TECHNICAL ASSISTANCE PAPER

IPV6 POLICY, STRATEGY AND TECHNICAL REQUIREMENTS/SPECIFICATION FOR AN IPV6 LABORATORY IN MONTENEGRO

Final version

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Note: Version 13 of this document is the final version of this document.

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1 Introduction

Although Internet Protocol version 6 (IPv6) has been in use for a while, its implementation is not developing fast enough to keep up with the exponential growth of the digital ecosystem. The largest number of applications still relies on the old protocol, IPv4, and the usage of the internet remained mostly the same, as a large number of servers and services uses only IPv4 protocol.

In 2012, the biggest Internet providers together with suppliers of network equipment and web companies around the globe, launched a so-called World IPv6 Launch, with the main goal of permanently acquiring IPv6 addresses for their own products and services. Since then, we have seen the significant growth in the usage of IPv6 protocol, albeit not fully substituting IPv4. For example, almost 30% of Google users use IPv6, more than 50% of Internet traffic from certain countries goes through IPv6, and almost all subscribers of the biggest mobile networks use IPv6.

Based on this Google data1, the IPv6 protocol is mostly implemented in Belgium, which has a penetration of 56%, followed by Germany with 51% and Greece with 48%. In Switzerland, Luxembourg, France, Estonia, United Kingdom, Hungary, Portugal, Netherlands and Finland this figure is over 30% whereas in all other European countries IPv6 penetration is lower than 30%. Besides the countries that are mentioned above, many other countries still have a very low availability of IPv6 protocol within their national ecosystems.

Due to the almost total absence of IPv6 in Montenegro, there is a need to raise awareness of the importance of IPv6, which would be a necessary functionality for the digitization of society, and a starting point for the development of services in IoT frames. In January of 2019 an expert team engaged by the Agency for Electronic Communications and Postal Services (EKIP) released a strategy for the implementation of IPv6 in Montenegro[2], a fundamental step towards the popularization of the implementation of the IPv6 protocol. The key point of this paper is a short review of above-mentioned national strategy to make a transition to the IPv6 protocol and creating a concept of an IPv6 laboratory.

As the digital transformation has become a fundamental cornerstone of all aspects of our lives since the outbreak of the global pandemic and is accelerating, ensuring a swift transition from IPv4 to IPv6 is ever more important. The objective of this report is to build upon the developments at the national level and identify a way forward to operationalize the implementation of IPv6 in Montenegro.

2 IPv6 Policy and Strategy

2.1 National plan for IPv6 transition in Montenegro

Awareness about the necessity of transitioning to the IPv6 protocol is necessary for all participants in the ICT ecosystem for efficient realization of this process. This awareness is currently missing in Montenegro, therefore the delaying of the process of implementation with the risk of creating negative arise for all users in the country. It is possible to assume that the low implementation percentage is due to the relatively high investments required to upgrade existing infrastructure and make it IPv6-ready. Taking into consideration the life cycle of devices, and that after relatively short period of time the infrastructure requires upgrading, equipment will naturally have all the necessary technical conditions for implementation of the new protocol. Apart from sporadic interventions on the topic by the academic community, the question about raising awareness of the need of implementation of the IPv6 protocol in Montenegro is not getting the appropriate attention.

Moreover, it is evident that in the near future the accent will be on the implementation of the 5G network which, due to its characteristics (gigantic leap in the speed of data transfer, possibility of large number of 5G devices in small geographic surfaces without loss of connection and problems of overwhelming of 5g spectrum), will soon show the potential for development of all kinds of services. This will not just be limited to mobile devices transferring speech and video, but will also allow the Internet of Things (IoT) to thrive and get a new space for implementation. In this context, should the transition away from IPv4 not materialize, the development of the market for innovative technologies will be limited.

In light of the above, there is the necessity for Montenegro, as for all other countries with limited or no IPv6 implementation, to launch a campaign with the goal of raising awareness about the possibilities which new Internet protocol could provide. Too slow pace of IPv6 implementation would lead to stepback in introducing new services and technologies dictated by market . The campaign would need to include the meaningful subjects involved in this process, including operators of public electronic and communication networks and services (ISP), business users (companies) and public institutions on local and state level, as well as the general public.

Usually, the National Regulatory Authority (NRA) in the field of electronic communications is the organization which is better positioned institutionally and qualified to work on raising awareness and promotion of implementation of IPv6 protocol. Beyond the NRA, which in the case of Montenegro is the Agency for Electronic Communications and Postal Services (EKIP), it is important to identify other organizations or bodies in Montenegro who can also contribute to this goal, such as the Ministry of Economic Development, Ministry of Public Administration, and the Chamber of Commerce and University of Montenegro.

In the context of a national strategic plan for IPv6 transition, the subjects who may directly influence the mass implementation of the IPv6 protocol should be identified and engaged. Traditionally, those are i) operators of public electronic networks and services (ISP), ii) business users and iii) public institutions on local and state level.

2.1.1 Raising awareness of operators of and ISPs on public electronic and communications networks and services

The biggest consumers of address spaces are Internet Service Providers (ISPs). As the space for IPv4 reduces and finding it increasingly difficult to allocate new segments according to market demand, ISPs will be the first to feel the pressure to migrate to IPv6. In addition, there is a growing number of demand from business users for adequate IP ranges with paid services . It can also be argued that the pandemic has caused an unexpected growth of various online services and that the growth can only be expected to continue.

On the other hand, by implementing 5G mobile telecommunication networks, and facilitating mass use of IoTs (Internet of Things) and MTC (Machine Type Communications) devices, the need for new address resources will dramatically grow and IPv4 will not be able to support that growing need.

Generally speaking, the operators of public electronic communications networks and services are aware of potential problems that may arise, and considering that they have expert staff, raising awareness about the need to transfer from IPv4 to IPv6 could be realized in a rapid and efficient manner by organizing round tables and expert conferences.

2.1.2 Raising awareness of local and State public institutions

Local and State public institutions have a very wide structure of connections and services. It is worth noticing that there is no unique approach to all the State institutions and every one has its own speed of development. Also, unlike ISPs, stuff in public institution generally don't have same business environment that allow professional growth, and that is a large obstacle in implementation of new technologies and standards. ICT staff often does not have enough training, or does not have the influence on the development of networks and services. The result is the lack of awareness among decision makers about the speed of implementation of new services, which are the key to giving significance to public institutions and their services and in turn strengthen the need for digitization of public institutions, including the transition to IPv6.

Holding capacity building activities such as workshops and meetings is important to give a strong vision of implementation of new services in public institutions and by that also highlighting the necessity of implementation of the IPv6 protocol on which the fast digitization would be depend on. On the other hand, by preparing the special courses and practical examples, decision makers can fully touch with hand the benefits of these new technologies. Moreover, training staff from various institutions could help accelerate the implementation within the respective organizations.

2.1.3 Raising awareness of business users

Business users are a significant part of the sector utilization of ICT solutions, as according to Montstat 99.5% of business users have Internet access in 20203. With the ongoing pandemic as well

as with the implementation of electronic fiscalization and digitization of public institutions, business users are forced to rely more on ICT solutions in their day to day operations, which contributes to accelerating the digitization and digitalization of society. In this context, the implementation of IPv6 protocol by their ISPs would only improve their business management.

On the other hand, taking into account the rise of 5G networks and the fact that a growing number of devices will rely on these networks, there is an expectation for dramatic change in business models, compared to what has been observed so far. By enhancing the speed and reliability it is expected that multimedia content that reaches the end users will grow substantially. This will lead to new customer concept that business users have to cover in order to keep their market share.

The focus for business users should be on a strong IPv6 protocol campaign (a similar one to that of the transition to digital television), which would be targeted on , IT engineers and on business owners. Professional societies of managers as well as consulting companies should play a key role, as it is in their interest, as well as should Economic Chambers, whose role is to foster the competitiveness of their members.

It is necessary to emphasize to business users which are not taking the steps for implementing IPv6 protocol within their network will bring about losing the competitiveness of companies in the future. Basic information about the IPv6 protocol, its benefits and the risk from lack of implementation should be provided to the business community by means of a simple educational program and reference materials. This could be achieved by the Government, which may wish to allocate some budget for this purpose, by industry operators, which can organize promotional lectures of IPv6 and use these events in their own promotion, or both.

The target group for these lectures should include system and network administrators in companies, leaders of IT departments and other people responsible for making decisions of technological goals and investments in those companies. Training could be performed by different institutions (e.g. University of Montenegro) and other organizations who can deploy qualified personnel. The focus of these activities should be on the characteristics of IPv6 protocol; usage of corresponding service architecture including standardized control and signal mechanisms; implementation of IPv6 to IPv4 structure; managing performances; promotion of regulatory knowledge, etc. In this way, the targeted groups will be able to acquire the advanced skills necessary for contributing to a successful IPv6 migration.

Implementing some or all activities mentioned above can achieve the additional benefit of raising awareness of the general public about the importance and innovations that IPv6 protocol can bring in relatively short period of time.

2.1.4 Existing activities aimed at raising awareness and current initiatives toward implementation of IPv6

In the 2016 government of Montenegro issued Strategy of development of informational society in Montenegro till 2020, and one of the key strategic points was elaborating an implementation plan for IPv6 in Montenegro. According to this strategic position, EKIP with support from ITU took the

necessary steps in order to fulfill the mission. In 2018 EKIP engaged Institute for Development and Research Montenegro 4 to make a Plan for migration to IPv6 protocol. A team of experts was engaged, and in January of 2019, the work with all demanded project details was published2:

- Reasons / motives for IPv6 implementation - advantages and challenges;
- Analysis of the current state of IPv6 implementation in Montenegro and existing challenges;
- Analysis of potential methods of IPv6 implementation - advantages and disadvantages;
- IPv6 implementation challenges related to security and privacy;
- Overview of experiences in IPv6 implementation in the most developed EU countries and in some countries from the rest of the world;
- Analysis of scenarios for the implementation of IPv6 in Montenegro, from a technical and economic aspect (especially for the private and public sector);
- Recommendations for the implementation of IPv6 in public institutions in Montenegro;
- Detailed plan for IPv6 implementation in one public institution (Ministry, UCG).

The analysis of current state in Montenegro showed that there was no systematic plan providing guidance on the direction to be taken regarding upgrading infrastructure to prepare for the implementation of the IPv6 protocol. Due to previous unawareness of decision makers in regards to importance of ICT, all networks are designed with lack of vision of IPv6, and many infrastructure devices don't have IPv6 support. In addition, the document identified public institutions as significant stakeholders for the ICT ecosystem in Montenegro, and that a plan to implement IPv6 must be largely directed towards these organizations. Specifically, the document included following activities:

- Establishment of a national body ("IPv6 task force") or team that will create an action plan for migration to IPv6 state institutions, coordinate activities, promote and monitor the migration process. Team members should be representatives of entities that will be responsible for the migration process (relevant state institutions, regulators, operators, academia, ICT business, etc.);
- Encouraging and organizing the promotion of the advantages of the IPv6 protocol and education on migration techniques of entities at all levels of public administration and residential users;
- Organizing and conducting surveys of operators on their plans for transition to IPv6;
- Forming and formalizing recommendations and guidelines to state institutions regarding the implementation of IPv6 at the administrative level;
- Establishment of a laboratory, within the University of Montenegro, for testing the steps of transition to IPv6;

- Encouraging planned migration in the network of the University of Montenegro to IPv6 as a pilot project based on which to document the experience and knowledge that can be applied to other state institutions;
- Preparation of a migration plan for state institutions based on the Project and documented activities of University of Montenegro;
- Realization of migration of state institutions by applying dual-stack technology to IPv6 protocol.

According to previously mentioned activities, at the end of 2019 the Ministry of Economic Development established a national body for coordination of process of implementation of IPv6 protocol. This body consist of representatives from the Ministry of Economic Development , the Ministry of Public Affairs, the Agency for Electronic Communications and Postal Services and the University of Montenegro. The activities under the scope of this body are:

- Coordination of activities necessary for implementation and migration to IPv6 protocol;
- Encourage and organize promotion of advantage of use IPv6 protocol;
- Organize education about migration of IPv6 protocol on all levels of public administration and residential users;
- Initiate establishing of laboratory at University of Montenegro in order to test necessary steps in implementation of IPv6;
- Prepare and monitor plan of migration to IPv6;
- Regular reports about the state of implementation toward Ministry of Economic Development.

As of March 2020, the global pandemic slowed down activities of this National body, and with state election in august of 2020 and the transition of government, there has been a natural delay in the activities planned within the National body.

On the other hand, it must be noted that some of the operators are already in the planning stage of implementation of IPv6. Some of them already made preliminary tests for transport networks, while others are elaborating strategies and comparing different approaches.

Telenor Montenegro has already successfully tested their core network for transport of IPv6. Their test took into account various models of implementation (tunneling, translation and dual stack), but dual stack was chosen as the solution creating less issues to the implementation. As reported in National Workshop for Montenegro IPv6 strategy, policy and implementation5, beside security assessment testing and user migration, their next steps include software upgrades and reconfiguration for IPv6 dual stack in these domains:

- EPC
- Billing & Mediation
- Provisioning

- Gi FW, CG NAT
- DNS

Montenegro Telekom also tested successfully their network for transportation of IPv6. All network segments of their network are IPv6 supported, and that includes not only Core and Gateway, but also Mobile Packet Core, MPLS Layer and Fix BB Core.

Their next plan is to implement IPv6 through 4 phases:

Phase 1: Transition model selection for Fix and Mobile BB

Phase 2: IPv6 and DNS features in service segment (DNS, AAA, DHSP)

Phase 3: IPv6 and DS functions on CPE (Fix BB HGW and mobile phones)

Phase 4: Support Environment: Provisioning, Charging, OM, Monitoring

Finally, it is worth noting that the Government started preliminary talks with operators in order to identify steps for connecting government institutions with IPv6. Their next steps include developing a pilot project that would involve IPv6 for the Government portal[1], and also implementing IPv6 in government institutions based in Government building Vektra. However, it remains unclear whether government has already established a strategy of implementation of IPv6 in its own infrastructure, and this is where possible support may be needed by external IPv6 experts.

2.1.5 Proposition for raising awareness in the future

Over the past two years there has been an extensive national effort in raising awareness with regards to IPv6. The national plan for implementation of IPv6 identified the current state of affairs, the key pillars for action and proposed necessary steps for further activities to be implemented by the National Body, with the Ministry of Economic Development, the Ministry of Public Affairs, EKIP and University of Montenegro having the mandate to influence both the public and private ICT sector, and act as the coordinating mechanism at the national level.

As discussed, 2020 was problematic from more than one perspective, including the pandemic, and the change in government which slowed down the activities of the National body. Hence, it is necessary to restart and hasten activities of National body. Moreover, as operators are driven by customers needs, it is necessary to highlight necessity of IPv6 protocol in government institutions, and by this request from the operators implementation of IPv6 for government customers. Ministry of Public Administration hosts many private and public services, and is a driver for implementing e-Government in Montenegro. Hence, this Ministry is a strategic asset in promoting new technologies. As many of other institutions and private users rely on services provided by Ministry of Public Administration, forcing IPv6 by this Ministry can be a leverage in larger acceptance of IPv6 implementation. Considering that the large number of government institutions greatly rely on

[1] www.gov.me

outsourcing provided by ISP's or outsource companies, special provisioning policy should be enforced in regards to IPv6 support. If possible, establishing overall government provisioning base that includes not only mandatory support for IPv6, but also for other protocols or new technologies for common or special benefit (i.e. support for people with disabilities etc), would be a missing link in converging to sustainable digital society.

Two of the major operators have already taken steps toward implementing IPv6, and this is a good development testifying greater awareness of IPv6 compared to some years ago. Nevertheless, there is no regular update from the National Body on the level of implementation. As an indicator of progress, there should be continuous activities in communication of National Body with key players in order to track their development of implementation plan and realization. Those activities can be direct type, or by organizing round tables/workshops for key players, including operators, government institutions, academy sector, regulators, and ICT companies.

Therefore the recommended activities of National Body for facilitating the migration toward IPv6 should include:

- More frequent communication with key players in Montenegro ICT ecosystem:
- Communication bridge between various ICT sectors of national and local public institutions;
- Organization of round tables/workshops for interested parties to exchange experiences gained.
- Ministry of Public Affairs as driving force in implementation of IPv6 at government level

To this end, the establishment of an IPv6 laboratory for the purposes of training of experts would be of great assistance to all parties involved in IPv6 implementation by:

- Providing education and training for interested parties in accordance with the IPv6 laboratory statute;
- Ongoing training for students of ICT orientation toward IPv6 and IoT
- Providing assistance to national and local ICT departments in implementation of the IPv6 protocol.

On the one hand, the national body would coordinate awareness raisin activities at the national level and track implementation progress. On the other hand, the IPv6 laboratory can provide necessary expertise to all parties involved in the implementation of IPv6. The main focus should remain on government and public institutions, as these can act as the necessary ignition spark to motivate the private sector to make the change.

3. IPv6 Lab – Technical background

This section of the report is aimed at identifying the technical requirements and equipment needed to implement an IPv6 laboratory in Montenegro. The Center of Information System (CIS) is a unit of University, and for several decades implements ICT services for the University on various fronts. For many years it served also as an incubator for many young people who could benefit of practical trainings through the CIS. Implementation of IPv6 laboratory at University would not only benefit external interested parties in obtaining knowledge about IPv6 and IoT, but also could be of enormous help to students in broadening and practically express their knowledge gained in studies.

One part of the equipment for laboratory to which students would not have access, would be set in a specially secured room. Its characteristics will be further analyzed in the next chapters. The other equipment for which students of the laboratory would need a physical approach can be located in the study classroom of CIS in which the laboratory learning will be performed.

3.1 Existing topology and main characteristics

The Academic network of University of Montenegro (ANUM) is spreading across six cities: Podgorica, Niksic, Cetinje, Kotor, Herceg Novi i Bijelo Polje. It connects 26 locations and is formed by a topology of multiple stars by optical infrastructure. Besides the University units, this network connects the Ministry of Education and student homes in Podgorica and Niksic with optical links with 1GB/s capacity. The Central network and data center is situated in Podgorica, in rectorate building, and is located in the Center of Information System.

The Academic network has a registered ASN (Autonomous System Number) AS40981 and other address ranges: IPv4 89.188.32.0/19 i IPv6: 2a02:4280::/32 from RIPE (Réseaux IP Européens). Besides these address ranges the University also has a registered ASN for the needs of MIXP (Montenegro Internet Exchange Point) AS200608 with the following address ranges: IPv4 185.1.44.0/24 and IPv6 2001:7f8:22::/48.

The Academic network is connected with the European Academic Network GEANT with a link of capacity of 1Gb/s. This link is divided to two virtual connections one of which is intended solely for the academic traffic inside the GEANT network, and the other solely for the Internet. The tender procedure to enlarge the total capacity of the link to GEANT to 10Gb/s is currently in progress and it is expected that by 20.05.2021 the new connection will be realized.

The ASR 9001 is in function as a gateway router from 01.02.2021. The Academic network of the University of Montenegro, MIXP, EKIP services, F root server are connected on the main router. The Academic network is concentrated with pair of firewall devices: ASA5540 and ASA5515-X which aggregate the traffic from the other members of the Academic network. On the ASA5515-X it is also connected the DMZ zone, as well as protected server segment. For the aggregation of the links from the other units are used two Allied Telesis AT-x930-28GSTX L3 switch with 24 100/1000 SFP ports. Remote units are connected via optical infrastructure. Infrastructure within

University campus is owned by University, and units that are outside the campus and in the other cities are connected through Telecom MIPNET infrastructure of 1Gb/s capacity.

The table below lists devices that exist inside the frame of the Academic network with current state of support for IPv6:

Table 1: Edge devices per University unit

	University Unit	Existing routing devices	number	IPv6 compatability
1	CIS (CORE)	ASR 9001	1	yes
2	CIS (CORE)	ASR 1002	1	yes
3	CIS (CORE)	Allied Telesis AT-x930-28GSTX	3	yes
4	CIS (CORE)	CISCO ASA 5515-x	1	yes
5	CIS (CORE)	CISCO Asa 5540	1	yes
6	CIS (CORE)	Mikrotik CCR1016-12S-1S	1	yes
7	CIS (CORE)	Mikrotik CRS326-24G-2S+RM	1	yes
8	Faculty of Architecture	Allied Telesis AT-AR770S	1	no
9	Faculty of Civil engineering	Allied Telesis AT-AR770S	1	no
10	Faculty of Metalurgy and Technology	Allied Telesis AT-AR770S	1	no
11	Faculty of Law	Allied Telesis AT-AR770S	1	no
12	CANU (Montenegrin Academy of Science and Art)	Allied Telesis AT-AR770S	1	no
13	Faculty of Medicine	Allied Telesis AT-AR770S	1	no
14	Faculty of Philosophy	Allied Telesis AT-AR770S	1	no
15	Faculty of Maritime Studies	Allied Telesis AT-AR770S	1	no
16	Biotechnical Faculty	Allied Telesis AT-AR770S	1	no
17	Physiotherapy studies	Allied Telesis AT-AR770S	1	no
18	Historical Institute	Allied Telesis AT-AR770S	1	no
19	Faculty for Sport and Physical Education	Allied Telesis AT-AR770S	1	no
20	Faculty of Tourism and Hospitality	Allied Telesis AT-AR770S	1	no
21	Faculty of Electrical Engineering	Mikrotik CRS326-24G-2S+RM	1	yes
22	Faculty of Science and Mathematics	Allied Telesis AT-RP24i	1	no
23	Faculty of Mechanical Engineering	Allied Telesis AT-RP24i	1	no
24	Faculty of Economics	Allied Telesis AT-9924SP	1	no
25	Student campus	Allied Telesis AT-AR750S	1	no
26	Faculty of Economics – Bijelo Polje	Allied Telesis AT-AR750S	1	no
27	Institute of Marine Biology	Allied Telesis AT-AR750S	1	no
28	Faculty of Fine Arts	Mikrotik CRS326-24G-2S+RM	1	yes

On the figure 1 it is shown the current topology of connectivity in the Academic network frame:

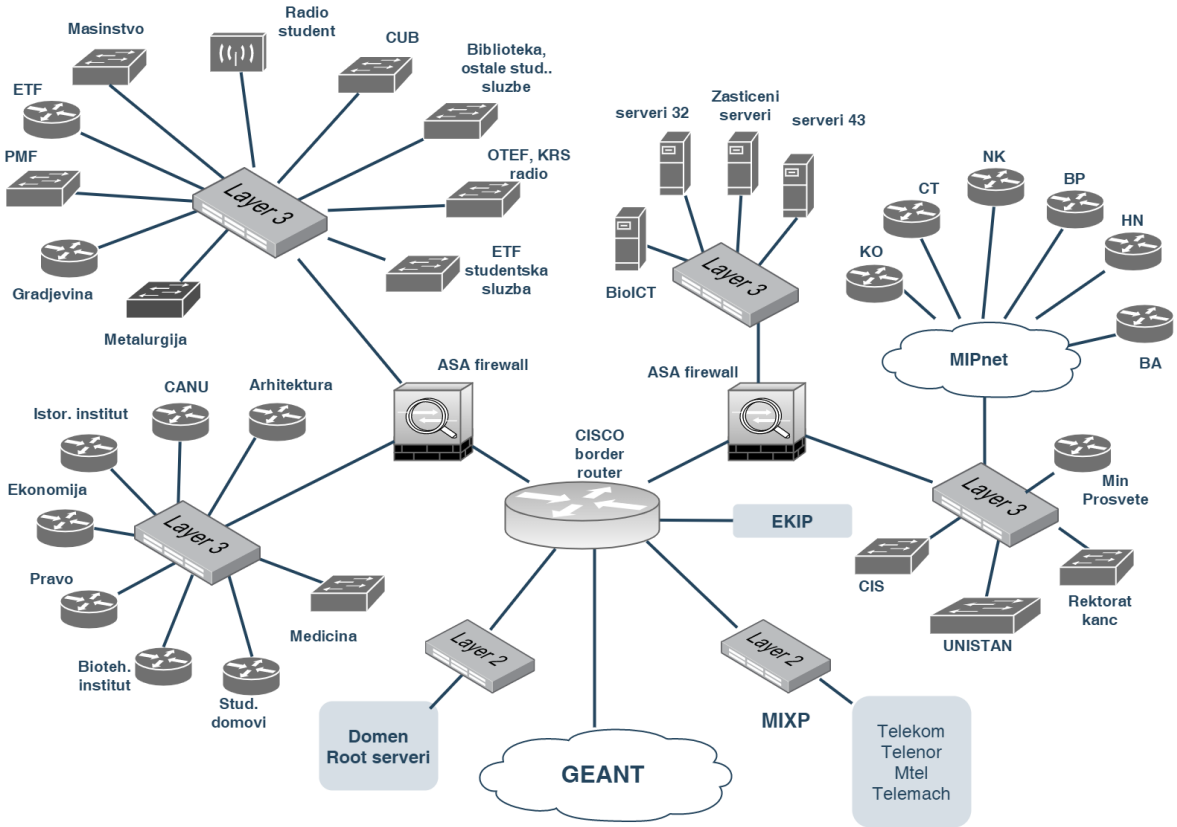

Figure 1: Topology of Academic network

As it is shown in the Figure 1, the complete data center is located in the core of the network, with aggregation switches, firewall devices, edge routers, server and service components. Tables 2 and 3 show the list of key equipment in the data center.

Table 2: Main server infrastructure

	device	number
1	Storage MSA 2050	1
2	HP Proliant DL380 Gen10	3
3	HP Proliant ML350C Gen9	1
4	Server HP Proliant BL685C sa 2 HDD	1
5	Server HP Proliant BL460C sa 2 HDD	4
6	HP Proliant ML350	2
7	HP Storage Works X1600 sa 6 HDD od 1TB	1
8	HP Storage Works sa 12 HDD od 450GB	1
9	HP Storage Works HSV300	1
10	Server HP DL360	1
11	SAS Disk HP 3PARa 7200c 900GB	20

Table 3: Main communication infrastructure

	device	number
1	CISCO ASR 1002 Router	1
2	CISO ASR 9001 Router	1
3	CISCO ASA 5540	1
4	CISCO ASA5515 FirePOWER	1
5	Switch Allied Telesis GS924 MX	1
6	Mikrotik CRS328-24P-4S +RM	1
7	Allied Telesis AT-GS950/48-50	1
8	Allied Telesis AT-GS930-28GSTX	3
9	CISCO WS-C3850-24S-S	2
10	Cisco Nexus 3548P-10G	1
11	Switch Allied Telesis GS924 MX	1
12	Avtech Room Alert 8 ports	1

3.1.1 Laboratory of the Center of Information System

The Laboratory classroom is located near the data center. At the beginning of the 2021, new equipment was acquired, as well as presentation equipment (projector and smart board). Currently, there are 25 all in one personal computers, as shown in the Figure 2.

Figure 2: Lab classroom

In the rack there is existing equipment for the Cisco Network Academy program, and it consist of 6 Cisco 1760 routers, and 3 catalist 2900 switches. As this old equipment and it does not support IPv6, this equipment cannot be used for IPv6 labs, merely only for the IPv4 part of the lab.

Figure 3: Lab classroom schematic

3.1.2 Implementation of IPv6 at University of Montenegro

In 2013 the University of Montenegro has ensured through RIR (Regional Internet Registry) a block of IPv6 addresses for the needs of AMUCG. One block is globally seen and the other (intended for MIXP) is still globally invisible (Table 4).

Table 4: IPv6 allocations

AS40981 UNIVCG (visible since 14.02.2013. ,16:00:00 UTC)	
Inet6Num:	2a02:4280::/32
NetName:	ME-MREN-20110711
Org:	ORG-UoM41-RIPE
Address>	2a02:4280::0
Address Range Start>	2a02:4280::1
Address Range End>	2a02:4280:ffff:ffff:ffff:ffff:ffff:ffff
Mask Bits>	32
Usable Addresses>	79 228 162 514 264 337 593 543 950 336
AS40981 UNIVCG (not globaly visible)	

Inet6Num:	2001:7f8:22::/48
NetName:	ME-MREN-20150526
Org:	ORG-UoM41-RIPE
Address>	2001:7f8:2200::0
Address Range Start>	2001:7f8:2200::1
Address Range End>	2001:7f8::22ff:ffff:ffff:ffff:ffff:ffff
Mask Bits>	48
Usable Addresses>	1 208 925 819 614 629 174 706 176

According to the strategy for implementing IPv6 at University of Montenegro, the first approach was to adequately plan an address space having in mind possible further developments of the network with other institutions that are currently not in the Academic network. There are various methodologies of planning of address range, and regarding the segment which is allocated to Academic network (2A02:4280://32) following categorization of address range was chosen:

2A02:4280:ITTJ:JJ::/56

In this categorization, I stands for Institutions, T stands for type, and J stands for department.

Regarding the fact that Academic network has already set and IPv4 address scheme and that all devices in the IT center and several edge routers toward University units are IPv6 enabled, dual stack is the optimal end to end solution for configuration of the devices.

Regarding the architecture of the Academic network which is by nature a multiple star, the static routes are set on all devices in the IT center. On the inside, where was necessary to dynamically assign addresses the ND protocol was enabled by which the border devices propagates its own IPv6 network prefix and the devices alone generate the part of the address for their own interfaces. With server segment it was not recommended to enable the ND protocol because it was necessary to set the static IPv6 addresses and those addresses further propagate with DNS.

Enabling IPv6 in total is compatible with the existing configuration VLAN interface and trunk interface, which was very convenient for setting the IPv6 addresses on to server segment.

As a first step, IPv6 was realized on critical services that are used the most: DNS, MAIL, WEB. Regarding the sole servers and setting the IPv6 address on the same interface in order to get IPv6 connectivity, it was necessary to adjust the configuration of services to also function through IPv6 addresses.

For the purpose of MIXP a new virtual machine was created with the instance of BIRD service (routing service) which is configured for working with IPv6 addresses only. In this parallel work this route server is functioning only with IPv6 addresses while existing root server functions with IPv4 addresses. As it was mentioned earlier, IPv6 support existing configuration of VLANs and trunk interfaces, so the implementation went with minor changing of existing configuration of the devices.

Besides the IT center CIS personnel decided to firstly approach the connection of one of the major units of University of Montenegro which by its structure also has functionally separated segments. Implementation of IPv6 on Faculty of Electrical Engineering gives an extraordinary user case that

can serve for the other implementations on the other units of University for configuring their own devices and planning of IPv6 infrastructure.

For the Faculty of Electrical Engineering the following network address is assigned 2a02:4280:10:100::/56. This network has 256 subnetworks and it allows great flexibility in configuring the inside topology.

The inside topology can be divided into 3 parts: offices, laboratories/study rooms, services (student service and accountant services). Regarding the fact that /56 was assigned to mentioned faculty, these major 3 segment can be given /60 prefix, and with that those segments will have enough for further segmentation within.

3.2 Physical characteristics

3.2.1 Data Center

All the equipment within the frame of the Academic Network core is located in the data center. Data center is 80m2 with the anti-static floor on all its surface. The room is equipped with an alarm for entrance and with adequate notification for administrative staff. It has two entrances with automatic doors and also a RFID card reader and finger print reader. The entrance is allowed only to engineers with adequate security level. On the west side of the hall there is a outer wall of the building with outside windows. On the windows there are metal bars for physical barriers to prevent break-ins and also a parallel wall with inside windows. The hall is secured with 2 separate air condition sources: 4 air conditioners of large capacity with the outside units and with the system to cooling the whole building. Two of these air conditions are connected to aggregate system and they provide the adequate cooling in case of power outage.

Figure 5: Data Center

Figure 4: Data Center

The aggregate system is realized with diesel generator that has a capacity of 33KWh, which currently satisfies the capacities of the existing equipment. The time necessary for the aggregate system to turn on is 10 seconds. The system is serviced regularly and there are also certain amount of stash of fuel in case of the longer power outage. The aggregate power is completely separated from distribution power and industrial switches are set 380V 32A 3P+N+T, as the mono phase power outlets. Every rack is secured with UPS of high performances which allow automated work in average to 30 minutes.

The hall is conceptually planned in two parallel rows of rack closets and the ceiling electrical vertical riser of communication cables is set. Rack closets are also grouped in more conceptual groups: IXP, Server rack infrastructure, Communication rack infrastructure, Collocation rack infrastructure and Domain .me infrastructure. In the figure 6 the schematic of the data center with rack positions and aggregate system power plugs is shown. Figure 7 shows the fire alarm system.

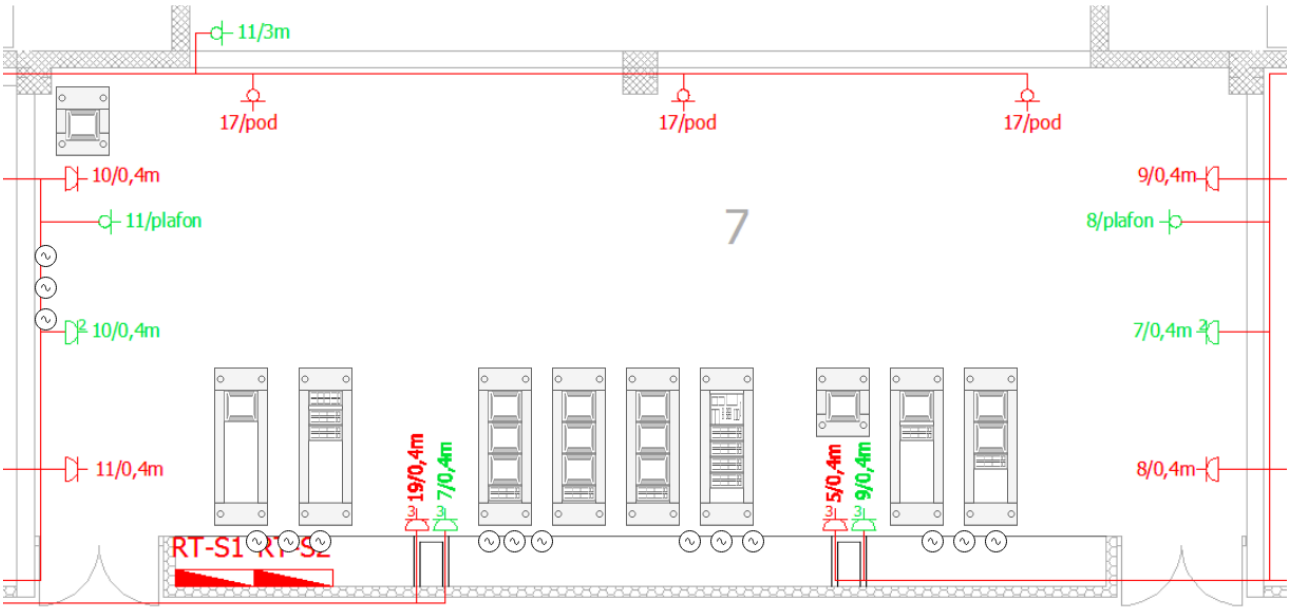

Figure 6: Data Center schematic

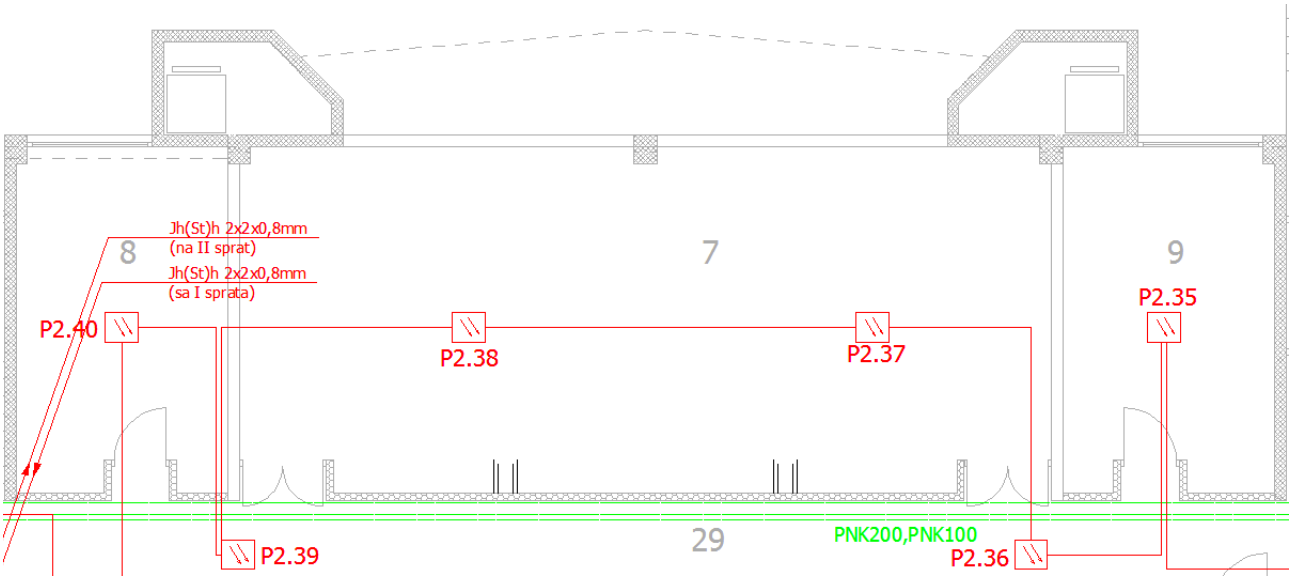

Figure 7: Data Center fire alarm system

3.2.2 The lab classroom

The existing computer classroom within the Center of Information System served as academic and master courses as well as the study room for Cisco Network Academy Program. The classroom is 75m2 and it was reconstructed in December of 2020 when the new user equipment arrived.

It is on the same floor as the data center and it has direct network connectivity. Inside the classroom there is a rack closet for storing equipment necessary for the training of the students.

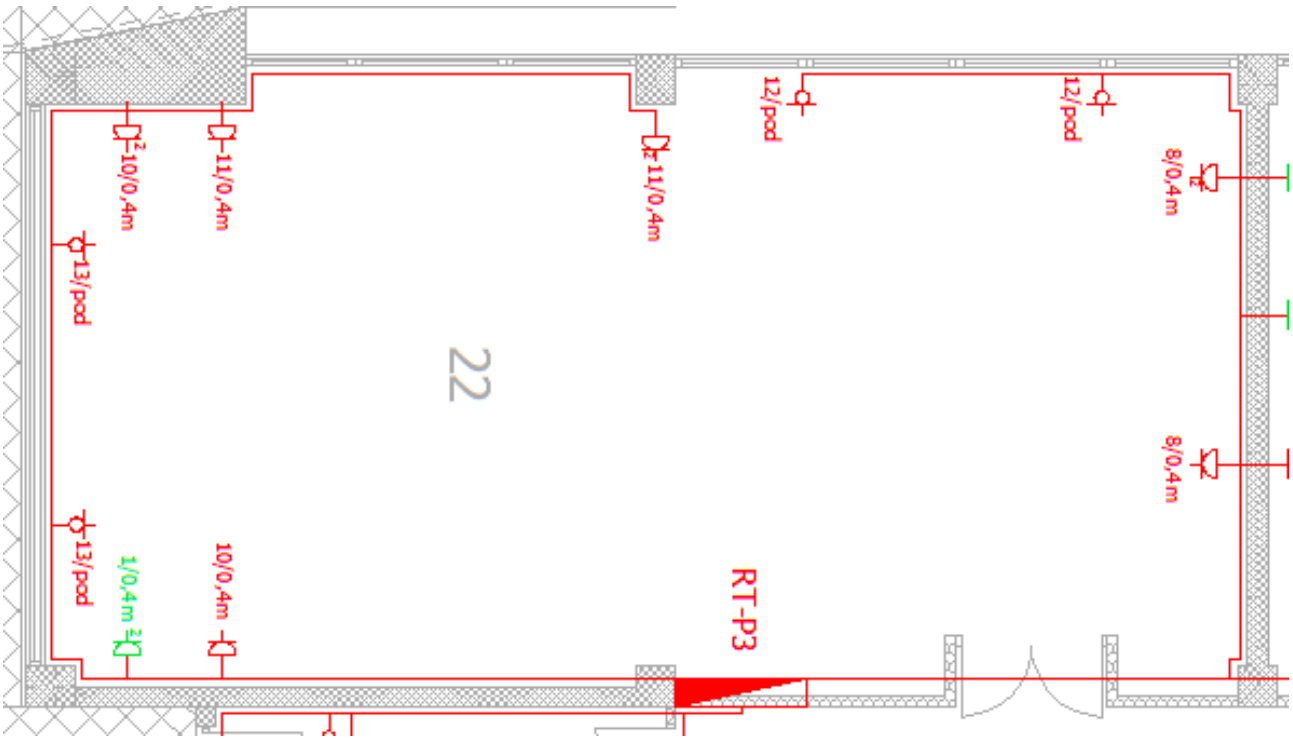

Figure 8: Lab classroom with electrical power schematics

The classroom is not covered by the aggregate system, but the rack closet is secured by the UPS system with small capacity. Inside the classroom there is a fire protection (figure 9) and the entrance to the classroom is secured by video surveillance and security guard system.

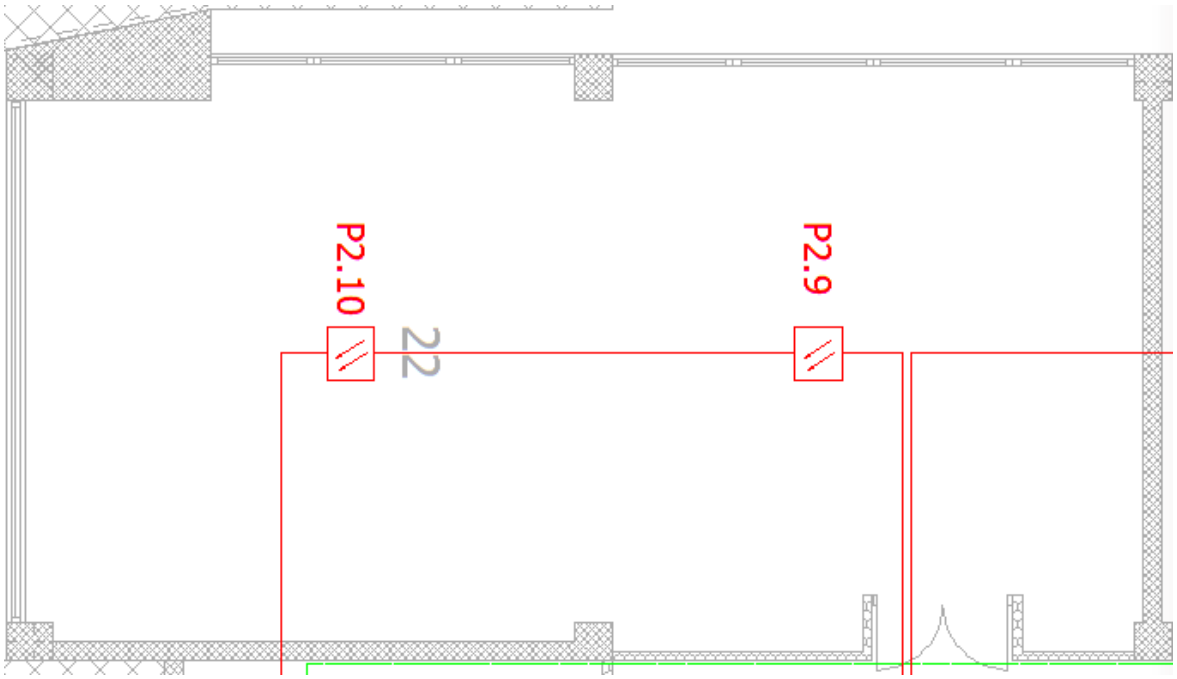

Figure 9: Lab classroom with fire alarm system

3.3 IPv6 Lab concept proposition

In the earlier sections the system hall and the classroom were described. Considering the technical details of these rooms, the equipment necessary for the laboratory would be partly situated in the data center and partly in the classroom. The data center is covered by aggregate system as well as anti-burglary and fire alarms. All the parts that have a purpose of virtualization of the laboratory should be situated in the data center. Instead, it is necessary to settle in the classroom those parts of the laboratory in which the participants would be actively working.

By conceptualizing the IPv6 laboratory, the implementation dimension must be considered. Regarding the fact that it is necessary to cover the wide spectrum of scenarios, the laboratory should be able to emulate the most often used transition mechanisms like 6RD, DS-lite and DS (figure 10). Besides learning the model of implementation of IPv6 protocol, in practice students must also to learn to upgrade the existing system based on IPv4. So the laboratory must create the conditions to test out the real models by which the end users would find the transition simpler and even unnoticeable.67

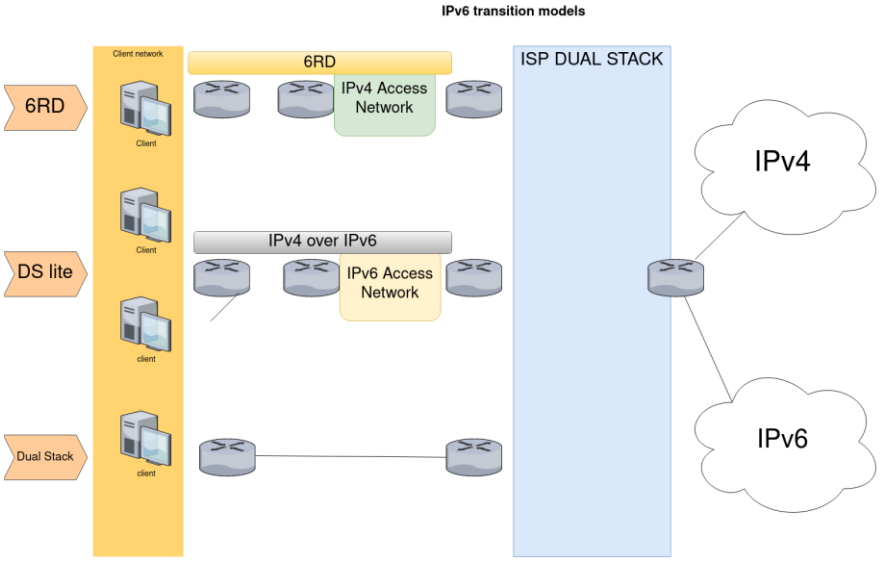

Figure 10: IPv6 transition mechanisms

The IPv6 laboratory should be practically applicable and must include almost all elements for end-to-end realization. The Laboratory should consider routers, switches (L2 and L3), edge routers, firewalls and client appliances as well as optional security appliance.

Moreover, it is necessary to take into consideration remote access as well. The pandemic caused more intense online traffic, and remote access can assure more flexible work toward users and additional time for practice in lab environment. According to that, it is necessary to plan not only VPN access, but enable infrastructure in such topology and configuration so users of the lab can access the devices they used during sessions.

This paper discussed three possible realizations of laboratory:

- Full hardware realization
- Realization based on virtual laboratory
- Hybrid model

To make detailed specification in order to satisfy given presumptions, a couple of scenarios which would be necessary to simulate in the laboratory are presented.

- **Scenario 6RD:**

For this scenario, the symbolic laboratory is created as shown in the figure 11.

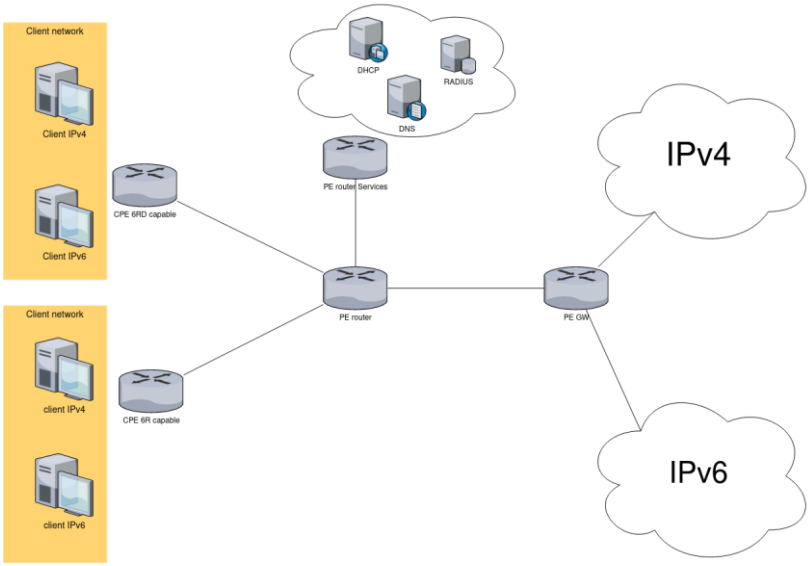

Figure 11: 6RD concept lab

For realization of 6RD scenario, the necessary devices are shown in table 5:

Table 5: 6RD concept equipment

Device/Function	number	Description
CPE 6rd enabled	2	Customer side router with 6RD capability
PE router	1	Provider side router that performs BR function
PE router services	1	Provider side router IPv4 for servers
PE GW	1	Provider main GW. IPv4 and IPv6 capable
Servers	1-3	Servers for DNS, DHCP and AAA
Firewall	1	Firewall as protective layer on the GW side and VPN concentrator
Host IPv4	2	Host IPv4 devices
Host IPv6	2	Host IPv6 devices

- **Scenario DS lite:**

For this scenario a symbolic laboratory is created that is shown in the figure 12.

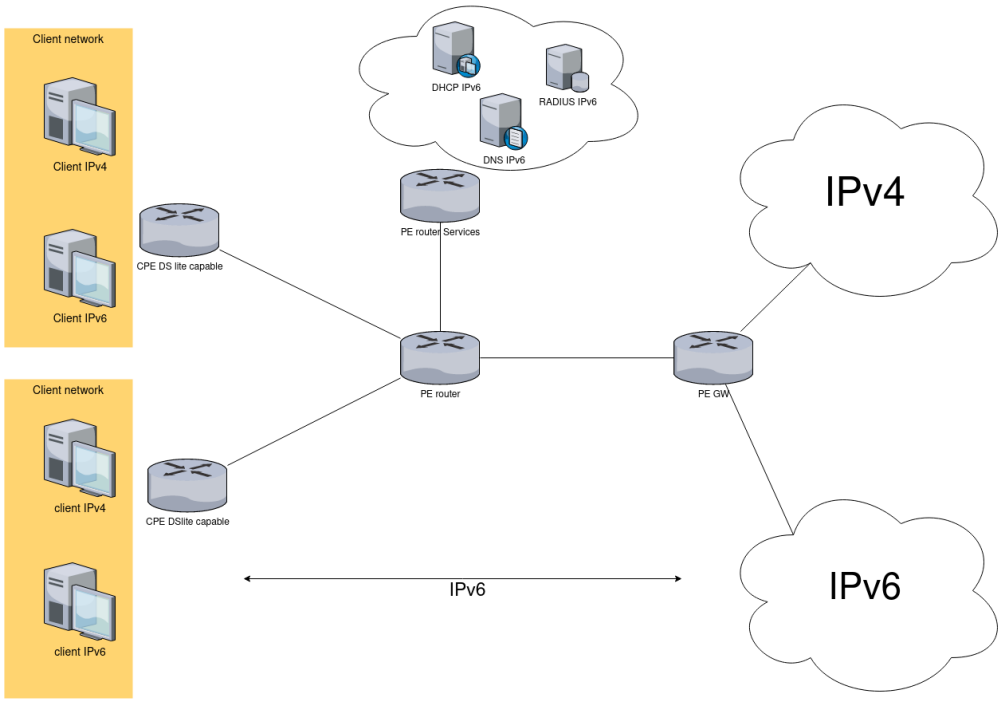

Figure 12: DS lite concept

For the realization of DS lite scenarios, devices are shown in table 6:

Table 6: DS lite concept

Device/Function	number	Description
CPE 6rd enabled	2	Customer side router with DS lite capability
PE router	1	Provider side IPv6 aggregation router
PE router services	1	Provider side router IPv6 for servers
PE GW	1	Proveder main GW. with DS-lite AFTR function
Servers	1-3	Servers for DNS, DHCP and AAA with IPv6
Firewall	1	Firewall as protective layer on the GW side and VPN concentration
Host IPv4	2	Host IPv4 devices
Host IPv6	2	Host IPv6 devices

Besides the above mentioned devices it is optional to add a security appliance to simulate that aspect also.

3.3.1 Approach 1

As stated in the introduction part, the laboratory should cover the bigger scope of scenarios. The first approach describes the model which is based on hardware devices and appliances. With regards to the fact that in the Academic network is already implementing the IPv6 protocol on the Dual Stack mechanism, the laboratory already gets both types of connections. Regarding the big number of vendors for laboratory conditions, it is decided to base the specifications on CISCO devices. Of course, this does not exclude devices from the vendors in the final solution, but most of the companies invest in the certification of their engineers through some of the CISCO certified programs. A minimum of equipment to satisfy some of the predisposed needs includes list shown in table 7.

Table 7: Approach 1 concept list

	concept role	device	number
1	CPE	Cisco ISR 4221	16
2	PE router/switch	Cisco MS410-16-HW	1
3	PE router/switch services	Cisco 7204 VXR NPE400 /optional	1
4	PE GW	Cisco ASR1001-X	1
5	Servers	HPE ProLiant DL380 Gen10, 32GB RAM min, storage 2 RAID diska min	1
	Firewall	FortiGate 40F	1
6	Host IPv4	N/A	2
7	Host IPv6	N/A	2

Explanation:

The alleged number of devices covered the current capacity of the spaces in the laboratory. On the provider boarder router side it is suggested the ASR 1001-X that belongs to Aggregation Service Router line.

Provider Edge is a 16-port L3 switch MS410-16-HW as an aggregation switch and link to service segment of the provider. Besides this function, the aggregation switch can be connected with different devices for demonstration of IoT over IPv6.

HP DL 360 server is planned with very modest capacities on which it could host necessary testing services by virtualization. The bigger accent is going to be on the configuration of physical network appliances and creation of topology, while server infrastructure would be a support for realization of services or eventually IoT scenarios.

3.3.2 Approach 2

For this approach a totally virtual architecture is foreseen. The realization would be based on a server of significant capacities or 3 clustered servers with hypervisors and orchestration.

The difference between the two models is in the redundancy of the systems. 3 clustered servers guarantee a reliable system with storage functionality as well as fail over ability.

The mentioned infrastructure would be based on a proxmox virtualization VE 6: 3-node cluster with storage system based on Ceph. In its frame based on laboratory needs, solution can be based on independent virtualization of network devices, or with simulation under specific simulators like GNS3. 11

GNS3 is an open-source simulation software that can simulate various scenarios, even on cloud infrastructures. The advantage of this approach is in the possibility of virtualization of devices of different vendors, and by that the possibility of operators to simulate their surroundings so they could in adequate way plan the realization in their own systems. On GNS3 portal there is already a great number of image appliances of different vendors. Moreover, this solution enables the simulation of network solution of different kinds of complexity which can match the market solutions as well as potential real typologies.

The necessary equipment for this scenario is shown in table 8.

Table 8: Approach 2 concept list

	concept role	Device	number
1	Servers	HPE ProLiant DL360 Gen10, 256GB RAM min, storage 4 diska with 960 GB, 10GB ethernet min x2,	3
2	PE router/switch	Cisco MS410-16-HW	1
3	Firewall	FortiGate 40F	1

3.3.3 Approach 3

The third scenario combines physical and virtual type of implementation.

In this case the physical approach of configuration topology have reduced number of CPE to four in comparison with first approach, while the rest of topology would remain. The specification of the servers could be a lot more demanding, because besides the realization of service, in this case virtualization is a significant part of the training. It is also advised to keep the high degree of performance as well as redundancies of the virtualization system. That is why this solution can have two variants, one with single server with large performance and great capacity in CPU, RAM and disk, and 3 lesser solutions but with redundancies.

The rest of the physical appliances is smaller by the number of CPE devices, because starting point is that the higher part of the training is realized with virtual topology, while physical devices substitute the real feel of connectivity of topology and it would function parallel with virtualization topology. This approach gives also an added value to laboratory because it enables end to end simulation which is especially important in eventual demonstration of IoT examples. In the table 9 list of the equipment is specified.

Table 9: Approach 3 concept list (two possible concepts)

	concept role	device	number
1	CPE	ISR 4221	2
2	PE router/switch	MS410-16-HW	1
3	PE router/switch services	CISCO 7204 VXR NPE400 /optional	1
4	PE GW	ASR1002-ESP10	1
5	Servers	HPE ProLiant DL380 Gen10, 512 GB RAM min, storage 8 diska 1.2 TB	1-3
	Firewall	FortiGate 40F	1

3.3.4 Modularity of concept - IoT

As the primary focus of the lab is to present various implementation methods and transitions of IPv6, it also has to emphasize future benefits of the IPv6. The primary function of the IPv6 is the scalability and larger address pool, but also better QoS, authentication and privacy support and more efficient routing among other features. All of these benefits make the IPv6 standard resolving many issues of IPv4 in regards of full implementation and development of Internet of Things. This lab can be extended in showing various implementation and significance of IPv6 in regards of IoT. There is a vast resource list of demonstrating IoT over IPv6, and some of the concepts include sensor network based on Arduino boards, or using open source IoT appliance. On the other hand, these lab setting can be eye opener to users, and show the limitless possibilities that can extend to applications used to implement smart home, smart industry and smart cities concept. Of course this concept is somewhat hard to include in the early stage of lab setting, but can be guideline of future development of the lab.

One of the great modular smart system that can be used to demonstrate the application of IoT is open source solution called Home Assistant. It is a full home automation system that has very large community that actively contribute in the development. Not only that community is contributing with various ready to go solutions, but also with development of integration with other industry smart devices. There are currently about 1771 possible integration solutions with Home Assistant, and those include among other Google, Sony, Samsung, Philips, LG, Amazon Alexa etc.

As a concept that can be used in lab setting it can include installation of Home Assistant core on virtual platform, and with adequate integration option, connect HA with various services. Users of the lab can also include their own equipment and test it in lab setting with connecting with HA. In the table 10 are listed IoT kits with various applications.13

Table 10: IoT lab kits

	device/kit	number	price
1	Arduino Explore IoT Kit	12	1200
2	NEEGO Raspberry Pi 3 Ultimate Starter Kit	6	900
3	ELEGOO Upgraded 37 in 1 Sensor Modules Kit with Tutorial Compatible with Arduino IDE UNO R3 MEGA2560 Nano	12	1000
4	Gravity: 27 Pcs Sensor Set for Arduino	12	660
5	Arduino Oplà IoT Kit	6	600

Many of these kits have predefined IoT examples that can be made with them. Also, these kits can mainly be utilizes by Home Assistant, and there are vast number of possible lab applications that can be set using these tools.

4 Conclusion

As discussed throughout the document, implementation of IPv6 requires many different efforts in order to create the incentive for all parties to enact the transition to IPv6. In the national plan for transition toward IPv6 several approaches were identified, including efforts mainly aimed at ISPs, national public institutions, and business customers.

Depending on the targeted subject, the approach may differ. It is expected that ISP have very well trained ICT experts, and lab concept is expected to be as test bed for various scenarios, whereas for national public institutions and business customers lab surroundings can be very valuable resource in order to broaden the knowledge about IPv6 and speed up implementation of IPv6.

Three possible models can be identified for the realization of the laboratory: i) fully physical, ii) fully virtual, and iii) hybrid model. Possible redundancies were also taken into consideration, particularly for the hybrid model. Prices shown in the approach specification are drawn according to Global Price Lists (GPL), and they are expected to drop by between 30% and 40% for the tender process.

This document provides a conceptual approach and by no means constitutes a practical recommendation or endorsement of equipment providers. The realization of the tender will need to be based on the premise that all equivalent equipment available in the market that satisfies minimum requirements set by this document is acceptable.

5 References and Terminology

a. References

References

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b. Definitions

6rd (IPv6 Rapid Deployment)An IPv6 transition technology defined in RFC5969 [23].

DS-Lite (Dual- Stack Lite) An IPv6 transition technology defined in RFC6333 [24].

Dual Stack A network element that supports both IPv4 and IPv6 natively.

c. Abbrevation

AFTR	Address Family Translation Router
BBF	Broadband Forum
BNG	Broadband Network Gateway
BR	Border Router or Border Relay
DHCP	Dynamic Host Configuration Protocol
DNS	Domain Name Service
DS-Lite	Dual-Stack Lite
LAN	Local Area Network
CIS	Center Of Information System
IoT	Internet of Things
MTC	Machine Type Communication
UoM	University of Montenegro
ANUM	The Academic network of University of Montenegro
RIP	Réseaux IP Européens

6 ANEX1: Expense analysis of various implementation scenarios

a. Approach 1 GPL price list with specification

Table 11: Approach 1 GPL price list in USD with specification

Line Number	Part Number/Device	Description	Qty	Unit Net Price	Extended Net Price	unit	conversion
1	ISR4331-SEC/K9	Cisco ISR 4331 Sec bundle w/SEC license	16	4800	76800	usd	76800
1.0.1	CON-SNT-ISR4331S	SNTC-8X5XNBD Cisco ISR 4331 Sec bundle w/SEC license	16	529	8464	usd	8464
1.1	SL-4330-IPB-K9	IP Base License for Cisco ISR 4330 Series	16	0	0	usd	0
1.2	PWR-4330-AC	AC Power Supply for Cisco ISR 4330	16	0	0	usd	0
1.3	CAB-ACE	AC Power Cord (Europe), C13, CEE 7, 1.5M	16	0	0	usd	0
1.4	SL-4330-SEC-K9	Security License for Cisco ISR 4330 Series	16	0	0	usd	0
1.5	MEM-FLSH-4G	4G Flash Memory for Cisco ISR 4300 (Soldered on motherboard)	16	0	0	usd	0
1.6	NIM-BLANK	Blank faceplate for NIM slot on Cisco ISR 4400	16	0	0	usd	0
1.7	MEM-43-4G	4G DRAM (1 x 4G) for Cisco ISR 4300	16	0	0	usd	0
1.8	SM-S-BLANK	Removable faceplate for SM slot on Cisco 2900,3900,4400 ISR	16	0	0	usd	0
1.9	SISR4300UK9-169	Cisco ISR 4300 Series IOS XE Universal	16	0	0	usd	0
1.11	FW-7455-LTE-GN	FW Switching Load for 7455 Generic - Europe	16	0	0	usd	0
1.12	4G-AE010-R	Single Unit antenna Extension Base (10 foot cable included)	32	0	0	usd	0
1.13	LTE-ANTM-D	LTE articulating dipole antenna 698-960,1448-1511,1710-2690	32	0	0	usd	0
2	MS410-16-HW	Meraki MS410-16 Cld-Mngd 16x GigE SFP Switch	1	8500	8500	usd	8500
3	MA-PWR-CORD-EU	Meraki AC Power Cord for MX and MS (EU Plug)	1	19	19	usd	19
4	LIC-MS410-16-1YR	Meraki MS410-16 Enterprise License and Support, 1YR	1	500	500	usd	500
5	MA-SFP-1GB-TX	Meraki 1 GbE SFP Copper Module	18	395	7110	usd	7110
6	ASR1001-X	Cisco ASR1001-X Chassis, 6 built-in GE, Dual P/S, 8GB DRAM	1	17000	17000	usd	17000
6.0.1	CON-SNT-ASR1001X	SNTC-8X5XNBD Cisco ASR1001-X Chassis, Crypto, 6 built	1	1354.7	1354.7	usd	1354.7

6.1	SLASR1-IPB	Cisco ASR 1000 IP BASE License	1	9000	9000	usd	9000
6.1.0.1	CON-SNT-SLASR1IK	SNTC-8X5XNBD Cisco ASR 1000 IP BASE License	1	717.6	717.6	usd	717.6
6.2	ASR1K-RR	ASR1k-Router Reflector - Tracking only	1	0	0	usd	0
6.3	M-ASR1001X-8GB	Cisco ASR1001-X 8GB DRAM	1	0	0	usd	0
6.4	NIM-BLANK	Blank faceplate for NIM slot on Cisco ISR 4400	1	0	0	usd	0
6.5	SPA-BLANK	Blank Cover for regular SPA	1	0	0	usd	0
6.6	ASR1001-X-PWR-AC	Cisco ASR1001-X AC Power Supply	2	0	0	usd	0
6.7	CAB-C13-C14-AC	Power cord, C13 to C14 (recessed receptacle), 10A	2	0	0	usd	0
6.8	SASR1K1XUNLIK9-169	Cisco ASR1001-X IOS XE UNIVERSAL W/O LI	1	0	0	usd	0
6.9	GLC-TE	1000BASE-T SFP transceiver module for Category 5 copper wire	3	450	1350	usd	1350
7	FG-40F	5xGE RJ45 ports (including 1x WAN port, 4x Internal ports)	1	452.93	452.93	eur	543.516
8	867959-B21	HPE ProLiant DL360 Gen10 8SFF Configure-to-order Server	1	2070	2070	eur	2484
8.1	867959-B21 B19	HPE DL360 Gen10 8SFF CTO Server	1	0	0	eur	0
8.2	P02571-L21	Intel Xeon-Silver 4208 (2.1GHz/8-core/85W) FIO Processor Kit for HPE ProLiant DL360 Gen10	1	752	752	eur	902.4
8.3	P00922-B21	HPE 16GB (1x16GB) Dual Rank x8 DDR4-2933 CAS-21-21-21 Registered Smart Memory Kit	2	401	802	eur	962.4
8.4	P00922-B21 0D1	Factory Integrated	2	0	0	eur	0
8.5	P18424-B21	HPE 960GB SATA 6G Read Intensive SFF SC Multi Vendor SSD	2	725	1450	eur	1740
8.6	P18424-B21 0D1	Factory Integrated	2	0	0	eur	0
8.7	804394-B21	HPE Smart Array E208i-p SR Gen10 (8 Internal Lanes/No Cache) 12G SAS PCIe Plug-in Controller	1	350	350	eur	420
8.8	804394-B21 0D1	Factory Integrated	1	0	0	eur	0
8.9	865408-B21	HPE 500W Flex Slot Platinum Hot Plug Low Halogen Power Supply Kit	2	280	560	eur	672
8.11	865408-B21 0D1	Factory Integrated	2	0	0	eur	0
8.12	874543-B21	HPE 1U Gen10 SFF Easy Install Rail Kit	1	100	100	eur	120
8.13	874543-B21 0D1	Factory Integrated	1	0	0	eur	0
9		in the price include installation, configuration and training					
					TOTAL		138659.616

b. Approach 2 GPL price list with specification

Table 12: Approach 2 GPL price list in USD with specification

Line Number	Part Number/Device	Description	Qty	Unit Net Price	Extended Net Price	unit	conversion
1	MS410-16-HW	Meraki MS410-16 Cld-Mngd 16x GigE SFP Switch	1	8500	8500	usd	8500
1.1	MA-PWR-CORD-EU	Meraki AC Power Cord for MX and MS (EU Plug)	1	19	19	usd	19
1.2	LIC-MS410-16-1YR	Meraki MS410-16 Enterprise License and Support, 1YR	1	500	500	usd	500
1.3	MA-SFP-1GB-TX	Meraki 1 GbE SFP Copper Module	18	395	7110	usd	7110
2	FG-40F	5xGE RJ45 ports (including 1x WAN port, 4x Internal ports)	1	452.93	452.93	eur	543.516
3	867959-B21	HPE ProLiant DL360 Gen10 8SFF Configure-to-order Server	3	2070	6210	eur	7452
3.1	867959-B21 B19	HPE DL360 Gen10 8SFF CTO Server	3	0	0	eur	0
3.2	P02592-L21	Intel Xeon-Gold 5218 (2.3GHz/16-core/125W) FIO Processor Kit for HPE ProLiant DL360 Gen10	3	1967	5901	eur	7081.2
3.3	P02592-B21	Intel Xeon-Gold 5218 (2.3GHz/16-core/125W) Processor Kit for HPE ProLiant DL360 Gen10	3	1967	5901	eur	7081.2
3.4	P02592-B21 0D1	Factory Integrated	3	0	0	eur	0
3.5	P00924-B21	HPE 32GB (1x32GB) Dual Rank x4 DDR4-2933 CAS-21-21-21 Registered Smart Memory Kit	24	823	19752	eur	23702.4
3.6	P00924-B21 0D1	Factory Integrated	24	0	0	eur	0
3.7	P18424-B21	HPE 960GB SATA 6G Read Intensive SFF SC Multi Vendor SSD	12	725	8700	eur	10440
3.8	P18424-B21 0D1	Factory Integrated	12	0	0	eur	0
3.9	804394-B21	HPE Smart Array E208i-p SR Gen10 (8 Internal Lanes/No Cache) 12G SAS PCIe Plug-in Controller	3	350	1050	eur	1260
3.11	804394-B21 0D1	Factory Integrated	3	0	0	eur	0
3.12	652503-B21	HPE Ethernet 10Gb 2-port SFP+ 57810S Adapter	3	643	1929	eur	2314.8

3.13	652503-B21 0D1	Factory Integrated	3	0	0	eur	0
3.14	865408-B21	HPE 500W Flex Slot Platinum Hot Plug Low Halogen Power Supply Kit	6	280	1680	eur	2016
3.15	865408-B21 0D1	Factory Integrated	6	0	0	eur	0
3.16	874543-B21	HPE 1U Gen10 SFF Easy Install Rail Kit	3	100	300	eur	360
3.17	874543-B21 0D1	Factory Integrated	3	0	0	eur	0
4	J9283D	Aruba 10G SFP+ to SFP+ 3m Direct Attach Copper Cable	6	189	1134	eur	1360.8
4.1	J9734A	Aruba 2920/2930M 0.5m Stacking Cable	2	133	266	eur	319.2
4.2	JL319A	Aruba 2930M 24G 1-slot Switch	2	2689	5378	eur	6453.6
4.3	JL083A	Aruba 3810M/2930M 4-port 100M/1G/10G SFP+ MACsec Module	2	1226	2452	eur	2942.4
4.4	JL085A	Aruba X371 12VDC 250W 100-240VAC Power Supply	4	491	1964	eur	2356.8
4.5	JL085A ABB	Aruba X371 12VDC 250W 100-240VAC Power Supply Europe English	4	0	0	eur	0
4.6	JL325A	Aruba 2930 2-port Stacking Module	2	867	1734	eur	2080.8
5		in the price include installation, configuration and training					
					TOTAL		93893.716

c. Approach 3.A GPL price list with specification (One server with better performance)

Table 13: Approach 3.A GPL price list in USD with specification (One server with better performance)

Line Number	Part Number/Device	Description	Qty	Unit Net Price	Extended Net Price	unit	conversion
1	**ISR4331-SEC/K9**	Cisco ISR 4331 Sec bundle w/SEC license	4	4800	19200	usd	19200
1.0.1	CON-SNT-ISR4331S	SNTC-8X5XNBD Cisco ISR 4331 Sec bundle w/SEC license	4	529	2116	usd	2116
1.1	SL-4330-IPB-K9	IP Base License for Cisco ISR 4330 Series	4	0	0	usd	0
1.2	PWR-4330-AC	AC Power Supply for Cisco ISR 4330	4	0	0	usd	0
1.3	CAB-ACE	AC Power Cord (Europe), C13, CEE 7, 1.5M	4	0	0	usd	0
1.4	SL-4330-SEC-K9	Security License for Cisco ISR 4330 Series	4	0	0	usd	0
1.5	MEM-FLSH-4G	4G Flash Memory for Cisco ISR 4300 (Soldered on motherboard)	4	0	0	usd	0
1.6	NIM-BLANK	Blank faceplate for NIM slot on Cisco ISR 4400	4	0	0	usd	0
1.7	MEM-43-4G	4G DRAM (1 x 4G) for Cisco ISR 4300	4	0	0	usd	0
1.8	SM-S-BLANK	Removable faceplate for SM slot on Cisco 2900,3900,4400 ISR	4	0	0	usd	0
1.9	SISR4300UK9-169	Cisco ISR 4300 Series IOS XE Universal	4	0	0	usd	0
1.11	FW-7455-LTE-GN	FW Switching Load for 7455 Generic - Europe	4	0	0	usd	0
1.12	4G-AE010-R	Single Unit antenna Extension Base (10 foot cable included)	8	0	0	usd	0
1.13	LTE-ANTM-D	LTE articulating dipole antenna 698-960,1448-1511,1710-2690	8	0	0	usd	0
2	MS410-16-HW	Meraki MS410-16 Cld-Mngd 16x GigE SFP Switch	1	8500	8500	usd	8500
3	MA-PWR-CORD-EU	Meraki AC Power Cord for MX and MS (EU Plug)	1	19	19	usd	19
4	LIC-MS410-16-1YR	Meraki MS410-16 Enterprise License and Support, 1YR	1	500	500	usd	500
5	MA-SFP-1GB-TX	Meraki 1 GbE SFP Copper Module	18	395	7110	usd	7110
6	ASR1001-X	Cisco ASR1001-X Chassis, 6 built-in GE, Dual P/S, 8GB DRAM	1	17000	17000	usd	17000
6.0.1	CON-SNT-ASR1001X	SNTC-8X5XNBD Cisco ASR1001-X Chassis, Crypto, 6 built	1	1354.7	1354.7	usd	1354.7
6.1	SLASR1-IPB	Cisco ASR 1000 IP BASE License	1	9000	9000	usd	9000

6.1.0.1	CON-SNT-SLASR1IK	SNTC-8X5XNBD Cisco ASR 1000 IP BASE License	1	717.6	717.6	usd	717.6
6.2	ASR1K-RR	ASR1k-Router Reflector - Tracking only	1	0	0	usd	0
6.3	M-ASR1001X-8GB	Cisco ASR1001-X 8GB DRAM	1	0	0	usd	0
6.4	NIM-BLANK	Blank faceplate for NIM slot on Cisco ISR 4400	1	0	0	usd	0
6.5	SPA-BLANK	Blank Cover for regular SPA	1	0	0	usd	0
6.6	ASR1001-X-PWR-AC	Cisco ASR1001-X AC Power Supply	2	0	0	usd	0
6.7	CAB-C13-C14-AC	Power cord, C13 to C14 (recessed receptacle), 10A	2	0	0	usd	0
6.8	SASR1K1XUNLIK9-169	Cisco ASR1001-X IOS XE UNIVERSAL W/O LI	1	0	0	usd	0
6.9	GLC-TE	1000BASE-T SFP transceiver module for Category 5 copper wire	3	450	1350	usd	1350
7	FG-40F	5xGE RJ45 ports (including 1x WAN port, 4x Internal ports)	1	452.93	452.93	eur	543.516
8	867959-B21	HPE ProLiant DL360 Gen10 8SFF Configure-to-order Server	1	2070	2070	eur	2484
8.1	867959-B21 B19	HPE DL360 Gen10 8SFF CTO Server	1	0	0	eur	0
8.2	P02592-L21	Intel Xeon-Gold 5218 (2.3GHz/16-core/125W) FIO Processor Kit for HPE ProLiant DL360 Gen10	1	1967	1967	eur	2360.4
8.3	P02592-B21	Intel Xeon-Gold 5218 (2.3GHz/16-core/125W) Processor Kit for HPE ProLiant DL360 Gen10	1	1967	1967	eur	2360.4
8.4	P02592-B21 0D1	Factory Integrated	1	0	0	eur	0
8.5	P00924-B21	HPE 32GB (1x32GB) Dual Rank x4 DDR4-2933 CAS-21-21-21 Registered Smart Memory Kit	16	823	13168	eur	15801.6
8.6	P00924-B21 0D1	Factory Integrated	16	0	0	eur	0
8.7	872479-B21	HPE 1.2TB SAS 12G Enterprise 10K SFF (2.5in) SC 3yr Wty Digitally Signed Firmware HDD	8	618	4944	eur	5932.8
8.8	872479-B21 0D1	Factory Integrated	8	0	0	eur	0
8.9	804394-B21	HPE Smart Array E208i-p SR Gen10 (8 Internal Lanes/No Cache) 12G SAS PCIe Plug-in Controller	1	350	350	eur	420
8.11	804394-B21 0D1	Factory Integrated	1	0	0	eur	0
8.12	865414-B21	HPE 800W Flex Slot Platinum Hot Plug Low Halogen Power Supply Kit	2	361	722	eur	866.4
8.13	865414-B21 0D1	Factory Integrated	2	0	0	eur	0
8.14	874543-B21	HPE 1U Gen10 SFF Easy Install Rail Kit	1	100	100	eur	120
8.15	874543-B21 0D1	Factory Integrated	1	0	0	eur	0
9		in the price include installation, configuration and training					
							97756.416

d. Approach 3.B GPL price list with specification (Three servers with redundancy)

Table 14: Approach 3.B GPL price list in USD with specification (Three servers with redundancy)

Line Number	Part Number/Device	Description	Qty	Unit Net Price	Extended Net Price	unit	conversion
1	ISR4331-SEC/K9	Cisco ISR 4331 Sec bundle w/SEC license	4	4800	19200	usd	19200
1.0.1	CON-SNT-ISR4331S	SNTC-8X5XNBD Cisco ISR 4331 Sec bundle w/SEC license	4	529	2116	usd	2116
1.1	SL-4330-IPB-K9	IP Base License for Cisco ISR 4330 Series	4	0	0	usd	0
1.2	PWR-4330-AC	AC Power Supply for Cisco ISR 4330	4	0	0	usd	0
1.3	CAB-ACE	AC Power Cord (Europe), C13, CEE 7, 1.5M	4	0	0	usd	0
1.4	SL-4330-SEC-K9	Security License for Cisco ISR 4330 Series	4	0	0	usd	0
1.5	MEM-FLSH-4G	4G Flash Memory for Cisco ISR 4300 (Soldered on motherboard)	4	0	0	usd	0
1.6	NIM-BLANK	Blank faceplate for NIM slot on Cisco ISR 4400	4	0	0	usd	0
1.7	MEM-43-4G	4G DRAM (1 x 4G) for Cisco ISR 4300	4	0	0	usd	0
1.8	SM-S-BLANK	Removable faceplate for SM slot on Cisco 2900,3900,4400 ISR	4	0	0	usd	0
1.9	SISR4300UK9-169	Cisco ISR 4300 Series IOS XE Universal	4	0	0	usd	0
1.11	FW-7455-LTE-GN	FW Switching Load for 7455 Generic - Europe	4	0	0	usd	0
1.12	4G-AE010-R	Single Unit antenna Extension Base (10 foot cable included)	8	0	0	usd	0
1.13	LTE-ANTM-D	LTE articulating dipole antenna 698-960,1448-1511,1710-2690	8	0	0	usd	0
2	MS410-16-HW	Meraki MS410-16 Cld-Mngd 16x GigE SFP Switch	1	8500	8500	usd	8500
3	MA-PWR-CORD-EU	Meraki AC Power Cord for MX and MS (EU Plug)	1	19	19	usd	19
4	LIC-MS410-16-1YR	Meraki MS410-16 Enterprise License and Support, 1YR	1	500	500	usd	500
5	MA-SFP-1GB-TX	Meraki 1 GbE SFP Copper Module	18	395	7110	usd	7110
6	ASR1001-X	Cisco ASR1001-X Chassis, 6 built-in GE, Dual P/S, 8GB DRAM	1	17000	17000	usd	17000
6.0.1	CON-SNT-ASR1001X	SNTC-8X5XNBD Cisco ASR1001-X Chassis, Crypto, 6 built	1	1354.7	1354.7	usd	1354.7
6.1	SLASR1-IPB	Cisco ASR 1000 IP BASE License	1	9000	9000	usd	9000

6.1.0.1	CON-SNT-SLASR1IK	SNTC-8X5XNBD Cisco ASR 1000 IP BASE License	1	717.6	717.6	usd	717.6
6.2	ASR1K-RR	ASR1k-Router Reflector - Tracking only	1	0	0	usd	0
6.3	M-ASR1001X-8GB	Cisco ASR1001-X 8GB DRAM	1	0	0	usd	0
6.4	NIM-BLANK	Blank faceplate for NIM slot on Cisco ISR 4400	1	0	0	usd	0
6.5	SPA-BLANK	Blank Cover for regular SPA	1	0	0	usd	0
6.6	ASR1001-X-PWR-AC	Cisco ASR1001-X AC Power Supply	2	0	0	usd	0
6.7	CAB-C13-C14-AC	Power cord, C13 to C14 (recessed receptacle), 10A	2	0	0	usd	0
6.8	SASR1K1XUNLIK9-169	Cisco ASR1001-X IOS XE UNIVERSAL W/O LI	1	0	0	usd	0
6.9	GLC-TE	1000BASE-T SFP transceiver module for Category 5 copper wire	3	450	1350	usd	1350
7	FG-40F	5xGE RJ45 ports (including 1x WAN port, 4x Internal ports)	1	452.93	452.93	eur	543.516
8	867959-B21	HPE ProLiant DL360 Gen10 8SFF Configure-to-order Server	3	2070	6210	eur	7452
8.1	867959-B21 B19	HPE DL360 Gen10 8SFF CTO Server	3	0	0	eur	0
8.2	P02592-L21	Intel Xeon-Gold 5218 (2.3GHz/16-core/125W) FIO Processor Kit for HPE ProLiant DL360 Gen10	3	1967	5901	eur	7081.2
8.3	P02592-B21	Intel Xeon-Gold 5218 (2.3GHz/16-core/125W) Processor Kit for HPE ProLiant DL360 Gen10	3	1967	5901	eur	7081.2
8.4	P02592-B21 0D1	Factory Integrated	3	0	0	eur	0
8.5	P00924-B21	HPE 32GB (1x32GB) Dual Rank x4 DDR4-2933 CAS-21-21-21 Registered Smart Memory Kit	18	823	14814	eur	17776.8
8.6	P00924-B21 0D1	Factory Integrated	18	0	0	eur	0
8.7	P18424-B21	HPE 960GB SATA 6G Read Intensive SFF SC Multi Vendor SSD	6	725	4350	eur	5220
8.8	P18424-B21 0D1	Factory Integrated	6	0	0	eur	0
8.9	804394-B21	HPE Smart Array E208i-p SR Gen10 (8 Internal Lanes/No Cache) 12G SAS PCIe Plug-in Controller	3	350	1050	eur	1260
8.11	804394-B21 0D1	Factory Integrated	3	0	0	eur	0
8.12	652503-B21	HPE Ethernet 10Gb 2-port SFP+ 57810S Adapter	3	643	1929	eur	2314.8
8.13	652503-B21 0D1	Factory Integrated	3	0	0	eur	0
8.14	865408-B21	HPE 500W Flex Slot Platinum Hot Plug Low Halogen Power Supply Kit	6	280	1680	eur	2016
8.15	865408-B21 0D1	Factory Integrated	6	0	0	eur	0
8.16	874543-B21	HPE 1U Gen10 SFF Easy Install Rail Kit	3	100	300	eur	360

8.17	874543-B21 0D1	Factory Integrated	3	0	0	eur	0
9	J9283D	Aruba 10G SFP+ to SFP+ 3m Direct Attach Copper Cable	6	189	1134	eur	1360.8
9.1	J9734A	Aruba 2920/2930M 0.5m Stacking Cable	2	133	266	eur	319.2
9.2	JL319A	Aruba 2930M 24G 1-slot Switch	2	2689	5378	eur	6453.6
9.3	JL083A	Aruba 3810M/2930M 4-port 100M/1G/10G SFP+ MACsec Module	2	1226	2452	eur	2942.4
9.4	JL085A	Aruba X371 12VDC 250W 100-240VAC Power Supply	4	491	1964	eur	2356.8
9.5	JL085A ABB	Aruba X371 12VDC 250W 100-240VAC Power Supply Europe English	4	0	0	eur	0
9.6	JL325A	Aruba 2930 2-port Stacking Module	2	867	1734	eur	2080.8
10		in the price include installation, configuration and training					
							133486.416

e. IoT lab kit specification with prices

Table 15: IoT lab kit specification with prices in EUR

	device/kit	number	price
1	Arduino Explore IoT Kit	12	1200
2	NEEGO Raspberry Pi 3 Ultimate Starter Kit	6	900
3	ELEGOO Upgraded 37 in 1 Sensor Modules Kit with Tutorial Compatible with Arduino IDE UNO R3 MEGA2560 Nano	12	1000
4	Gravity: 27 Pcs Sensor Set for Arduino	12	660
5	Arduino Oplà IoT Kit	6	600
		Total	4360