Cloud computing solutions and security of EU remote interactive laboratories network

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Doctoral Thesis Summary

Tomas Bata University in Zlín

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Cloudcomputingové riešenia a bezpečnosť siete vzdialených interaktívnych laboratórií EU

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Acknowledgements

Abstract

The submitted work deals with the problems, which has faced the Consortium REMLABNET of remote laboratories – Tomas Bata University Zlín, 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, its embedding into 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, ošetrenie bezpečnosti a overenie tohoto nového cloudového systému testovaním optických tras, penetračným testovaním a vytváraním špeciálnych cloudových služieb. Súčasťou dizertačnej prace sú tiež riešenia prospievajúce 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.

Content

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. 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 [1] 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 [2] (the whole history of e-experimentation is described in [3]).

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 [4]:

- 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 [5]. 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 [6]. 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 Zlín) 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.

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 [7]. More details about the ISES and how to build computer – oriented hands on experiments are to be found in the recent monographs [6] [8].

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 1 [9] 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. It is conceived as an FSM that can be in one of a finite number of states [10].
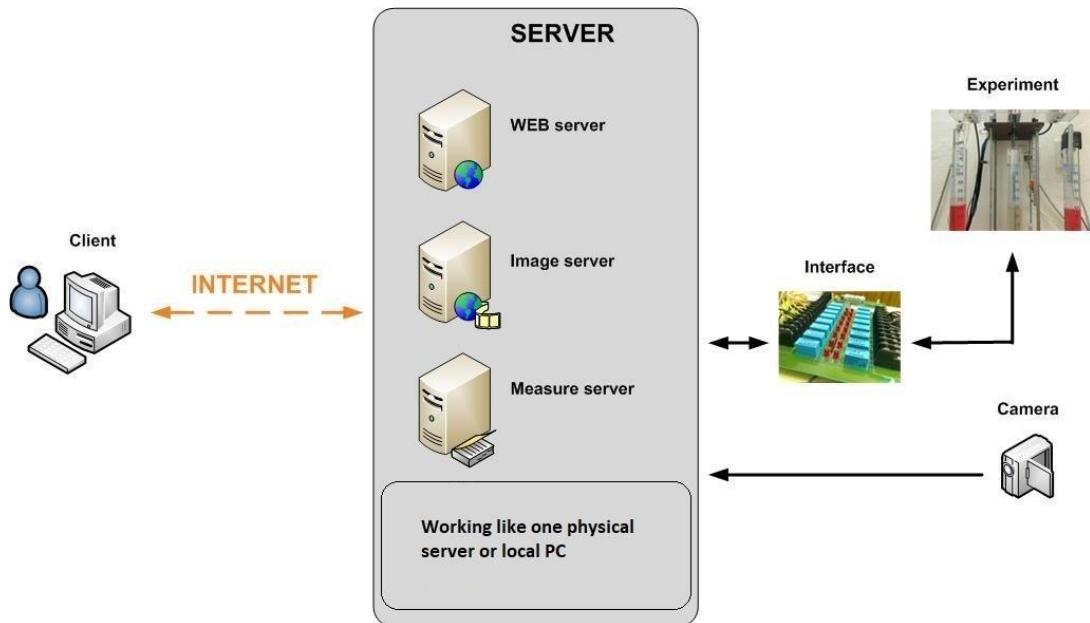
Figure 1 Basic scheme of the server-client communication in RL

2. INTRODUCTION TO REMOTE LABORATORIES MANAGEMENT SYSTEM REMLABNET

The general trend is the connecting of standalone RLs to one management system, where it is possible to connect different laboratories under one unified layout. System like this is generally denoted Remote Laboratory Management System (RLMS) [11]. RLMS and whose main features are depicted in Figure 2.
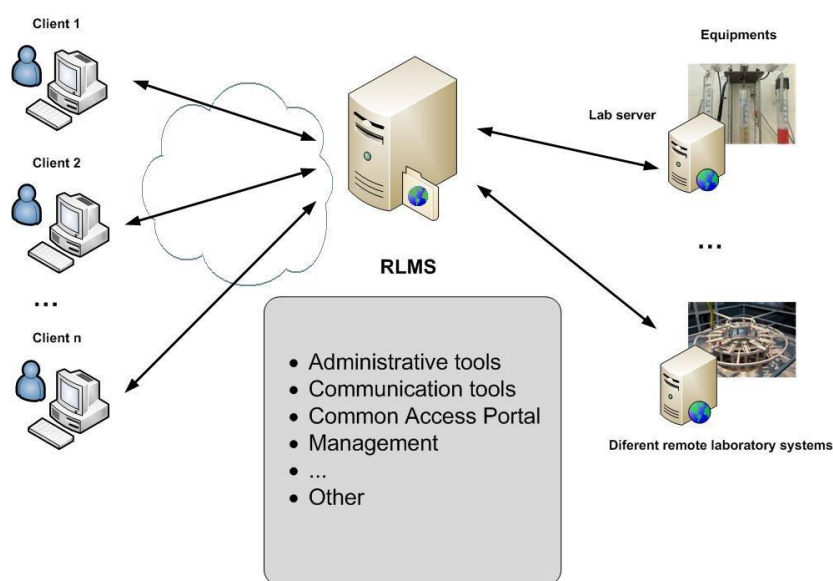
Figure 2 Remote laboratory management system – the example of arrangement

TU, TBU and 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 provided via portal www.remlabnet.eu. In general, three methods for the access to RL are available [12]:

− 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 in 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 C.

4. 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.

4.1 REMLABNET as a working method

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. To assure the sophisticated and complex functions of any RLs there is Content Management System (CMS) (Figure 3), 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 5) 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 letter part of the Data warehouse database is based on the MYSQL, where all data from CMS and of the modules are stored.
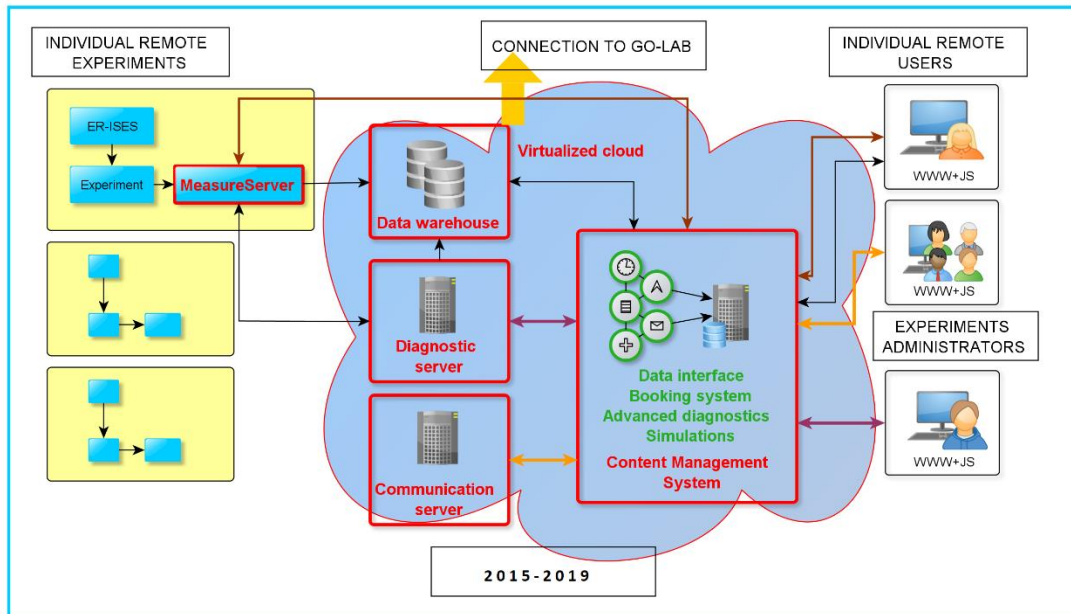
Figure 3 Idea of the representation of the Remote Laboratory Management System REMLABNET schematically embedded in a virtualized cloud (shaded area) Mind the "federalization" connection to the RLMS Go-Lab, also serving to Graasp interface

The Diagnostic server (Figure 3), 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 [13].

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. Here are some methods used to build increased security.

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.

4.2.2 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 4, namely the relation of attenuation on fiber optic in relationship with used radius and wavelength (bending loss). In Figure 4, we depict 3 options of attenuation of optical fiber and we use mostly the wave lengths 1310nm, 1490nm and 1550 nm.
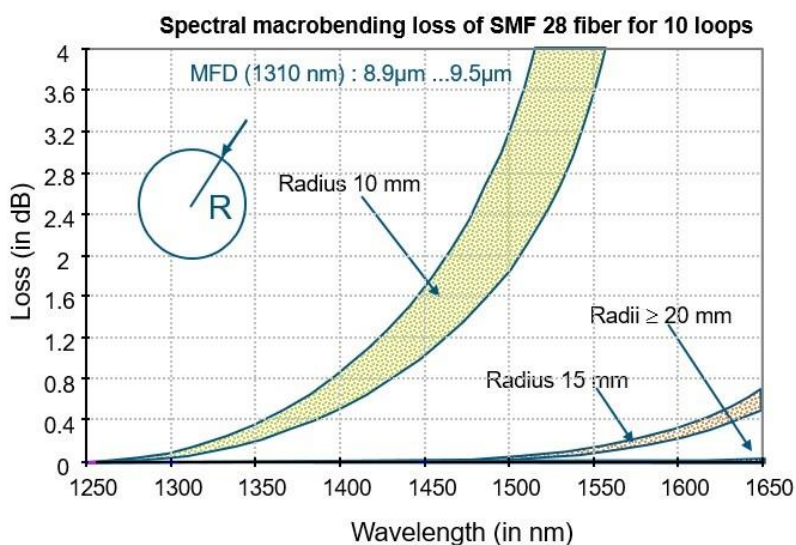
Figure 4 Bending loss of performance of standard SM fiber (ITU-T G. 652D)

4.2.3 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 in main thesis, 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.

4.2.4 Modeling of the University network failure spreading

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 [14]. Statistical modeling tools such as variable distributions, queueing models and Markov models [15] 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.

4.2.5   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 [16].

To increase chances of recovering lost or corrupted data, disaster recovery of REMLABNET, we follow the 3-2-1 rule [17]:

- 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 8.

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 to the Panel 2 in Figure 5 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 5. They are

services, pertinent to creation of infrastructure (IaaS), platform (PaaS) and software providing (SaaS). In Panel 4 there is the scope of services, forced by the improvement of RLs functioning, designed by the team of CC providers.

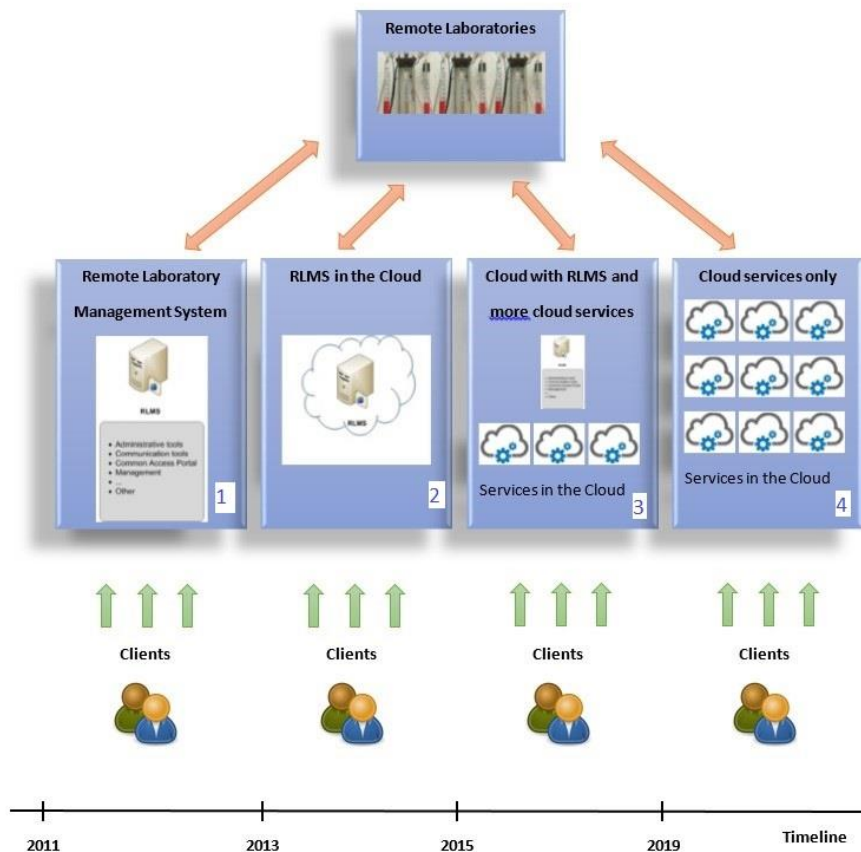*Figure 5 Steps and timeline of REMLABNET and RLs embedding into the cloud*

Let us next describe the basic functions of CC:

− **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),

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- **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).

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.

4.4 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. 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.

5.1 REMLABNET functions – choice of cloud SW and its optimization

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 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 [18]. The private cloud and its infrastructure require 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.

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.

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 [19]). Let us shortly present SW. The VMware vCloud SW combines a vCloud Director server group with the vSphere platform. Weset 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.

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.

5.2.1   Penetration testing

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.

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 in the main thesis):

- Network service penetration test (see next text and Appendix B in the main thesis),

- Social engineering penetration test: it examines the confidence of clients to provide personal data by phishing (Appendix C in the main thesis),

- Web application penetration test: it examines vulnerability of the application (Appendix D in the main thesis),

- Cloud penetration testing: it examines the reliability of the special features of cloud (Appendix E in the main thesis).

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. It should be strictly prohibited to allow the failure to move within one system from one node

to the other, described in [20] [21] [22]. 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.

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).

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. 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).

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 6 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 6a. We discovered, that the attenuation of communication is on the level of 4.11dB (Figure 6b), 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 6c).
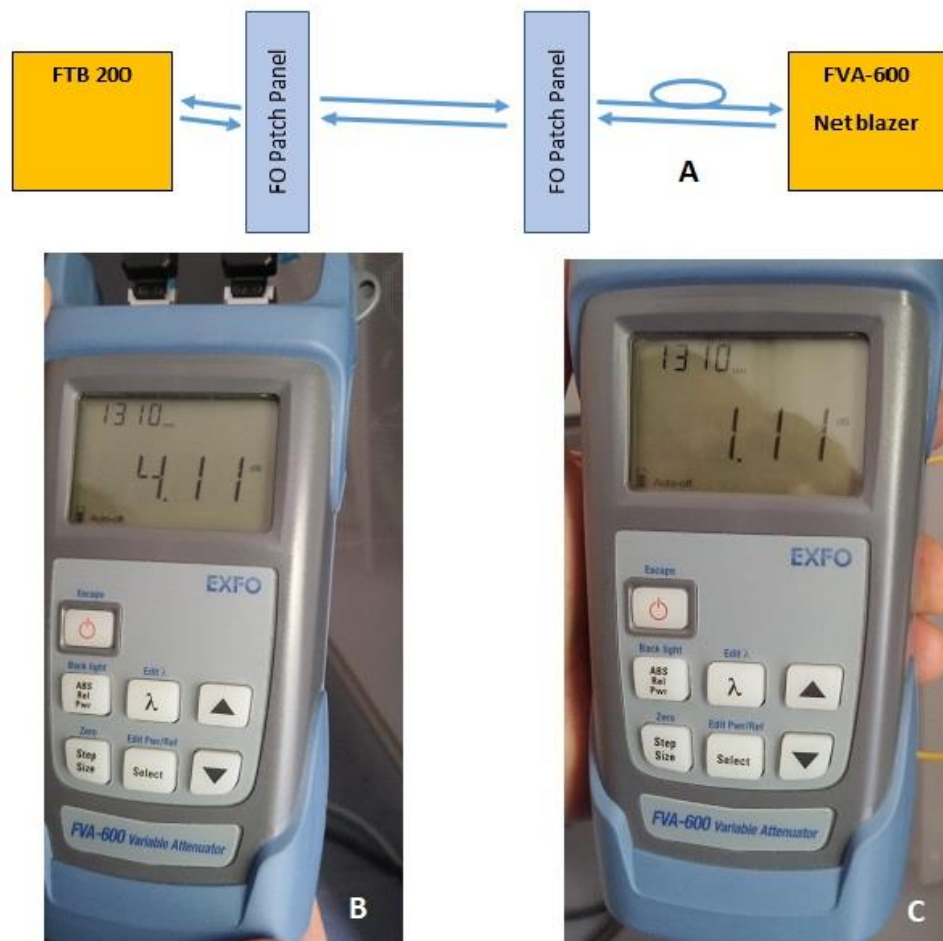

Figure 6 Overload measurements of the SFP modules, a)arrangement of measurements with additional attenuator b)attenuation measurements by EXFO

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 7.
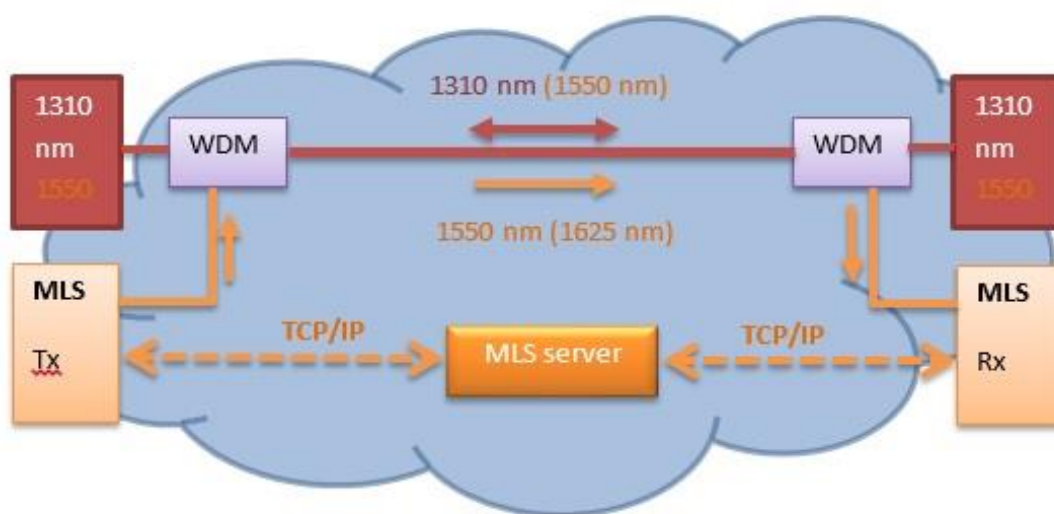
Figure 7 Schematical arrangement of on line delay and attenuation measurements on the optical network

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. 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 8.

Figure 8 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 Europea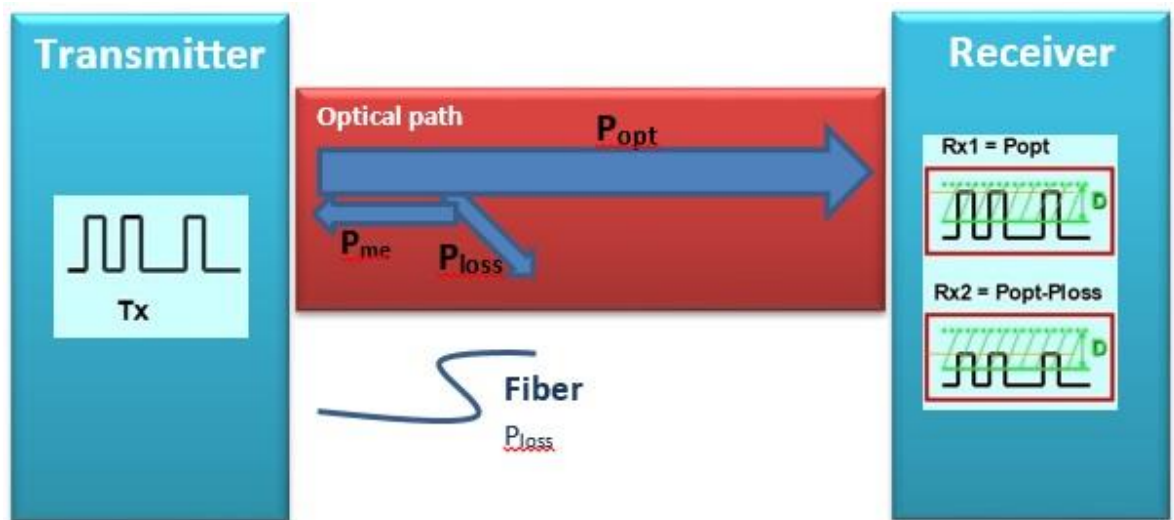n Union, which edits and replaces existing law about personal data protection [23]. As to the REMLABNET, which we started to operated in the frame of the law 69/2018 Z.z. "Law about cyber security" of the Slovak Republic, which was even more stringent that one of the EU. Because of the mentioned regulations, 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 in main thesis – 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 in main thesis.

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 choice for the problem solving the criterion function of the necessary throughput for ensuring reliable functioning of the application

$$T = f(L, PL) \qquad (1)$$

where two variables are latency L є(0,30)ms, and loss of packets PL є(0,2)%, which we knew for REMLABNET from orientation measurements, whereas fixed variables were window size $W = 85KB$ 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 9) to find optimum of the criteria function for variable quantities latency L and loss of packets with fixed the other.

Variables: L є(0,30)ms, PL є(0,2)%

Server A — Server B

Fixed variables: $W = 85KB$, $\Delta t = 30$ s, 2Gbps FC line shaped to 1Gbps
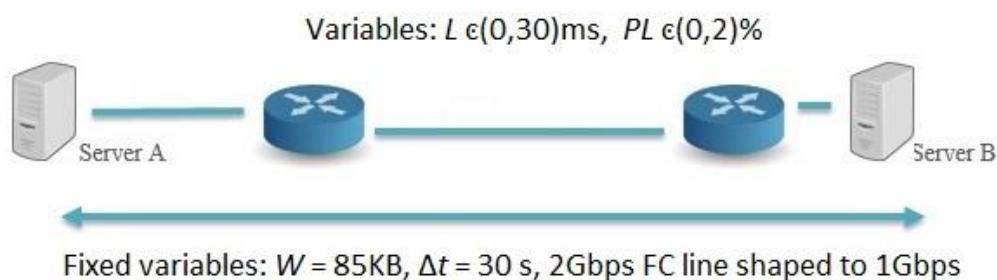
Figure 9 Scheme of interconnection of two host for throughput T optimization

The results of the optimization procedure are summarized in detail in Figure 10 is corresponding results in graphical form. Here it presents the results of the criterion function (1) 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%.
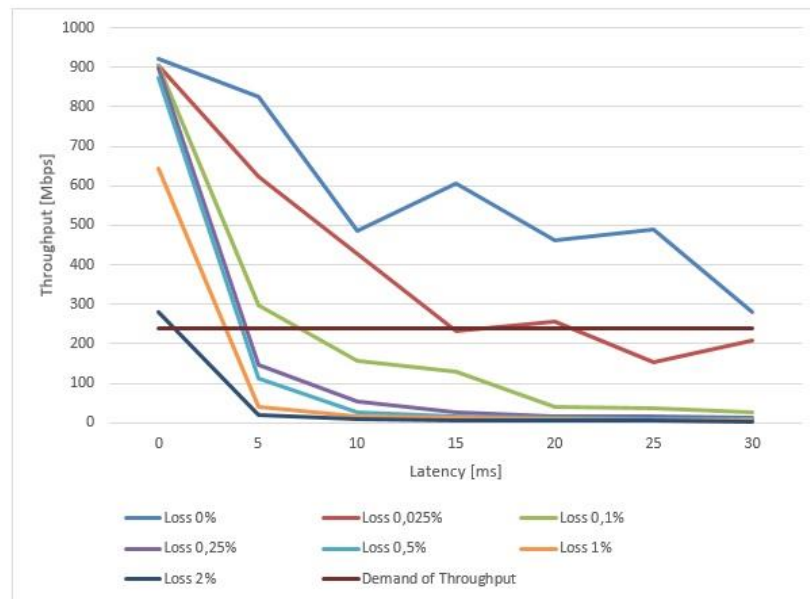
Figure 10 Network throughput T=f(L, PL) (Eq.(5)) for values of packet loss 0% (light blue), 0.025% (light brown), 0.1% (green), 0.25% (violet), 0.5% (cyan), 1% (orange), and 2% (dark blue);also denoted are the requirements of REMLABNET (dark brown).

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

Data backup 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.

5.3 Cloud Computing solutions

In our case, main issue of REMLABNET is provided like Software as a Service. 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.

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.

5.3.1 REMLABNET implementation in the cloud

Our CC planned concept and idea of Cloud Computing REMLABNET (CC-R) was documented in chapter 4.1 in Figure 3. Let us describe it more detail.
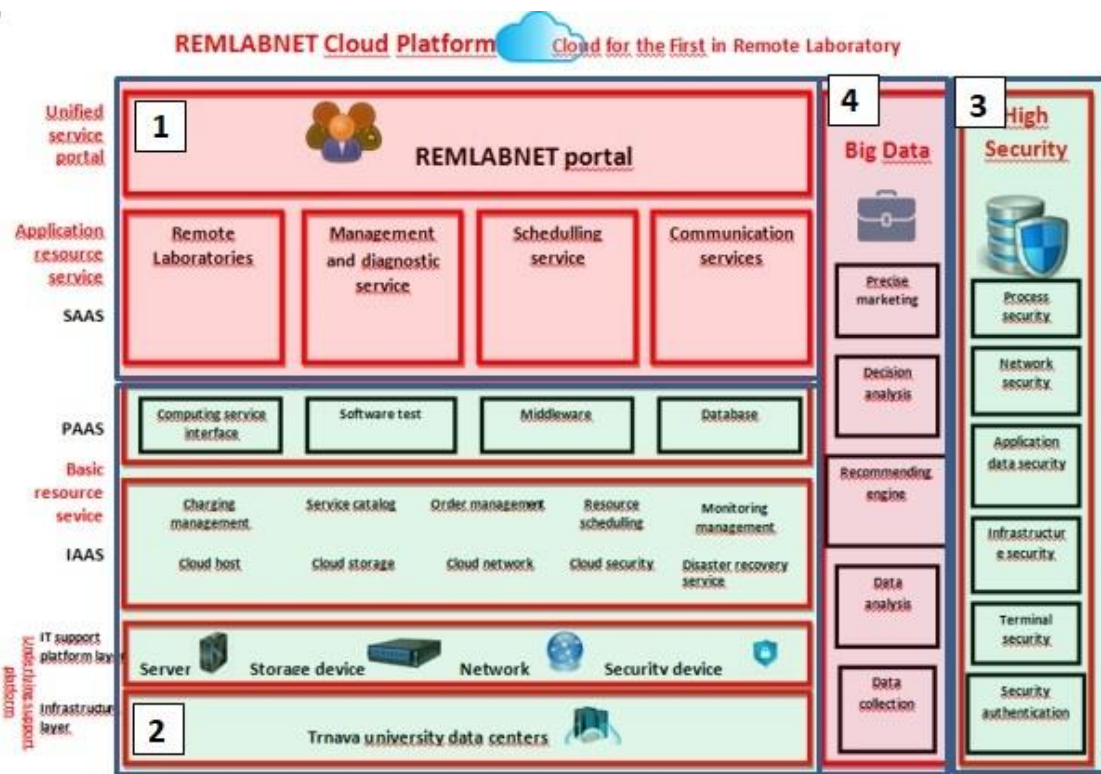
Figure 11 CC-REMLABNET - cloud implementation - detailed structure (version 2014)

In Figure 11 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 11) represents the standard and known functions of REMLBNET containing **Remote laboratories**, **Management and diagnostic service, Scheduling service** and **Communication services** [24]**.** 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

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.

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 12)

a) **Equipment level,** contains RLs to allow the distance measurement or observation by individual clients without limitation on time or location [25] [26],

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 [27],

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 [28] [29],

d) **Interoperability level,** this level allowing interoperability between different models, unifying their communication interface and opens the possibilities of sharing RLs despite these differences [30].

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Figure 12 Scheme of levels of federalization integration

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 [31] and the associated knowledge management system Graasp [32]. Second interface is based on the Learning Tools Interoperability (LTI) [33] [34] protocol, which is primary designed to connect learning systems such as a learning management system (LMS) [35] 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 13).
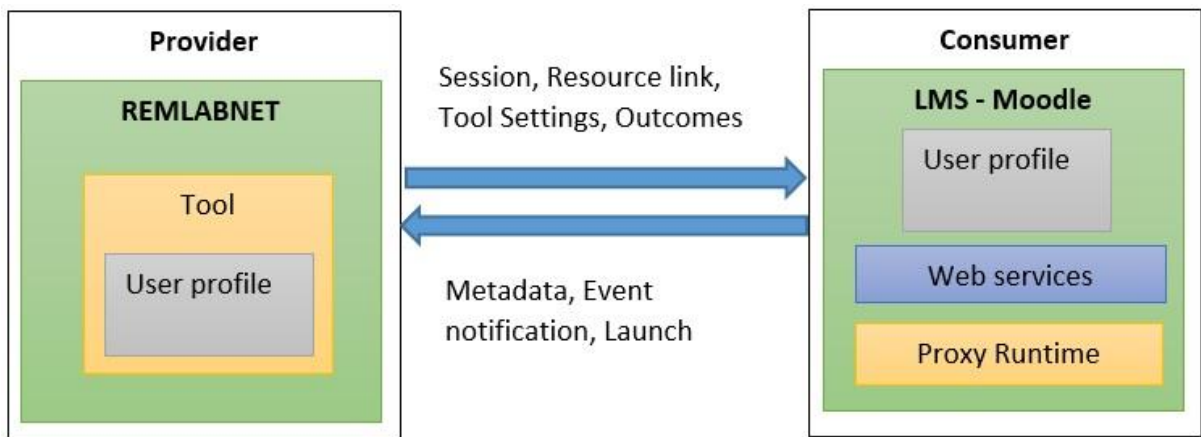
Figure 13 The general scheme of Interoperability between REMLABNET and Learning Management System

REMLABNET was federated into Go-Lab project ecosystem with an HTTP plugin [36] for the Smart Gateway. HTTP plugin is used like web. Technical solution and used methods are fully described in [37]. 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 [38] which is an affiliated part of GoLab project [39]. 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 [40] 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 [41] program of the Swiss National Science Foundation (SNSF) and The Swiss Agency for Development and Co-operation (SDC) [42] 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 [43]. 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 [44] [45], Radioactivity [46] and Electromagnetic induction [47].

6. DISCUSION OF RESULTS

Let us discus 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 Chapter *5.1 REMLABNET functions – choice of cloud SW and its optimization.* 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 *5.1.1 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 (Planning and preparation, Reconnaissance, Discovery, Analysing information and risks, Active intrusion attempts, Final analysis and Report Preparation*)* 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* 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 6) 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 7 and 8) 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>15ms, 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 14 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).
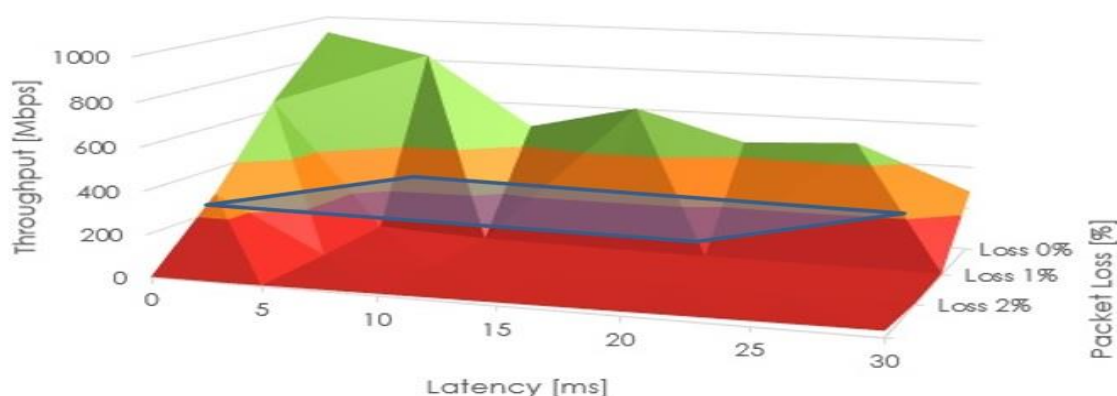

Figure 14 3D view of Throughput T as function of both Latency L and Packet Loss PL
(0, 1, 2 %), together with demands of REMLABNET on cloud qualities
(blue plane).

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 11 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 fulfilment 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. OUTLOOK AND CONCLUSIONS

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.

9. DOCTORAL THESIS SUMMARY IN SLOVAK LANGUAGE

Skúsme si teraz prediskutovať zadanú tému "Cloud computing solutions and security of EU remote interactive laboratories network" preložené "*Cloudcomputingové riešenia a bezpečnosť siete vzdialených interaktívnych laboratórií EU*" podľa zadaných cieľov práce.

Hlavným predmetom práce je problém samostatnej aplikácie vytvorenej tímom programátorov – PhD študentov na FAI UTB – Remote Laboratory Management System (RLMS) REMLABNET na administráciu a management okolo 40 vzdialených laboratórií (RL) Konzorcia UTB, TU and KU. Tento SW balíček bol vytvorený v rokoch 2012-2013 a pracoval samostatne pre niekoľko RL. Problém nastal, keď počet RL vzrástol, zapríčinený vyučovacím procesom. V tom čase REMLABNET obsiahol individuálne RL a ich funkcie, podporoval diagnostiku, komunikáciu v rámci virtuálnych tried, umožňoval pripojenie klientov z ľubovoľnej lokality, povolil rezervačným systém, ukladanie meraných dát a doplnil konektivitu k iným RLMS (Go-Lab a Graasp). Toto popisujeme v Kapitole *4.1 REMLABNET as a working method* a *5.1 REMLABNET functions – choice of cloud SW and its optimization.*

Prvým cieľom bolo vnorenie samostatného REMLABNET do virtualizovaného cloud prostredia so všetkými výhodami. Výsledný cloud SW, služby a funkcie popisujeme v Kapitole *4.1 REMLABNET as a working method and cloud implications* a Kapitole *5.1 REMLABNET functions – choice of cloud SW and its optimization.* Pre využitie sa po detailnom preskúmaní a porovnávaní pozdával najpoužiteľnejší SW – VMWare vCloud s výhodami, nevýhodami a vlastnými črtami , ktoré popisujeme v Podkapitole *5.1.1 Suitability of cloud software for the Remote Laboratories.* K zaisteniu všetkých existujúcich

funkcionalít na stupni inštalácie sa vytvorili služby IaaS (Infrastructure as a Service), PaaS (Platform as a Service) a SaaS (Software as a Service) ktoré boli inštalované pre využitie v rámci REMLABNET a popisujeme ich v Kapitole *5.3 Cloud computing solutions* a špeciálne v podkapitolách *5.3.1 REMLABNET implementation in the cloud* a *5.3.2 Advanced cloud computing services*.

Druhým cieľom bola bezpečnosť, ktorá je rozoberaná v Kapitole *4.2 Security and reliability of CC-REMLABNET* od všeobecnej úrovne po najnutnejšie predpoklady so špeciálnymi cieľmi bezpečnosti laboratórií. Následne, v Kapitole *5.2 Security and reliability optimization of REMLABNET* je problém zabezpečovaný exkluzívne pre RL a CC-REMLABNET. Využívame niekoľko testov na zaistenie bezpečnosti. V Podkapitole *5.2.1 Penetration testing* využívame a aplikujeme sedem krokov penetračných testov (Planning and preparation, Reconnaissance, Discovery, Analyzing information and risks, Active intrusion attempts, Final analysis and Report Preparation), ktoré ponúkajú výsledky sociálneho inžinierstva skúškami klientov na poskytovanie osobných údajov prostredníctvom phishingu. Ďalej využívame výsledky testov Network service penetration test (sieťových), Web application penetration test (webaplikačných), ktoré ukázali zraniteľnosti aplikácie a Cloud penetration testing (cloudových testov), ktoré ukázali odolnosť špeciálnych vlastností cloudu. Špeciálne prekvapivé boli výsledky Social ingeneering penetrating test, ktoré poukázali neznalosť klientov z oblasti bezpečnosti, kde inštruovanie klientov sa ukázalo ako nutnou podmienkou reálneho fungovania. V Podkapitole *5.2.3 Remote laboratories data protection* poukazujeme na všeobecné požiadavky bezpečnosti a k nim prislúchajúce zákonné normy Slovenskej republiky a nariadenie EU v podobe GDPR. Podkapitola 5.2.5 *Optimization of data collection, saving, backup and archiving results* poukazuje, ako ukladať a obnovovať dáta v CC-REMLABNET.

Tretí cieľ obsahoval zabezpečenie možných sieťových porúch, ich príčiny, šírenie a odstránenie. V Podkapitole *5.2.2 Communication quality of REMLABNET* sa zaoberáme týmto problémom a celkovej stabilite siete v Trnave s REMLABNET, špeciálne s problémom prenosu a redundancie. Následne generovanie poruchy, jej príčinu a určenie pozície popisujeme vo výsledkoch merania pri použití zariadení EXFO FTB 200 (Figure 6), ktoré dávajú zaujímavé výsledky s potrebou využitia umelého tlmiaceho člena na zabezpečenie optimalizácie fungovania a stability. Rovnako vložené merania náhodných porúch (na obrázkoch Figure 7 a 8) poukazujú zaujímavé nedostatky optických vlákien a poukazujú o protišpionážnej kontrole na optickom vlákne.

Hlavná Podkapitola 5.2.4 *Optimization of the Cloud,* poukazuje na zobrazenie potrieb REMLABNET a cloud vlastností s využitím Latencie (Latency), straty paketov (Packet loss), veľkosti prenášaného okna (Windows size) a množstva prenesených dát (Transferred data) na výslednú kvalitu priepustnosti (Throughput). Toto je možné určiť pre akékoľvek aplikácie vnorené do cloud prostredia a využiť potreby REMLABNET na priepustnosť T=250 Mbps v rozsahu povolených latencií na stávajúcej sieti, kedy dátové centrá s RL sú umiestnené aj v inej destinácii (UTB Zlin). Využívame hodnoty latencie L<15ms, kde sa jednoducho ukladajú dáta a určuje ľahšie cena HW, pri povolení celkovej straty paketov 0.1%. Na sumarizáciu výsledku optimalizácie cloudu s ohľadom na CC-REMLABNET využijeme obrázok Figure 15, ktorý znázorňuje 3D graf priepustnosti *T* ako funkcie Latencie *L* a straty paketov *PL (0, 1, 2 %)*, spoločne s požiadavkami REMLABNET v cloude (modrá plocha).
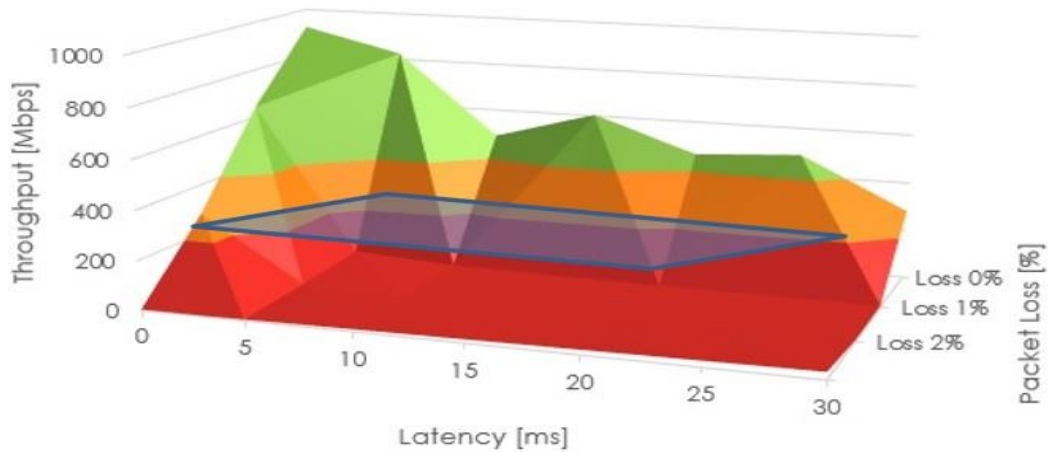
Figure 15 3D view of Throughput T as function of both Latency L and Packet Loss PL (0, 1, 2 %), together with demands of REMLABNET on cloud qualities (blue plane).

Štvrtý cieľ vytvorenie virtuálneho cloud prostredia je pojednávané v Podkapitole *5.3.1 REMLABNET implementation in the cloud*, a sumarizované na obrázku Figure 11, kde popisujeme hlavné bloky od samostatného REMLABNET až k pridanému dizajnu CC-REMLABNET. Rozšírené služby vytvorené pre prácu s REMLABNET a RL, kde IaaS - Infrastructure as a Service, PaaS – Platform as a Service and SaaS – Software as a Service sú vytvorené ako pridaná hodnota, ich fungovanie a popis uvádzame v podkapitole *5.3.2 Advanced cloud computing services*.

Plnenie piateho cieľu je popísané v Podkapitole *5.4.1 The SCOPES project*. Toto bolo súčasťou projektu SCOPES agentúr Swiss National Science Foundation (SNSF) a The Swiss Agency for Development and Co-operation (SDC) v sekcii „Scientific co-operation between Eastern Europe and Switzerland" a projekt bol s názvom "Enabling Web-based Remote Laboratory Community and Infrastructure (IP)" pod číslom IZ74Z0_160454. Projekt umožnil čiastočné financovanie budovania CC-REMLABNET a REMLABGRAB. Rovnako projekt SCOPES umožnil federalizáciu a aktivity smetom k Go-Lab, Graasp a LTI.

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List of figures

List of acronyms and abbreviations

ADDA	-	Analog Digital Digital Analog
AI	-	Artificial Inteligence
API	-	Application Programming Interface
ARP	-	Address Resolution Protocol
CC	-	Cloud Computing
CC-R	-	Cloud Computing REMLABNET
CLI	-	Command Line Interface
CMS	-	Content Management System
DTaaS	-	Data as a Service
DTC	-	Dataceneter
DTCs	-	Datacenters
ER ISES	-	Easy Remote Insternet School Experimentation System
EU	-	Europen Union
FO	-	Fiber Optic
FSM	-	Finite State Machine
GDPR	-	General Data Protection Regulation
GE	-	Gigabit Ethernet
Gbps	-	Gigabit per a second
HSRP	-	Hot Standby Router Protocol
HTTP	-	Hyper Text Transfer Protocol
HW	-	Hardware
IaaS	-	Infrastructure as a Service
ICT	-	Information and Communication Technologies
IP	-	Internet Protocol
IPs	-	Institutional Partnerships
ISES	-	Internet School Experimental System
JS	-	Java Script
KMS	-	Knowledge Management System
L	-	Latency
LaaS	-	Laboratory as a Service
LAN	-	Local Area Network
LMS	-	Learning Management System
LMSs	-	Learning Management Systems
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
OS	-	Operating System
OSPF	-	Open Shortest Path First
PaaS	-	Platform as a Service
PL	-	Packet Loss
PT	-	Penetration Testing

PTR	-	Packet Tracer
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
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	-	Throughput
TBU	-	Tomas Bata University
TC	-	Thin Client
TCP	-	Transmission Control Protocol
TLS	-	Transport Layer Security
TOL	-	Transient Optical Loss
UCaaS	-	Unified Communications as a Service
UCS	-	Unified Computing SystemTM
UCT	-	Unified communications technology
VRRP	-	Virtual Router Redundancy Protocol
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
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5. Marketing Identity, Explosion of Innovations; International Scientific Conference, 4th-5th November 2014, Smolenice, Slovak republic, ISBN978-80-8105-666-6, ISSN1339-5726
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10. SIT 2016 – International Scietific Days, University network with security aspects and redundancy to ISP, 19.-20.May.2016, Nitra – Slovakia
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13. SIT 2018 – International Scietific Days, Cloud Computing concept for digital consumers, 16.-17. May.2018, Nitra – Slovakia, DOI: 10.15414/isd2018.s10.01
14. Marketing Identity 2019 – accepted article, 6.11.2019 conference lecture

Curriculum vitae

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Date of birth:	5. October 1977
Marital status:	divorced
Mother language:	Slovak language

Education:

2011 –	Postgraduate student, UTB Zlín
2008 – 2009	Additional pedagogical minimum
1996 – 2002	Slovak University of technology,
	Faculty of material science and technology,
	Applied informatics and automatization in industry, certificated in MSc. Eng.
1992 – 1996	Secondary agricultural vocational school,

Study Mechanics-Electronics, digital and control technology, certificated on work on the electronic systems

Professional experiences:

2010 – present   Centre of ICT, University of Trnava; Headmaster of department, Security manager, Network administrator, administration of virtualization

2006 – 2010   Division of communication and information systems MTF STU, deputy-head; Department of systems and technological support, head of department

2002 – 2006 Department of information systems, administrator of network, security administrator

Other in years 2002-2010:

Member of SANET (Slovak Academic Network) – administrator and project member of the network;

Assistant and teacher on Slovak University of Technology and The University of SS. Cyril and Methodius in Trnava;

CO-PI of SCOPES project for Slovakia and Czech Republic.

Language:

English

Russian

Other language:

Latin

Chinese

Skills:

Communicableness

Responsibility

Flexibility

Independence

Interest in communication with people

Leading with human resources

PC skills

Project management

Projects:

COPMA III – VÚJE a.s. Trnava, security procedure for nuclear power station

Webmail – MTF STU Trnava, communication driver for employees

GIS MTF – MTF STU Trnava, geographic information system

VOIP – MTF STU Trnava, IP telephony

Dochádzka – MTF STU Trnava, system for monitoring of staff

Security system – system for monitoring SDaJ (student hostel) area, camera system

FVE – projects for photovoltaic power plants

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

Many projects and publications of medicine, wushu and taiji

Participate on projects from EŠF (5.1.1, 5.1.2, 5.1.3, 5.1.4, 5.1.5, 1.1, 1.2) – Europe Union projects

DochOKS – system for monitoring of staff, University of Trnava

Hobby:

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 Chanpionship 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:

Programing 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 Summary