10.01
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*VOIP* – MTF STU Trnava, IP telephony

*Dochádzka* – MTF STU Trnava, system for monitoring of staff

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FO and TP – projects for construction fiber optic, Wi-Fi and metallic network topology (Sanet, Ideacreative, CableCom)

TK – system thin the client (SUN Microsystems/Oracle/Huawei)

Safetica – implementation system for desktop security and monitoring activity of the users

MLS – system for monitoring connectivity of fiber optic cable

Poseidon – system for monitoring of the DTC

MARS – system for monitoring and administration of the DTCs

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Computers network and technology

Part of Artificial Intelligence, Neural network

Part of martial arts, head coach of wushu (WuShu team Slovakia), winner on International wushu Championship in HongKong [CN], winner on the International wushu Championship in ShenZhen [CN], four times winner on the International wushu festival in Huludao [CN]

Research in computer networking and neural networking

Travelling

Chinese medicine – acupressure, fire methods

**Other knowledge:**

Programming languages: C, C++, Java, Shell, (particulary Delphi, Pascal, Assembler)

Networking: LAN, MAN, WAN; UTP, STP, Fiber Optic, WiFi

Technology: Cisco (prefered), AlliedTellesyn, SMC, Zyxel, Transition

Operating Systems: Linux - Unix, Solaris, Windows

Virtualization: VMWare (VSP, VTSP certified), MS HyperV, Huawei Fusion, Open Stack

Web application: PHP, Java, JavaScript, XML, CSS

Databases systems: MySQL, MS SQL

Remote experiments: remote laboratory for physics, ISES

Servers: email, www, ftp, sql, dns, dhcp, other...



Pavel Beňo

Cloudcomputingové riešenia a bezpečnosť siete vzdialených  
interaktívnych laboratórií EU

Cloud computing solutions and security of EU remote interactive laboratories  
network

Doctoral Thesis

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