Paper

Why is IPv6 Deployment Important for the Internet Evolution?

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Abstract—Replacing the IPv4 protocol with IPv6 on the Internet is currently one of the aims of the European Union policy. The main reason for this replacement is the effeteness of the addresses pool in the IPv4 protocol, which can cause serious complications in the evolution of the Internet and its adaptation in new areas, e.g., in next generation mobile telephony or the so called Internet of Things. Simultaneously, the addressing capabilities of the IPv6 protocol are practically unlimited and its new functionalities increase the attractiveness of its usage. The article discusses the problems connected with the IPv6 deployment on the Internet. Especially, the rules for realization of the IPv6 deployment and rules for cooperation of IPv4 with IPv6 (including cooperation tests) in network infrastructure and in applications are presented. Moreover, the European projects' results and the activity's directions of the national project Future Internet Engineering are discussed.

Keywords—Internet evolution, IPv6, migration, mobility, Next Generation Internet, research.

1. Introduction

Work on the new protocol intended to replace IP version 4 (IPv4) began in the early Nineties and led to the adoption by standardization institution Internet Engineering Task Force (IETF) the first standard (RFC 2460) in 1998 for a protocol called IPv6 [1]. One of the main reasons for taking this work was limited address space in IPv4, and very large dynamic allocation of free addresses. In addition, before developing a new IP protocol many new functions were defined, including support for the security, routing, and mobility. Current forecasts for the depletion of free IPv4 addresses made by the Internet assigned numbers authority (IANA) indicate that these addresses will run out between 2010 and 2013. Figure 1 shows the forecast exhaustion of IPv4, depending on the method of determining the rate of increase in the allocation of IPv4 addresses [2]. The paper presents four methods of estimating the growth rate of allocation of free addresses: smooth, polynomial, exponential and linear. In the case of the smooth method, the IPv4 addresses pool is expected to be exhausted before 2011, and in the case of the linear method the addresses pool will be exhausted before 2013. Methods: polynomial and exponential estimate the depletion of addresses during the year 2012. Regardless of the method of research, the prospect of exhaustion of IPv4 addresses is so close that the urgent implementation of IPv6 has become a necessity.

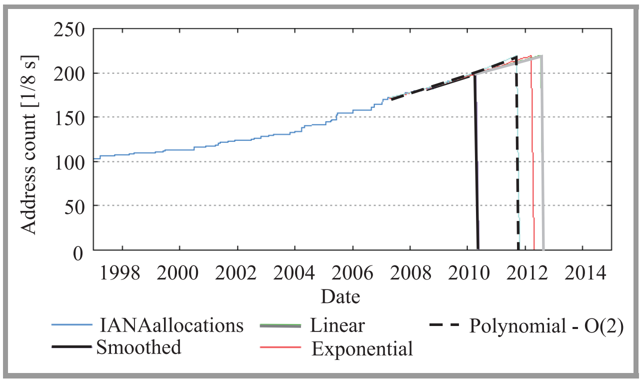

Fig. 1. Forecast rate of IPv4 addresses allocation in the IANA organization.

Use of IP in new application areas, such as mobile phones [3] or the Internet of Things [4] has forced increased budget and efforts on development of the IPv6 protocol and services applications associated with it. At the same time, works on the acceleration of migration processes and the implementation of IPv6 in telecommunication operators networks and end-user operating systems were intensified. The article presents the main features of IPv6 and the development of the protocol in the context of ongoing research projects. Then the state of implementation of IPv6 within research networks environment in Poland is reviewed and the scope of the IPv6 research in the Future Internet Engineering project is covered.

2. IPv6 Functionality

The modern Internet is based almost entirely on the use of the IPv4 protocol developed in the 1970s. At that time no one foresaw the development of the Internet on the scale observed today, especially the limitations of the available address space size. The problem of availability of addresses space was identified in the Nineties and it was the main reason to work on IPv6. Early estimates concerning the availability of addresses were predicting a few-year period. It is true that since then it has been several years and today it is still possible to obtain IPv4 addresses, although conditions to do it are tightened and much more restrictive than ever before. The demand for IPv4 addresses managed to slow down not only exacerbating the criteria for granting them, but also through the introduction of classless routing (called classless inter-domain routing), a mask of variable length (called variable length subnet mask), dissemination NAT (network address translation) mechanisms, as well as by the ability to configure multiple virtual Web servers on a single public IP address.

Although initial estimates indicated the exhaustion of the address space within just a few years during work on the new protocol assumed a large freedom of design and abolishment of ensuring full backward compatibility with IPv4. Thus, IPv6 is distinguished not only a much larger address space, but offers many other interesting features in regard to confidentiality, authentication, fragmentation only at the sender's side, no checksum in IPv6 datagram and easier to use mobility.

An IPv4 address is 32 bits, giving 2^{32} (approximately 4 billion) possible values, while an IPv6 address has a length of 128 bits giving a staggering number of addresses – more than 340 undecillion (or $6.5 \cdot 10^{23}$ addresses per square meter surface). It is much easier to imagine the enormity of the space by stating that if any device with the Internet connectivity were replaced by a network as big as today's Internet, 64-bit address space would be enough.

In the IPv4 protocol support for IPSec (IPSec enables the encryption/authentication of transferred data) is optional, while in the IPv6 protocol it is mandatory. It allows not only to ensure confidentiality but also provides the basis for further extension of the protocol features such as mobility.

IPv6 solves the performance problems observed when using IPv4. In the IPv4 packet might be re-fragmented/defragmented on each node that participates in the exchange of traffic between the sender and the recipient. In IPv6 fragmentation is possible only at the sender side: datagrams have to be in a size not exceeding the smallest MTU of any of the links on the route.

Other changes include fixed length 40 bytes in size of header, removed the header checksum and abandoned a validation of data at each stage of the transmission – all these changes were dictated by the need to reduce the demand for computing power in network devices and shorten the time required for a handling/routing datagram. Nowadays, thanks to technological advances and protocols such as MPLS these features have no longer a significant impact on increasing performance, as in the years when IPv6 was designed.

Today we can observe growing popularity of portable devices with wireless access to the Internet, and support for the mobility is becoming more and more important. Mobility is also possible to be implemented in IPv4 networks, but its use causes many problems. Mandatory implementation of IPSec in IPv6 as well as the large address space make the implementation of mobility in next generation networks using IPv6 much simpler. In addition, the MIPv6 protocol allows mobile terminal moving between networks without changing IP address. The movement of the mobile terminal is transparent to the transport protocol, and upper layer protocols.

During the design process of the IPv6 protocol special emphasis was put on the mechanisms of automatic configuration. There are two possible modes of autoconfiguration. The first one called a stateless configuration allows to configure the basic parameters of the hosts, such as an IPv6 address and routing configuration. The second available mechanism is stateful configuration, implemented using DHCPv6 [5]. Compared to its predecessor known from IPv4, DHCPv6 servers offer redundancy, the possibility of a smooth renumbering/readdressing of the network and configuration of large numbers of additional parameters, such as the delegation of address pools (prefix) instead of individual addresses. Currently 57 configuration options are approved [6] and the IETF is intensively working on further development of mechanisms for automatic configuration.

These features confirm that the IPv6 protocol has been considerably improved in comparison to IPv4. However, there are also some drawbacks. The mentioned lack of backward compatibility affects the pace of implementation of the new protocol and its popularity. Although most modern devices and applications could support both protocols or only the IPv6 protocol, the availability of IPv4 addresses inhibits the implementation of new mechanisms for IPv6. Currently, only the efforts of large corporations operating on the Internet can help to accelerate the migration to IPv6 networks. A good example is Google, which recently applied for the transmission of IPv6 traffic inside Youtube [7], thus increasing the overall level of IPv6 traffic on the Internet by thirty. Other companies are constantly working on developing their applications to adapt them to work with IPv6. For example, the producer of the popular MySQL database system speeds up work on completing the implementation of all modules in order to support IPv6. Last year, communications based on IPv6 protocol between the user of the MySQL system (mysqld) and MySQL server (ndb_mgmd) were implemented, but the communication between the MySQL server (ndb_mgmd) and databases repositories (ndb_d) is still to be implemented, and has been so far performed basing on IPv4 [8].

3. Development of IPv6

For many years IPv6 has been strongly supported as the next generation Internet protocol by both the European Commission and other government organizations, and its further development and popularization are the target of many projects funded by the European Union and other organizations supporting researches. This section presents a brief overview of the major projects supporting the development of IPv6 in the world. Among the major projects financed by the European Commission are the following projects: 6NET and its continuation 6DISS and 6DEPLOY and Euro6IX. Other presented projects include worldwide Moonv6, Indo-European project 6CHOICE and a Japanese project known as KAME.

The largest research project (at the time of its inception) funded by the European IST program (IST-2001-32161) was a project called Euro6IX [9], which involved leading telecommunication operators operating in Europe. The main objective of the project was to support the rapid deployment of IPv6 in Europe, including works such as designing and implementing a native IPv6 network, the study of advanced network services, application development and active participation in the standardization organizations.

An example of another large European project to stimulate the development of IPv6 is 6NET [10], whose main beneficiaries are the national research & education networks and academic community. The project built a native IPv6 network connecting 16 countries in order to gain experience of IPv6 deployment and migration from existing IPv4 networks. This environment was also used for extended tests of new IPv6 services and applications, as well as interoperability testing with existing applications. Main objectives of the 6NET project were:

- Install and maintain an international pilot IPv6 network including static and mobile components to better understand the problems associated with the implementation of IPv6.
- Test migration strategy for the integration of IPv6 with the existing IPv4 infrastructure.
- Implement and test new IPv6 services and applications as well as existing services and applications on the IPv6 infrastructure.
- Evaluate the address allocation, routing and DNS for IPv6 networks.
- Cooperate with other activities and IPv6 standardization organizations.
- Promote IPv6 technology.

The 6NET project was completed on June 30, 2005, but the popularization, training and support for the IPv6 activity was continued in the 6DISS project [11]. The aim of this project was to promote a broader knowledge of IPv6 through a program of training and knowledge transfer to developing regions. The 6DISS project ended in September 2007, but the training materials and distance learning packages are still available on the Internet free of charge.

The development of the IPv6 protocol is supported by the European Commission also under the Seventh Framework Programme. An example of such two-and-a-half-year project providing training support to IPv6 and its implementation for network operators, service providers and industry, is a project called 6DEPLOY [12]. This project offers not only direct the training of engineers and network administrators but also transfers knowledge and best practices in the topic to other instructors who may benefit from the project materials to teach others. The project has IPv6 training laboratories available remotely to carry out practical exercises, both during seminars and in another time. Also, a professional e-learning course is available through the project site, 6DEPLOY. It uses training materials developed during the IPv6 6DISS (described above) as well as experiences with IPv6 implementation of projects such as 6NET, Euro6IX and GEANT, and the cooperation and contacts established with the IPv6 forum, European IPv6 Task Force and IETF. The project includes thirteen 6DEPLOY partners from the commercial sector and academic research.

An example of another project in the field of IPv6 is a worldwide project Moonv6 [13] established by the IPv6 forum organization. This project focuses on providing technical information related to the implementation of IPv6 and leads the global IPv6 Ready Logo Program [14]. The IPv6 Ready Logo Program is a program of testing and broader cooperation. The steering committee of the IPv6 Ready Logo Program is made up of equipment and service providers, academic institutions, organizations and members of the IPv6 TAHI project (Japan) [15], the University of New Hampshire (USA) IRISA/INRIA (France), European Telecommunications Standardization Institute ETSI, TTA Telecommunications Technology Association (Korea), Beijing Internet Institute BII (China), Chunghwa Telecom Labs CHT-TL (Taiwan) and Japan Approvals Institute for Telecommunications Equipment JATE (Japan). The program of tests for IPv6 Ready Logo is divided into 3 phases:

- **Phase 1** (Silver) logo means that the product includes IPv6 mandatory protocols and can communicate with other IPv6 implementations.
- **Phase 2** (Gold) logo means that the product also meets the strong demands raised by the IPv6 Logo Committee (v6LC).
- **Phase 3** the logo yet undefined during the planning phase, will mean compliance with the same requirements as Phase 2 with the difference that the extended test for the category of IPsec is mandatory here.

Database of the IPv6 Ready Logo Program includes the names of companies that have qualified to use the logo and product names whose samples have been tested and evaluated. Such a logo on the product may be helpful to customers when choosing equipment to work with IPv6 networks.

Another project related to the testing of IPv6 is the Go4IT project [16]. This project is aimed at providing “free” and universal tools to test IPv6 compliance and cooperation. The aim of this project was implementing software for the testing environment to perform a set of tests developed by ETSI and defined in the notation TTCN-3 (Testing and Test Control Notation Version 3).

Another interesting international initiative co-financed under the Seventh Framework Programme for cooperation in India and Europe to promote IPv6 project is 6CHOICE [17]. Selected were a few priority sectors such as research e-infrastructure and Internet security, mobile wireless networks the next generation, the migration of IPv4 to IPv6 in this project. This project supports close cooperation between scientific networks ERNET and GEANT, as well as between the Indian project GRID (GARUDA) and its European equivalent EGEE. This cooperation has been supporting through a combination of networks and joint planning of services with strong support for IPv6. India is one of the first countries with the possibility of using policy regulations to implement this new protocol on a national scale.

Finally, an example of a national project conducted in the years 1998–2006 in Japan is presented. This project called KAME [18] arose from a combination of the efforts of six companies in Japan in order to provide a free stack of IPv6, IPsec and Mobile IPv6 for different BSD system variants. Products of this project are available on the following operating systems: FreeBSD, OpenBSD, NetBSD and BSD/OS. The project officially ended in March 2006, and almost all implemented in the course of its code was switched to FreeBSD and NetBSD.

As is apparent from the above projects, topics of the next generation networks and in particular IPv6 are strongly supported not only in the European Union, but throughout the world by various governmental organizations, science and industry. It is particularly important for interaction of different proposals in this field and to achieve synergies in the final and successful implementation and popularization of IPv6 in the world and a smooth migration to IPv6 with the existing solutions.

The military projects are also worth mentioning. The U.S. Department of Defense, together with research organizations and the DARPA (Defense Advanced Research Projects Agency) and the DISA (Defense Information Systems Agency) adopted a strategy of migration to IPv6 in October 2001. Since 2010, IPv6 has replaced IPv4, and is referred to as the Mandatory Standard E2E (End-to-End) Protocol. This is a very tangible role in government procurement to be carried out, since only products that have IPv6 support can be offered in tender procedures.

4. IPv6 Implementations in R&D Environment in Poland

The R&D environments were the first interested in testing and development of IPv6 protocol. It was a year after elaboration of IPv6 protocol specification, when network community began to activate IPv6 in test networks and in this way in 1996 the test network 6BONE was built. Also in Poland a few 6BONE servers came into being (mainly in academic centers) offering the tunneled connections IPv6 in IPv4 to all interested units. The 6BONE network was the first environment with the global scope making it possible to become acquainted with the IPv6 protocol, to perform tests and develop services and applications.

A few years before the end of the 6BONE network (the 6BONE network was ended in 2006 year) the MAN networks operators in Poland began to obtain the production IPv6 addresses blocs and afterwards to run IPv6 in their networks. In the year 2003, with mediation of the European network GEANT, the Polish optical network PIONIER was connected to the global IPv6 network. Since this time the IPv6 protocol has been working parallel to the IPv4 in the core of the PIONIER network and is accessible to all metropolitan area networks. The IPv6 traffic is running on two Juniper T320 core routers in Poznań and on one M120 router in Łódź. There are the following routing protocols used: MBGP interdomain routing (for connections to other operators) and IS-IS intradomain routing (between the PIONIER network routers). The PIONIER network provides with the transport network for 22 academic MANs, assuring of access to global IPv6 resources. There are direct peering points with other Polish (e.g., ATMAN) as well as with foreign operators (neighbors research national networks NREN – e.g., academic network SANET in Slovakia). Figure 2 presents MANs with their own IPv6 address blocs.

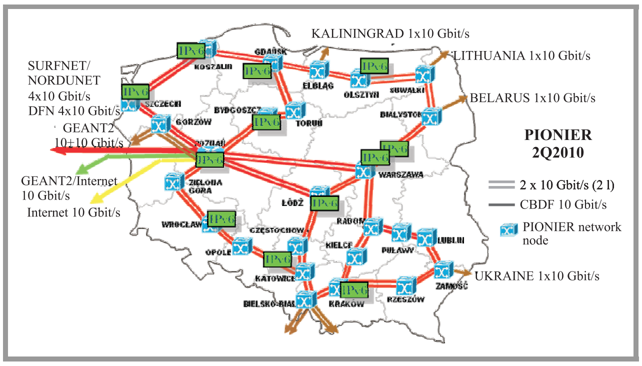

Fig. 2. The PIONIER network map with specified MANs operate IPv6.

The usage of the IPv6 protocol is dependent on resources and services which are accessible using this protocol. In the first row these are such services as ftp, news, servers for WWW, DNS and email. It is also worth mentioning that DNS for national domain .pl has been operating IPv6 since June 2005.

Besides, among the members of the PIONIER network in Poznań and in Warsaw, two nodes of SixXS network POP (point of presence) were activated. These nodes make it possible to connect to the global IPv6 network through tunneling in IPv4. This mode is offered as a transient way for all users, which cannot get the production IPv6 connectivity from their ISP. The node in Poznań activated in January 2005 offers tunnels to the following entities:

Łódź University of Technology, ZETO-Wrocław, Computer Science Institute of Warsaw University of Technology, Polish-Japanese Institute of Information Technology in Warsaw, University of Technology and Life Sciences in Bydgoszcz, Physics Institute of Warsaw University of Technology and AGH University of Science and Technology in Kraków. The SixXS project provides such mechanisms as IPv6 tunnel broker, ghost route hunter and IPv6 monitoring tools [19].

In the year 2004, the Polish IPv6 Task Force was brought into existence and inspired by Poznań Supercomputing and Networking Center [20]. Similar national initiatives (IPv6 Task Forces) exist in many other countries in Europe and in the world. This group is a non-profit initiative concentrating commercial firms, telecommunication operators, services providers, research and education centers – including the PIONIER network members, industrial centers, press and end users. The activity of members focuses on problems like development of network infrastructure, management of networks and security, implementation, development and testing of services and applications, education, experiences exchange, dissemination of results. The IPv6 Polish Task Force has an official web site [20], a publicly available mailing list and public knowledge base WIKI IPv6. The Task Force has cooperated with the Office of Electronic Communications (UKE) – in February 2009, the presentation to promote and stimulate implementation of IPv6 in Poland was worked out together with UKE, and on 24 March 2009 a common, public (PL IPv6-TF + UKE) debate took place to the point of acceleration of the IPv6 implementation in Poland.

In many universities in Poland the IPv6 protocol issues are discussed. For example, since 2002 the ETI department of Gdańsk University of Technology has been permanently running studies (lectures and laboratories) discussing the functionality and usage of the IPv6 protocol in network operation systems and LAN/MAN or WAN networks. Elaborated was also the first publication [21] which discusses the building and configuration of environments using the IPv6 protocol in both native and tunnel modes.

5. The Researched Problems of IPv6 Implementation in Project "Future Internet Engineering"

The importance of the IPv6 subject was noticed by the Ministry of Science and Higher Education and as a result the project Future Internet Engineering (IIP) in which one of the tasks are the research and implementation works in IPv6 technology scope [22] was accepted for realization. In the IIP project the research works related to the IPv6 technology were directed to 3 tasks:

– IPv6 resources virtualization,
– formulation of the cooperation rules and defining of the IPv4-IPv6 tests specification,
– elaboration of IPv6 applications and services.

In the scope of IPv6 resources virtualization the architecture of the "Virtual Internet" system will be designed and developed to make it possible to run users applications and services on dedicated virtual resources in the "on demand" mode.

The crucial element of ongoing works is the formulation of cooperation rules for IPv4-IPv6 protocols and the rules for secure and effective migration of the existing systems to the IPv6 environment. Within the framework of research different scenarios for cooperation of IPv4-IPv6 networks will be formulated and the solutions based on the use of tunneling mechanisms and protocol translation will be proposed. The next step will be the elaboration of good practices related to migration issues and automation of this process together with the tests confirming the correctness of realized activities. The application "IPv6 migration guide" with the knowledgebase (within the scope of IPv6 implementation in popular environments and IT systems or devices) which should support a user (administrator) in this process will come into being. The example dialog window of this application was presented in Fig. 3.

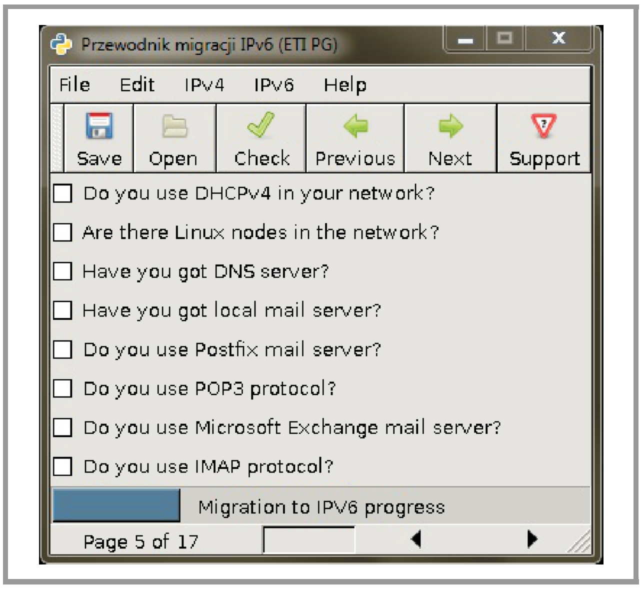

Fig. 3. The example dialog window of „IPv6 migration guide".

Also a version of the "IPv6 migration guide" in the LiveCD form integrated with a software which makes it possible to diagnose the network will be worked out.

The success of the Internet migration to the IPv6 protocol depends on possibilities to conduct this process in a way which does not break the continuity of services availability. Consequently, one of the key phases of this process is the testing of IPv6, which all the market participants should be interested in [23]. One of the first tasks in the scope of IPv6 tests realized in the project is the working out of the conception of tests realization in the small operators networks and the tools to perform these tests. Such choice comes out of the fact that the big entities which have appropriate big budgets and their own development departments can independently prepare and then to carry out the migration to IPv6. However, in many small firms there is a lack of appropriate know-how in the scope of IPv6 tests and in our opinion they need such support. Within the framework of this task works on the preparation of dedicated tool elaborated based on the TAHI project are currently being performed together with the set of tests adjusted to the small operator needs. We assume that the solution proposed in the project should be characterized by simplicity and availability. From this it follows that the test platform will be realized as dedicated LiveCD distribution of the FreeBSD system with installed TAHI environment. The advantage of such solution is no need to install the FreeBSD system and TAHI environment, which significantly accelerates and simplifies the phase of tests preparation. The tests available within the framework of this solution will make it possible to check the functionalities verified in the scope of cooperation tests. Importantly, they will be performed in a simple configuration which does not require from the one realizing the tests to configure many devices.

The factor which delays the implementation of IPv6 is the configuration complexity comparing to the IPv4 protocol and the lack of dedicated applications and services offering the additional quality. In the project the applications and services working in IPv6 environment will be developed using unique features of this protocol. Elaborated will be a prototype of a VoIP telephone for IPv6 with support of the SIP protocol or an IPTV system basing on the IPv6 network.

As the key element of IPv6 implementation the applications migration should be treated. It is necessary that this migration is running efficiently and does not cause temporary services unavailability. In order to do this it is necessary to work out the cooperation rules in the transient phase, in which the two IPv4 and IPv6 networks will coexist. Considering this, within the framework of the IIP project works will be taken up for the solution to assure the cooperation of IPTV systems based on IPv4 and IPv6 protocols. It will contribute to utilize the currently exploited devices supporting only the IPv4 protocol (e.g., set top box). We assume that the main element of this solution will be the server placed between IPv4 and IPv6 networks. The main tasks of this server will include the assurance of multicast traffic passing from? the IPv4 to IPv6 network. In this point we should notice that the simple translation mechanisms can be insufficient for this solution because the multicast addresses cannot be translated in a simple way. The important element of the research will be to determine the constraints related to the performance of elaborated solution. However, there is the danger that in case of concurrent servicing of many streams the IPv4/IPv6 translation server can be congested because of its hardware limitations. The proposed solution is presented in Fig. 4.

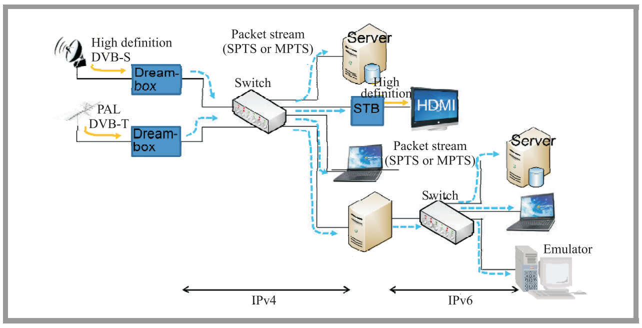

Fig. 4. The IPTV system in IPv4/IPv6 environment. PAL (phase alternating line), DVB-S (digital video broadcasting-satellite), DVB-T (digital video broadcasting-terrestrial), HDMI (high definition multimedia interface), STB (set top box), SPRS (single program transport stream), MPTS (multiple program transport stream).

Additionally, universal programing interfaces (API) between the virtualization system and users applications will be worked out.

What should be mentioned here is the development of comprehensive software served for automatic IPv6 network configuration. The solution called Dibbler is the implementation of DHCPv6 protocol offering the server, client, relay and requestor functionality. Thanks to broad support of various operating systems (Windows 2000-Windows 7, Linux, Mac OS), as well as hardware platforms (x86, amd64, HPPA, Sparc, PowerPC, arm9 etc.), but also because of open source distribution this solution has crowds of users not only in European Union but also in the world. The map of approved users (from over 30 countries) is presented in Fig. 5. Within the framework of the IIP project the significant expansion of functionality with remarkable consideration of the next generation network realities and requirements is anticipated, e.g., the development of servers infrastructure management, better support for mobile nodes.

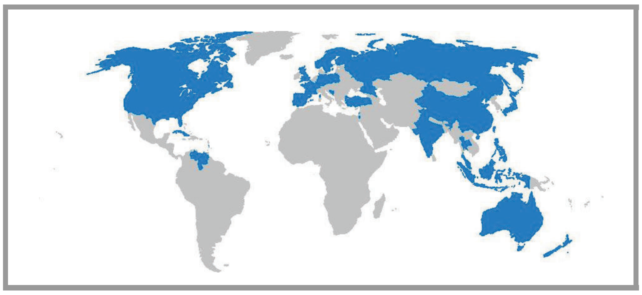

Fig. 5. The map presenting approved users of developed software DHCPv6.

Within the framework of research conducted in Gdańsk University of Technology on the subject of automatic configuration there are also anticipated activities which will aim at standardization of elaborated solutions. The example of such ongoing works is the initiative of standardization of the automatic DS-Lite tunnel configuration mechanism, proposed and accepted by the working group Softwire IETF [24].

In order to simplify the IPv6 solutions configuration in the project the works started to implement the new tunneling method 6RD – Rapid Deployment, defined by IETF in RFC 5569 [25] in January 2010. This method automates the client access devices configuration for IPv6 protocol including the mechanism for encapsulation of IPv6 datagrams in IPv4. Thanks to this it could be broadly used in building new generation access networks, not only used xDSL, HCF type of access but also WI-FI, WIMAX, etc.

6. Conclusions

This article has presented the arguments for quick implementation of the IPv6 protocol in operators networks, and considered the advantages of this technology comparing to the IPv4 protocol. This technology has the wide support in the scope of its development and implementation in the European Union policy as well as in national initiatives. The best known research projects realized within the framework of European projects and the projects with global meaning were discussed. The status of IPv6 technology implementation in Polish optical network PIONIER and academic metropolitan networks was presented. The important point in the development of IPv6 in Poland are activities performed within the framework of the project Future Internet Engineering.

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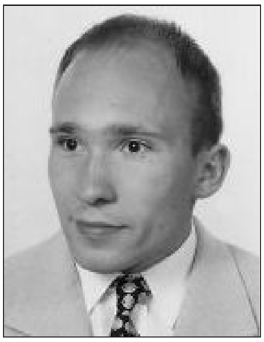

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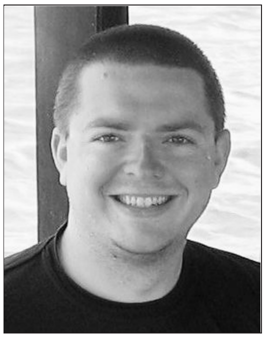

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