ANNUAL REPORT 2021

cesnet

Contents

CESNET, interest association of legal entities
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A word from the Director

CESNET CELEBRATED A SIGNIFICANT ANNIVERSARY – **25 YEARS SINCE ITS FOUNDING** – IN 2021. FOR ALL THOSE YEARS, THE ASSOCIATION WAS HEADED BY ING. JAN GRUNTORÁD, CSC., WHO ALSO WROTE INTRODUCTIONS TO ITS ANNUAL REPORTS. IN THIS RESPECT, 2021 WAS A YEAR OF CHANGE AS MR GRUNTORÁD DECIDED TO STAND DOWN AS DIRECTOR. AS HIS SUCCESSOR, I NOW HAVE THE FIRST OPPORTUNITY AND HONOUR TO TRY AND BRIEFLY EVALUATE THE PAST YEAR.

Despite a whole range of its research and service activities, CESNET's key task is still to provide backbone network infrastructure services. We carried out a substantial modernization of our main optical transport system in 2021. This was the first, successful stage of a large project under the Research, Development and Education operational programme, implemented under the e-INFRA CZ consortium, whose aim is to build and manage a unique research e-infrastructure in the Czech Republic.

Another domain in which CESNET traditionally provides its services to the scientific community is computing infrastructure and HPC. MetaCentrum, which focuses on this kind of services and is operated in collaboration with Masaryk University in Brno, modernized its hardware and expanded its range of services in 2021. Among other things, we significantly enhanced GPGPU capacities, which are fit for artificial intelligence tasks, and continued to support new services intended for scientific workflow modernization and automation and for open science facilitation.

Our traditional services, which include backbone network communication and the provision of computing power, are complemented by data storage services. We also enhanced capacity and added new hardware in this field – we put a new object storage facility located in Plzeň into operation at the beginning of the year and selected a contractor, based on a public tender, for an object storage facility in Ostrava, which was installed at the end of 2021.

As I have already mentioned, services relating to the research backbone infrastructure are provided under the e-INFRA CZ countrywide platform. CESNET strives to work with its partners in the consortium (Masaryk University and

25
years since its founding

VSB – Technical University of Ostrava) to achieve as much synergy as possible in making the services available to the research community. That was definitely one of the reasons why an international board gave the e-INFRA CZ platform an excellent rating in 2021.

In addition to the above-mentioned 'standard' activities, CESNET looked into some new, very promising technologies in 2021 that have high potential for development in future years. An example of such a field is quantum technology, specifically its application in encrypted, high-security transmissions or in high-precision time transfer. We carried out the first cross-border QKD transfer in collaboration with colleagues from VSB – Technical University of Ostrava and PSNC, the Polish research and education network, in 2021. CESNET experts also collaborate closely on a concept of up-to-date communications infrastructure modernization to realistically enable the expected adoption of quantum technologies in installed network resources.

I also have to mention our cybersecurity activities when looking back at 2021. Cybersecurity has been a hot topic lately not only because the sophistication of attacks increases constantly but also because more and more important data and process agendas have moved to digital. CESNET's salience in this field was documented by our colleague Andrea Kropáčová's induction into the Cybersecurity Hall of Fame. The award is given for key or long-term positive contributions to cybersecurity in the Czech Republic.

Owing to increasing cyber threats and regulatory requirements, CESNET as a provider of backbone network infrastructure became an entity subject to regulation under the Cyber Security Act. To meet its new obligations but also to improve the services it provides, especially data transport services, it **launched the CESNET SOC (Security Operations Center) project**, formalizing security services for Association members in the basic version during the initial stage.

I started my words with a mention of Mr Gruntorád. I would like to talk about him again in the conclusion, expressing my sincere thanks. Without his patience with gradually introducing the new director to the hugely broad 'repertoire' of CESNET's activities, I would have had serious trouble assuming my role. His contribution to our field was recognized at the highest international level at the end of the year, too. **Jan Gruntorád was the first person from Central Europe to be inducted by the Internet Society into the renowned Internet Hall of Fame.**

However, I would like to extend my thanks to an overwhelming majority of my colleagues, whose support and high-quality collaboration I experience virtually every day.

The year 2021 was a successful one for CESNET. Naturally, our thanks for that go also to our partners and members of the community. Our activities and efforts continue without interruption. That makes me believe that we will be satisfied with our results in 2022, too.

Ing. Jakub Papírník
Director of CESNET

The CESNET Association

THE ASSOCIATION'S HISTORY AND CURRENT TASKS

CESNET was founded by public universities and colleges and the Czech Academy of Sciences (CAS) in 1996.

CESNET's mission is to

- Provide the scientific, research and education community with unique and comprehensive e-infrastructure services with a quality comparable to the world's best and support the Open Science concept
- Offer stable services with high added value covering the widest possible spectrum of needs of our users
- Contribute our in-house research activities towards the development of information and communications technology and put their results into practice

When founded, the Association also operated as a commercial internet service provider in order to earn additional money from these activities for its principal activity. It discontinued that activity in 2000, chiefly for economic and legislative reasons. Since then, it has been engaged exclusively in the **development and operation of science, research and education e-infrastructure** and related activities.

Another milestone in the Association's history is the year 2010 when the CESNET e-infrastructure became part of the **Czech Republic Roadmap for Large Research, Experimental Development and Innovation Infrastructures**[1]. In 2014, the CESNET e-infrastructure received the highest research infrastructure rating possible and was included in the updated Czech Republic Roadmap for Large Infrastructures. Based on further assessment of large research infrastructures in 2017, the CESNET e-infrastructure was included in the top category of research infrastructures with excellent quality comparable to that of similar infrastructures worldwide, highly relevant to the future development of the Czech Republic's research and innovation environment and necessary for the enhancement of the Czech Republic's competitiveness. Furthermore, the international assessment board recommended the **CESNET, CERIT-SC and IT4Innovations** e-infrastructures to establish closer cooperation in terms of capacity building and the provision of services to users. The operators of those infrastructures (CESNET, Masaryk University and VSB – Technical University of Ostrava) formed a consortium in 2019 and have provided services under a unified brand, **e-INFRA CZ**, since 2020.

Since 2020, e-INFRA CZ has been the sole national e-infrastructure included in the Czech Republic Roadmap for Large Research, Experimental Development and Innovation Infrastructures for 2016 to 2022.

CESNET accepted its first two **associate members, the National Museum and the Moravian Gallery in Brno**, in 2020.

CESNET, Masaryk University and VSB – Technical University of Ostrava are now **members of the EOSC (European Open Science Cloud) association**.

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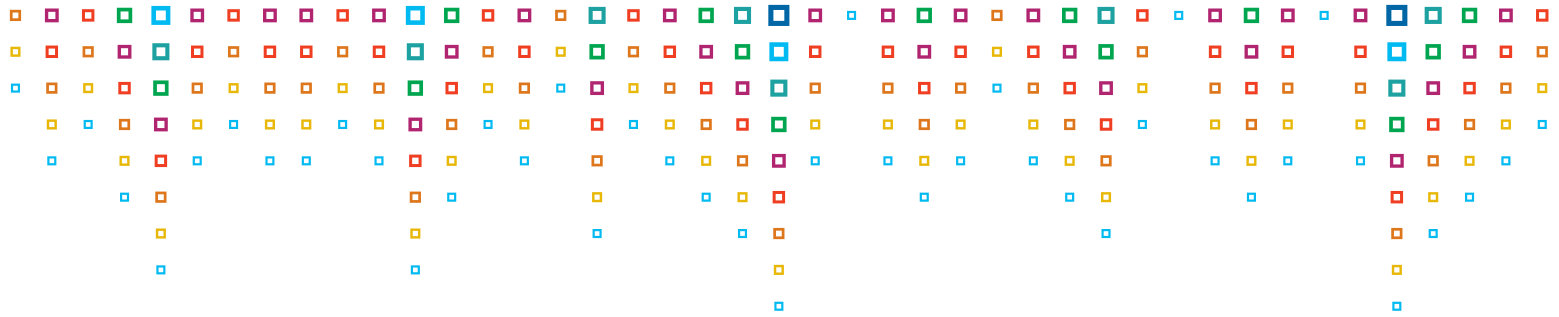
[1] A large infrastructure for research, development and innovation means a unique research facility, including its acquisition, associated investments and operational arrangements, which is necessary for comprehensive research and development activities with high financial and technological demands and is approved by the government and established by a research organization to be also used by other research organizations ("large infrastructure").'

Infrastructure definitions. *Ministry of Education, Youth and Sports* [online]. [viewed 2020-04-24]. Available from: http://www.msmt.cz/vyzkum-a-vyvoj/definice-infrastruktury



SCOPE OF ACTIVITIES

The scope of the Association's main activities is

1. Conducting independent research and development activities in information and communications technologies and providing research services in this field

2. Supporting education in information and communications technologies

3. Putting the results of in-house research and development into practice through technology transfer of internal nature

4. Undertaking the following activities for the benefit of its members, their subsidiary organizations as well as other entities:

   - Developing and operating the national communications and information infrastructure to enable the interconnection of their infrastructures, provide access to the CESNET infrastructure and connect to similar third-party infrastructures (including internet access)
   - Building shared hardware, communications and software and information services
   - Verifying new applications, collaboration and complementarity of member activities at a level comparable to that of leading academic and research infrastructures abroad

The Association performs and provides its activities within the scope of received subsidies and partial compensation for expenses associated with these activities. It is not the Association's objective to generate any profit on these activities.

The Association pursues supplementary activities in addition to its main activities, but solely for the purpose of making more efficient use of its property and without any negative impact on research activities. The services are not provided on a publicly available basis.

Any loss incurred in connection with the Association's supplementary activities will always be settled by the end of the fiscal period in question or the supplementary activity in question will be discontinued before the beginning of the following fiscal period.

The Association uses all of its profits to promote research and development.

The CESNET Association

MEMBERSHIP OF INTERNATIONAL AND NATIONAL ORGANIZATIONS

CESNET was a member of the following renowned organizations in 2021:

International organizations

- **EOSC AISBL** – an international association of institutions involved in the building of the European open science cloud concept (www.eosc.eu)

- **GÉANT Association** – an association of European national research networks that is engaged in the operation and advancement of the GÉANT European communications infrastructure and coordination of related activities (www.geant.org)

- **EGI.eu** – an organization focusing on coordinating European computing grids used for scientific computations and supporting their sustainable development (www.egi.eu)

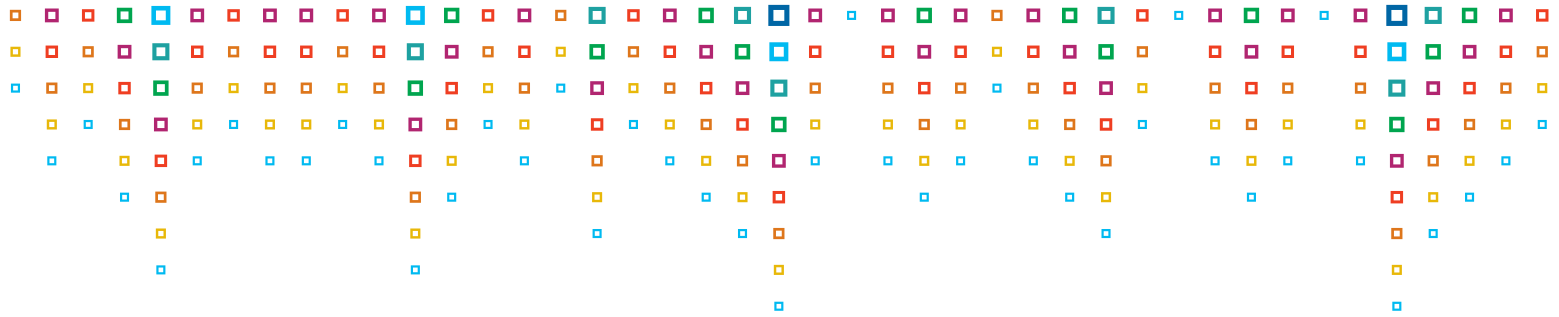
- **Shibboleth** – an international consortium for the coordination of the development of a service providing a single sign-on solution, meaning that a user can use multiple secured network resources using a single login. Shibboleth is the foundation for academic identity federations (www.shibboleth.net)

- **QUAPITAL** – a Central European partnership for secure communication with quantum-level security and a quantum internet (www.quapital.eu)

National organizations

- **NIX.CZ** – CESNET is one of the founders of NIX.CZ, z.s.p.o. (Neutral Internet Exchange), an association of internet service providers in the Czech Republic that provides interconnectivity for its members' networks (www.nix.cz).

- **CZ.NIC** – the Association is also one of the founding members of CZ.NIC, z.s.p.o., which administers the .cz domain and supports publicly beneficial projects and activities relating to the internet (www.nic.cz).



ASSOCIATION MEMBERS

The following institutions were regular members of the Association in 2021:

- Academy of Performing Arts in Prague
- Czech Academy of Sciences
- Academy of Fine Arts in Prague
- Czech University of Life Sciences Prague
- Czech Technical University in Prague
- Janáček Academy of Performing Arts
- University of South Bohemia in České Budějovice
- Masaryk University
- Mendel University in Brno
- University of Ostrava
- Police Academy of the Czech Republic in Prague
- Silesian University in Opava
- Technical University of Liberec
- University of Hradec Králové
- Jan Evangelista Purkyně University in Ústí nad Labem
- Charles University
- University of Defence
- Palacký University Olomouc
- University of Pardubice
- Tomáš Baťa University in Zlín
- University of Veterinary Sciences Brno
- VSB – Technical University of Ostrava
- Prague University of Economics and Business
- University of Chemistry and Technology, Prague
- Academy of Arts, Architecture and Design in Prague
- Brno University of Technology
- University of West Bohemia

The following institutions were associate members in 2021:

- National Museum
- Moravian Gallery in Brno

The CESNET Association

INTERNAL ORGANIZATIONAL STRUCTURE

CESNET has the following bodies:
- General Assembly
- Board of Directors
- Supervisory Board
- Director of the Association

The **Board of Directors** consisted of the following members in 2021:
- Mgr. Michal Bulant, Ph.D.
- RNDr. Igor Čermák, CSc.
- RNDr. Alexander Černý
- Ing. Jan Gruntorád, CSc.
- Mgr. František Potužník
- Doc. RNDr. Pavel Satrapa, Ph.D.
- Prof. Ing. Miroslav Tůma, CSc.

The **Chairman** was prof. Ing. Miroslav Tůma, CSc., and the **Vice Chairmen** were RNDr. Igor Čermák, CSc., and Mgr. František Potužník.

The **Supervisory Board** consisted of the following members until June 2021:
- Ing. Radek HOLÝ, Ph.D.
- Ing. Jaromír MARUŠINEC, Ph.D., MBA
- Ing. Jakub PAPÍRNÍK
- RNDr. David SKOUPIL
- Ing. Michal SLÁMA

The **Supervisory Board** consisted of the following members from June 2021 on:
- Ing. Radek HOLÝ, Ph.D.
- Mgr. Martin MAŇÁSEK
- Ing. Jaromír MARUŠINEC, Ph.D., MBA
- RNDr. David SKOUPIL
- Ing. Michal SLÁMA

Ing. Michal Sláma was the **Chairman** of the Supervisory Board in 2021.

The **Director** of the Association was Ing. Jan Gruntorád, CSc. until July 2021 and Ing. Jakub Papírník from August 2021 on.

Development Fund Board

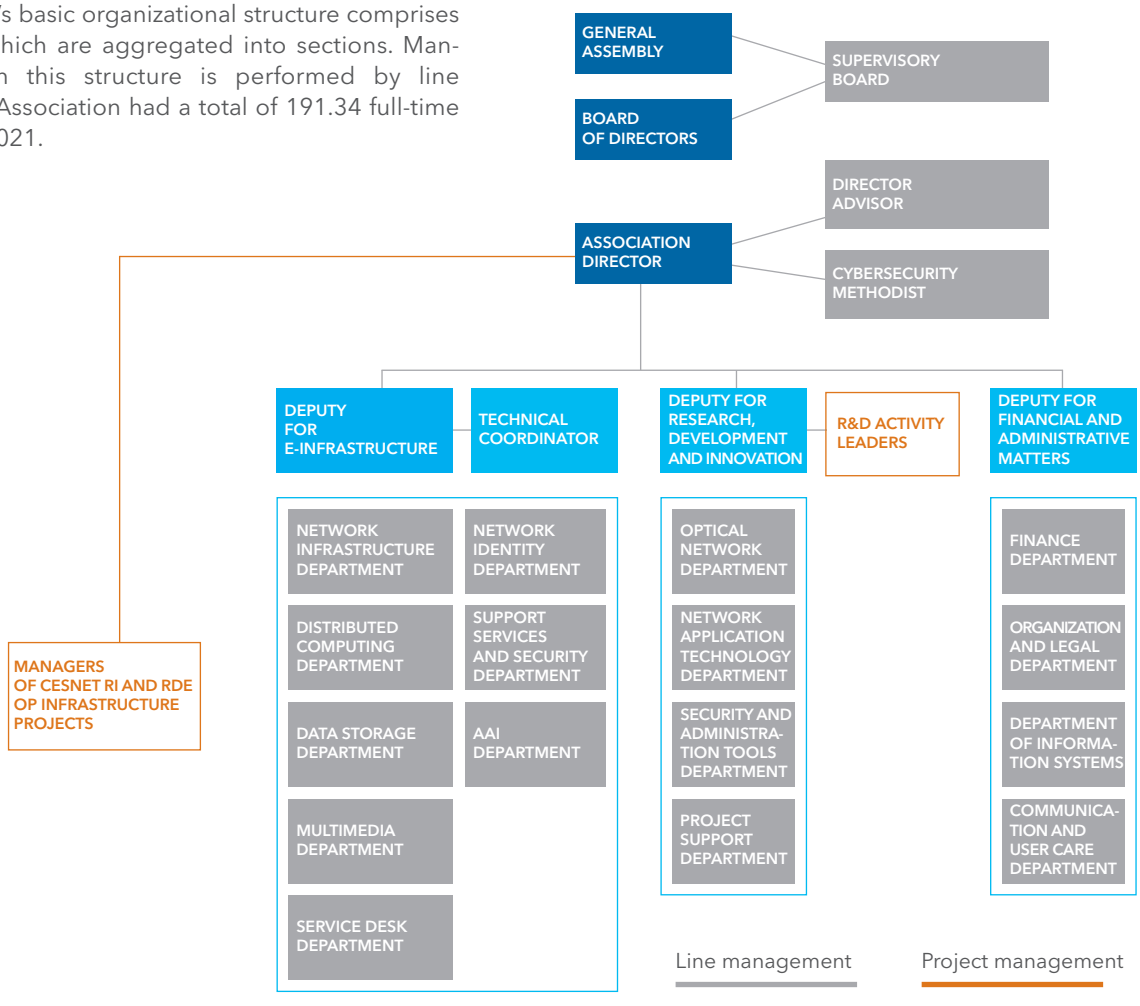
The **Development Fund Board** consisted of the following members until June 2021:
- Doc. RNDr. Eva HLADKÁ, Ph.D.
- Mgr. Monika HRABÁKOVÁ
- Ing. Olga KLÁPŠŤOVÁ
- Doc. RNDr. Antonín KUČERA, CSc.
- Ing. Jan PINTA, MBA
- Ing. Tomáš PODERMANSKI
- Prof. Ing. Zbyněk ŠKVOR, CSc.

The **Development Fund Board** consisted of the following members from June 2021 on:
- Doc. RNDr. Eva HLADKÁ, Ph.D.
- Ing. Jaromír HOLEC
- Mgr. Monika HRABÁKOVÁ
- Ing. Olga KLÁPŠŤOVÁ
- Doc. RNDr. Antonín KUČERA, CSc.
- Ing. Tomáš PODERMANSKI
- Prof. Ing. Zbyněk ŠKVOR, CSc.

The **Chairwoman** of the Development Fund Board was Ing. Olga Klápšťová in 2021..

ORGANIZATIONAL CHART

The Association's basic organizational structure comprises departments, which are aggregated into sections. Management within this structure is performed by line managers. The Association had a total of 191.34 full-time equivalents in 2021.



CESNET e-infrastructure

THE CESNET E-INFRASTRUCTURE IS PART OF E-INFRA CZ, A LARGE RESEARCH INFRASTRUCTURE THAT IS A MAJOR ELEMENT OF THE CZECH REPUBLIC ROADMAP FOR LARGE RESEARCH, EXPERIMENTAL DEVELOPMENT AND INNOVATION INFRASTRUCTURES FOR 2016 TO 2022. IT PROVIDES A UNIVERSAL ENVIRONMENT FOR THE TRANSFER, PROCESSING, SHARING AND STORAGE OF SCIENTIFIC DATA AND USER COLLABORATION THAT IS INDEPENDENT OF ANY SPECIFIC FIELD OF RESEARCH AND INDISPENSABLE NOWADAYS TO CONTEMPORARY RESEARCH, DEVELOPMENT AND INNOVATION IN ANY FIELD.

The CESNET e-infrastructure is used to **provide services for Czech science, research, development and education**. The following chapters describe the development of this e-infrastructure, the portfolio of offered services and the associated research activities. The Association provides these services to not only its members but also other entities that comply with the CESNET e-Infrastructure Access Policy.

CESNET is the host organization for e-INFRA CZ as well as the coordinator of two complementary projects for the development and operation of e-INFRA CZ:

- **e-Infrastruktura CZ** (LM 2019140, 2020–2022) funded under the Large R&D&I Infrastructure Projects programme (2010–2022). The special-purpose aid in the form of subsidy is earmarked for covering a portion of operating costs associated with e-infrastructure operation.

- **e-INFRA CZ: Modernization** (EF18_072/0015659, 2020–2022) funded from the Research, Development and Education operational programme, which is the main source of investment funds for a major e-infrastructure upgrade.

450 000
users

e-INFRA CZ infrastructure

Since 2020, the CESNET e-infrastructure has been part of a comprehensive national e-infrastructure for research, development and innovation (R&D&I), which is included in the Czech Republic Roadmap for Large Research, Experimental Development and Innovation Infrastructures for 2016 to 2022 under the name of e-Infrastructure CZ (abbreviated as e-INFRA CZ). e-INFRA CZ is the result of collaboration among three original e-infrastructures:

- **CESNET e-infrastructure** operated by CESNET,
- **CERIT Scientific Cloud** operated by Masaryk University, and
- **IT4Innovations national supercomputing centre** operated by VSB – Technical University of Ostrava.

The objective is to modernize and ensure the operation of individual e-INFRA CZ components. The members of the consortium thus build on the previous operation of their e-infrastructures while striving to **align their approach to users** so that they can see the e-INFRA CZ e-infrastructure as a coherent whole.

An assessment of large research infrastructures was carried out at the level of the Ministry of Education, Youth and Sports (MEYS) in 2021. An international assessment board reviewed many criteria of individual large research infrastructures, such as scientific and technological mission, relevance and significance to R&D&I, socio-economic impacts, management structure, capacity utilization, user support, or comparison with foreign infrastructures. **e-INFRA CZ was rated as an excellent infrastructure overall**, getting the highest possible rating.

CESNET e-infrastructure development

OUR ACTIVITIES RELATED TO BUILDING THE CESNET E-INFRASTRUCTURE FOCUSED ON THE MODERNIZATION OF E-INFRA CZ COMPONENTS THAT CESNET IS RESPONSIBLE FOR IN 2021.

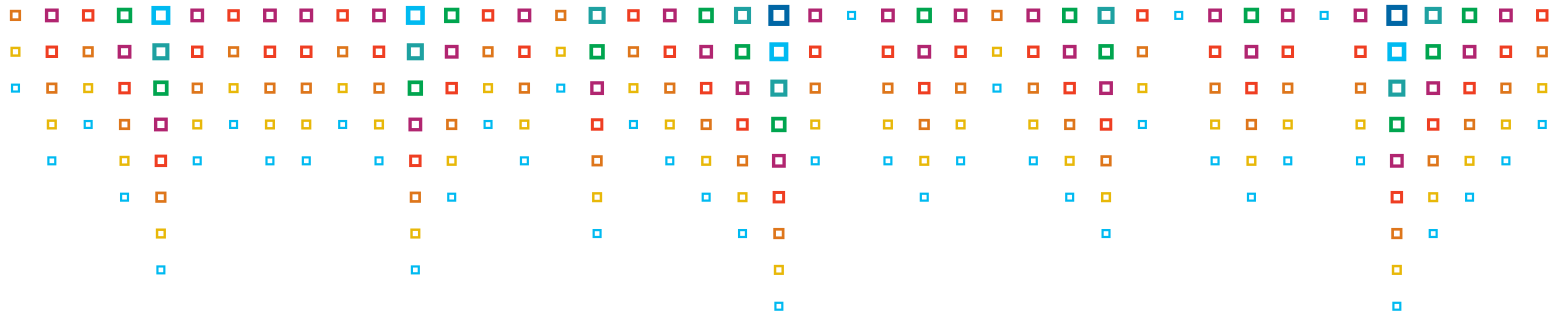
We carried out the following activities relating to the development of e-infrastructure services in 2021:

- Executing the first five stages of modernizing the main optical transport system by replacing technology in the Prague, Brno, Olomouc, Hradec Králové and Liberec nodes
- Upgrading international connectivity to fully redundant 2x10 Gbps in Prague and 2x10 Gbps transported from Bratislava to Brno
- Enhancing CESNET network security with protection provided by the Global AntiDDoS Mitigation service
- Upgrading the capacity of cross-border links to Slovakia (SANET) and Austria (ACONET) to 40 Gbps
- Replacing the outdated minos computing cluster with a new cluster, kirke, and commencing regular operation of a new disk storage facility for demanding computation needs
- Enhancing MetaCentrum security
- Providing selected user groups with pilot access to an open publication repository with metadata support
- Extending Zoom with webinar functionality for up to 500 participants and greatly enhancing the streaming infrastructure capacity
- Putting the eduID.cz Hostel IdP out of service
- Preparing a new version of the Ultragrid low-latency video and audio transmission tool
- Taking further steps to AAI unification under e-INFRA CZ

We modernized e-INFRA CZ components that CESNET is responsible for in 2021:

- Completing the modernization of the main optical transport system (the core of the DWDM network)
- Choosing a contractor and signing a contract for upgrading the IP/MPLS layer of the CESNET2 network
- Preparing and making a call for tenders for modernizing the peripheral circuits of the DWDM network
- Taking over a new object storage facility in Ostrava
- Preparing and making a call for tenders for an object storage facility in Brno
- Procuring an SMP and GPU computing cluster for MetaCentrum

Communications infrastructure



IN ADDITION TO ROUTINE OPERATION ACTIVITIES, WE WERE MODERNIZING THE NETWORK IN 2021 WITH THE AIM OF REPLACING EXISTING TECHNOLOGY NEARING THE END OF ITS SERVICE LIFE, **ENHANCING THE SPEED AND AVAILABILITY OF CESNET E-INFRASTRUCTURE SERVICES** AND ALLOWING CESNET E-INFRASTRUCTURE USERS TO CONNECT AT HIGHER TRANSFER RATES.

We started gradual **modernization of the main DWDM optical transport system** (referred to internally as FWDM0), which we finished successfully by the end of the year. The modernization was aimed at replacing existing technology nearing the end of its service life, enhancing the speed and availability of CESNET e-infrastructure services and allowing CESNET e-infrastructure users to connect at higher transfer rates. We also expanded the FWDM0 system by adding new routes and nodes (closing the southern Prague – Plzeň – České Budějovice – Jihlava – Brno ring, incorporating nodes at Pardubice, Zlín and Ústí nad Labem). The system is based on the latest FlexGrid technology and supports optical transport channels with 100 Gbps to 1 Tbps capacities. The subsequent IP/MPLS network layer will use capacities of 100 Gbps and 400 Gbps, using multiple channels in the network core. The system was designed with inherent support for transfers of precise time and frequency and QKD keys.

We also installed and commissioned a **new FWDM0 management and monitoring system**, EPNM, as part of the modernization. The modernization took place during full operation and was therefore divided into a total of 16 consecutive stages. Backup connection was provided for affected nodes during each stage so that user traffic remained unaffected. The modernization was completed on schedule in late December 2021. The FWDM0 main optical transport system is fully prepared for an upgrade to the higher-level IP/MPLS network layer (including 400 Gbps optical transport channels and their conversion into a universal 'grey' interface for the connection of IP/MPLS routers). A contract award procedure for the modernization of the IP/MPLS network layer, aimed at upgrading the transport and connection capacities of the network, was completed successfully. Testing included the assessment of declared technology properties, compatibility with the existing CESNET2 network, options for migration during full operation and the deployment of new promising functions such as IPv6 segment routing (SRv6) or network telemetry. A contract was made with the selected contractor in the autumn and the bulk of the modernization is a task for 2022.

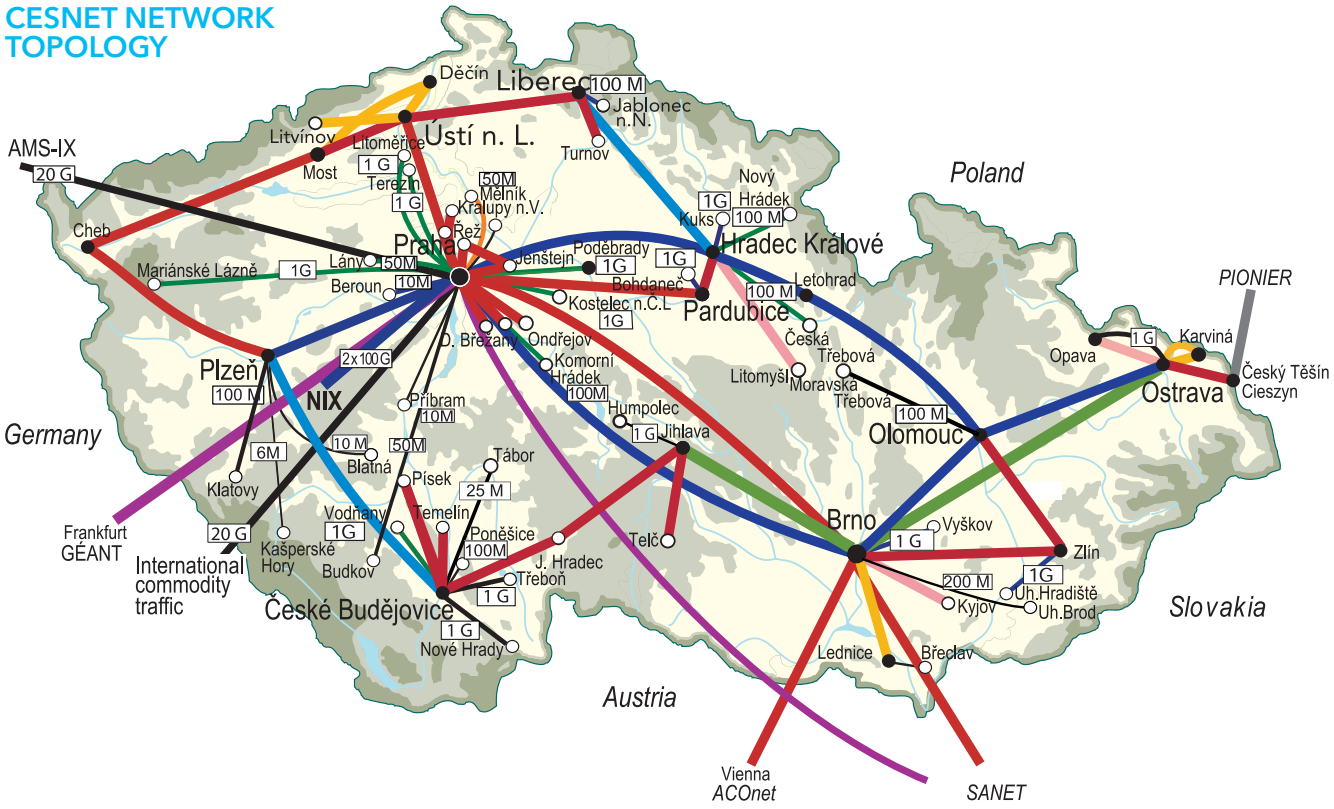
We prepared a contract award procedure for the replacement of the outdated CL DWDM technology (working designation: FWDM1) that is run on backup backbone routes and user access routes. These are routes where a large optical transport system such as FWDM0 cannot pay off technologically and economically but they still require the use of DWDM technology.

The **capacity of cross-border links to Slovakia (SANET) and Austria (ACONET) was upgraded to 40 Gbps**. The links provide, among other things, access to the countries' peering nodes, SIX and VIX, and allow distributing internet connection capacities. The links also serve for backup connection transport for global connectivity (IP transit).

As part of migrating the Prague node from our headquarters in Zikova street, which has no more potential to serve as the location of the node and other technologies, we **procured premises for expanding the Prague 2 node**.

The Prague node of the pan-European GÉANT network is being migrated to the same premises.

CESNET NETWORK TOPOLOGY



- Czech Light n x 100G
- Czech Light n x 10G
- Czech Light n x 10G started by 1G
- Czech Light n x 1G
- Cisco n x 100G
- Cisco n x 10G
- Infinera n x 100G
- Infinera n x 10G

- Single colour transmission system
- Leased capacity
- Microwave
- Optical and Microwave

- PoP
- User Point

A very important aspect of network operation is **securing the network communications infrastructure and connected users against attacks**. A deployed service providing global protection against volumetric attacks, having the form of a global scrubbing centre, proved itself meaningful and its application was more closely interconnected with well-established automated detection systems. CESNET participates in an hSOC (hospital SOC) activity, which is aimed at providing connected hospitals with better protection against cyber threats and attacks. It is a dedicated network within the CESNET e-infrastructure, isolated from standard traffic, with specific policies and rules, complemented by a number of security tools for the monitoring and management of communication with involved entities. The isolation allows for more comprehensive and more detailed protection of hospitals. Participants in the hSOC activity comprise 54 healthcare organizations, 8 hospital (regional) authorities and 8 other entities (such as NÚKIB, NAKIT or the Czech Ministry of the Interior). The isolated network (hSOC-VRF) connects 7 hospitals (Jihlava Hospital, St Anne's University Hospital in Brno, Na Homolce Hospital, the Military University Hospital in Prague, Liberec Regional Hospital, Olomouc University Hospital and the General University Hospital in Prague).

CESNET constantly ensured the operation of and provided support to other services of the CESNET e-infrastructure, connected network users and large research infrastructures. **It provides its members with connection to the backbone infrastructure, which is designed to provide sufficient capacity for data transfers and be as resilient to link and technology outages as possible.** The actual infrastructure is connected to neighbouring networks in various ways with an aggregated transfer rate of over 400 Gbps. This involves global connectivity (ISPs and interconnection nodes) and links to research networks (GÉANT, CBF) that provide users not only with connectivity having sufficient capacity and redundancy but also with specialized links for specific applications.

The offered network access services include:

- Dedicated circuits and networks
- Lambda services with physically reserved capacity and fixed delay
- Photonic services for the most demanding applications with an all-optical pathway between points
- Internet identifier administration (CESNET NIC), including a LIR Sponsoring service
- Authoritative and secondary DNS services
- Stratum 1 primary time servers with an internal time source
- Infrastructure monitoring and surveillance using tools such as FTAS, G3, Nagios/Icinga
- Services of an internationally accredited CSIRT security team, CESNET-CERTS
- Permanent network operability monitoring (NOC)
- 24 x 7 x 365 service desk – support contact point (monitoring centre and help desk)

CESNET pays a lot of attention to protecting the infrastructure against security incidents. The network deploys semi-automatic protection against DDoS attacks. An RTBH (Remotely Triggered Black Hole) filtering service is provided constantly in production mode. An ExaFS service is also deployed in operating mode, which allows administrators at connected institutions to use a BGP FlowSpec configuration in case of a massive DDoS attack to drop unwanted traffic already at CESNET2 routers or reroute the traffic to further analysis by the DDoS Protector (developed as part of CESNET's research activities), which filters out unwanted traffic. Another level of protection that can be applied before traffic enters the network perimeter is provided by using global protection against volumetric attacks in the form of a global scrubbing centre.

As part of its national activities, CESNET is also a trusted operator in the FENIX project. The whole defence ecosystem is developed continually because the protection of network communications infrastructure and subscribers against attacks must respond to new threats all the time.

Demanding computations

cesnet
metacentrum

WE SUBSTANTIALLY MODERNIZED EQUIPMENT LOCATED AT THE UNIVERSITY OF WESTERN BOHEMIA IN PLZEŇ AT THE BEGINNING OF 2021. WE FULLY INTEGRATED THE KIRKE COMPUTING CLUSTER, PURCHASED IN LATE 2020, INTO THE METACENTRUM ENVIRONMENT AND PUT A NEW DISK STORAGE FACILITY INTO REGULAR OPERATION. THE NEW KIRKE CLUSTER HAS A TOTAL OF 60 NODES WITH 3,800 CPU CORES, 512 GB OF RAM AND 4 TB OF SSD SCRATCH STORAGE AND REPLACES THE OUTDATED MINOS CLUSTER. THE NEW DISK ARRAY HAS 1.2 PB HDD AND 120 TB SSD CAPACITY. THE WHOLE METACENTRUM NODE IN PLZEŇ IS INTERCONNECTED BY AN FDR INFINIBAND HIGH-SPEED, LOW-LATENCY NETWORK. OTHER NEW CAPACITIES WERE PURCHASED IN LATE 2020 FOR THE EGI CLUSTER AT THE INSTITUTE OF PHYSICS (8 NODES) AND FOR CLOUD CAPACITIES (10 NODES WITH T4 GPGPUS). IN TOTAL, 5,632 CPU CORES AND 20 T4 GPGPUS WERE PUT INTO OPERATION.

Under the ELIXIR-CZ project, CESNET continued to provide operational support for new hardware deployed in late 2020, which includes, most notably, a high-performance computing cluster intended for natural science tasks located at the Institute of Organic Chemistry and Biochemistry and a 432 TB HDD and 46 TB SSD disk array located at BIOCEV. In early 2021, we also finished integration of new clusters acquired by the Department of Physical and Macromolecular Chemistry of the Faculty of Science of Charles University. We are currently preparing a contract award procedure for new HW (computing clusters with GPGPUs and disk arrays) to continue with the planned renewal and extension of installed HW. The main objective for 2021 was renewing clusters in Brno.

We continued to support new services intended for scientific workflow modernization and for open science facilitation (repeatability, transferability). Specifically, this concerns the JupyterHub service. The service allows using computing infrastructure resources in the form of Jupyter notebooks, which are becoming increasingly popular. We also paid attention to container support. With the Singularity technology and using the CVMFS file system, it is now easier to run computing tasks in MetaCentrum in a fine-tuned and completely portable environment, such as NVIDIA containers for efficient GPGPU support. This also applies to services provided in collaboration with CERIT-SC, namely Kubernetes and the OnDemand environment, which allows running grid tasks from a web client environment.

We held a full-day user workshop during the CESNET conference in April 2021. Its afternoon portion focused on practical demonstrations of working with those new tools and technologies.

At system level, AMD architecture and relevant development tools are now fully supported. We also continued to optimize application SW administration in connection with high demand for new SW, which we were able to satisfy over time (100 installations in a year).

2 606
users

In relation to an ISMS surveillance audit, which focused on MetaCentrum in 2020, and penetration tests (October 2020), we started and completed several projects based on risk analysis. These concerned an environment with enhanced security protection available to all services running on the virtualization platform (a new firewall with IDS/IPS functionality), the optimization of security elements (fail2ban protection against SSH attacks, targeted user notifications based on the detection of anomalies in logging in to individual accounts and on password quality analysis) and MetaCentrum network security monitoring using the FTAS + exaFS technologies.

In accordance with its hybrid strategy for cloud services, CESNET also ordered the services of commercial cloud providers under OCRE framework agreements procured by GÉANT.

The expansion and modernization of MetaCentrum computing capacities ran on schedule and in accordance with users' needs in 2021:

- The kirke computing cluster (60 nodes, 3,800 CPU cores, 512 GB of RAM, 4 TB of SSD scratch storage) and disk array (1.2 PB HDD, 120 TB SSD) procured in 2020 are in full operation and available to users using the grid model.
- ELIXIR users have access to new machines with 2 TB of RAM that allow using, among other things, RepeatExplorer services or the IOCB Database of Small Molecules.
- The EGI cluster at the Institute of Physics of the Czech Academy of Sciences was expanded by adding 8 nodes.
- Computing cloud capacities were expanded by adding 10 nodes with T4 GPGPUs, which are also available to users of the international EGI environment.
- Another cluster with NVIDIA cards (20 nodes, 80 NVIDIA A40 cards) and a cluster with more memory (30 servers with 1 TB of RAM), totalling 3,250 CPU cores, were procured in 2021 based on the evaluation of resource requirements.
- Disk capacity in Brno will be expanded by 1 PB for operational storage of processed data; 500 TB will be added to the adan cluster at Biocev to complement its capacity; 250 TB will be installed at the Institute of Organic Chemistry and Biochemistry to renew capacity for ELIXIR CZ services.

34 084
CPU cores

We continued to support new services intended for scientific workflow modernization and automation:

- We expanded the JupyterHub service by adding support for the JupyterLab interface and ability to create custom notebooks using the Binder tool and we launched another instance of the service within the EGI European infrastructure.
- We developed the application of the Kubernetes environment in collaboration with CERIT-SC with the aim of creating a new solution for specific computing environments, including a pilot installation of the Sensitive cloud, which will be intended for the processing of sensitive data.
- To facilitate the utilization of GPUs, we support the Singularity tool that allows using images prepared by NVIDIA for the NVIDIA GPU Cloud.
- We launched the AlphaFold service for the ELIXIR project.

In accordance with our hybrid strategy for cloud services, we ordered the services of commercial cloud providers under OCRE framework agreements procured by GÉANT. MetaCentrum prepared and tested options for using such resources for computations in the form of virtual computing clusters. Another activity in this field was a pilot project for the use of hardware provided by a commercial partner, ProZeta.

12 million
tasks/year

METACENTRUM

The virtualization platform underwent major modernization, too. A new joint node of the network infrastructure was created at the Brno site, connecting both the virtualization platform and computing clusters. The Prague portion of the installation was moved to the DCTower site and the capacity of both installations was extended by the end of the year, which included the procurement of a new backup disk system that was delivered at the end of the year.

Security was a crucial issue for MetaCentrum, so activities aimed at maintaining security were carried out on an ongoing basis. A service for targeted user notifications based on the detection of anomalies in logging in to individual accounts was put into regular operation and cooperation was promoted in the field of MetaCentrum network security monitoring using the FTAS technologies (detection of compromised virtual machines and their misuse for cryptocurrency mining, detection of anomalies in network traffic in general).

When presenting the capabilities of the infrastructure, focus was on specifically oriented events in the second half of 2021. They comprised a presentation of the C-SCALE project at an EGI conference, a workshop on the implementation of the EOSC initiative in the Czech Republic, an ESA meeting – workshop for the collaborating ground segment, a Copernicus user forum and a MUNI Sitola lab seminar.

Data storage

cesnet datacare

THE DATA STORAGE INFRASTRUCTURE WAS IN ROUTINE OPERATION. THE INFRASTRUCTURE INCLUDES **A HIERARCHICAL DATA STORAGE FACILITY IN OSTRAVA, A STANDARD DISK ARRAY IN JIHLAVA AND OBJECT STORAGE FACILITIES IN JIHLAVA AND PLZEŇ**. WE CARRIED OUT A REPEATED TENDERING PROCEDURE FOR ANOTHER DATA STORAGE FACILITY; THE SYSTEM HAS ALREADY BEEN DELIVERED TO OSTRAVA. IT WILL BE LAUNCHED FOR USERS IN 2022. WE PREPARED AND STARTED A TENDERING PROCEDURE FOR THE NEXT OBJECT SYSTEM, WHICH WILL BE LOCATED IN BRNO.

It will provide a broad portfolio of services, from file system access to object storage access via both blocks and an S3 interface, to special services for syncing and sharing, file transport or binary data consistency safeguarding.

In addition to infrastructure building, the Association's activities focused on continuity of operations, development of services and international cooperation, as well as support of application communities. A long-term archives service with a high guarantee of binary data preservation was in operation. An **open publication repository with metadata support** was in pilot operation for selected user groups. Other development activities included the preparation of auxiliary mechanisms for object storage, which will enable delegation of the management of provided space, efficient administration of users and credentials and easy configurability of data sharing. This also involves changes in the operational metrics collection system and modifications to the accounting system. The Association joined the CS3MESH4EOSC project to participate in the development of sync'n'share systems for easy management of access to data, applications and other resources. The capacity of object storage facilities is made available through Virtual Access under the DICE project.

Data storage facilities administer an object system for the cloud computing platform (MetaCentrum/CERIT-SC) and provide data space for the virtualization platform. Especially the cloud platform represents a community-based approach to the development of an infrastructure in which resources provided by Masaryk University are directly deployed. Several external user groups participated in its pilot operation.

Data storage facilities participate intensely in preparations for EOSC implementation in the Czech Republic. Key EOSC components will include a multi-tenant repository platform as part of a national data infrastructure that will serve to store data together with metadata to ensure long-term availability, searchability and reusability of scientific outputs.

100 PB
of total gross capacity

e–Infrastructure security

cesnet-certs

7
penetration tests carried out

600
contestants in The Catch

SINCE 2018, CESNET HAS HELD INTERNATIONALLY RECOGNIZED **CERTIFICATION OF ITS INFORMATION SECURITY MANAGEMENT SYSTEM (ISMS) TO ČSN EN ISO/IEC 27001:2014**, WHICH SPECIFIES REQUIREMENTS FOR AN INFORMATION SECURITY MANAGEMENT SYSTEM WITHIN AN ORGANIZATION'S ACTIVITIES AND PROVIDED SERVICES WITH THE AIM OF ELIMINATING THE RISKS OF LOSS OF DATA AVAILABILITY, CONFIDENTIALITY AND INTEGRITY. THE FIRST RECERTIFICATION AUDIT WAS SUCCESSFULLY CARRIED OUT IN JUNE 2021.

In the field of security incident prevention and facilities for efficient handling of identified security incidents, an important component is technology complexes for backbone network monitoring, security event and incident detection and sharing such information through the **FTAS, G3, Warden and Mentat** services. All of those systems are under continuous development, which reflects requirements made by both the Association as the operator of the e-infrastructure and users (members and subscribers). All systems continue to prove to be stable and useful projects that have potential to serve, among other things, as means for fulfilling requirements imposed by the Cyber Security Act (CSA) on either CESNET or connected institutions that are subject to CSA.

The **CESNET Forensic Lab (FLAB) did seven penetration test jobs, two social engineering test jobs** (phishing tests) and **two analyses of a serious incident** in 2021. It also held a Forensic Training session.

Forensic Lab staff were **part of the Czech team in the annual Locked Shields 2021 exercise**, which took a nice third place. To further intensify collaboration with its members, the Association continued to be a **supporting partner in the MEYS 2021 centralized development project named 'Enhancing Cybersecurity in the Public College Environment'**, for which it prepared 3 workshops held during regular meetings, concerning ISMS implementation and operation, risk analysis, CESNET security services and the operation and organization of the CESNET-CERTS security team. We also revived the tradition of working groups for network and security specialists from member networks; the first meeting on the subject of 'Protecting the e-Infrastructure and Connected Institutions' was held in September 2021.

A **number of training sessions and consultations for connected hospitals and medical facilities** were held as part of the hSOC (hospital SOC) activity.

Our colleague **Andrea Kropáčová**, head of Support Services and Security, was **inducted into the Cybersecurity Hall of Fame**, becoming the person of the year 2021. The award is given for key or long-term positive contribution to cybersecurity in the Czech Republic. She was presented the award by Miloš Vystrčil, President of the Senate, and Michal Frankl, member of the board of directors of CETIN, at the 22nd annual international Information Security Summit.

The **Network and Services Security Workshop**, focusing on the operation and security of networks, services and internet applications, was held past year, too. It was attended by over 400 participants online.

On the occasion of the Cybersecurity Month (October), FLAB prepared, as annually, **The Catch**, an educational competition in which over 600 contestants took part, this time under the title of 'Lost Civilization'.

Network identity

THE NETWORK IDENTITY DEPARTMENT SPLIT INTO TWO NEW DEPARTMENTS – FEDERATED IDENTITIES DEPARTMENT AND AAI DEPARTMENT – IN APRIL 2021.

Identity federation

The purpose of authentication infrastructure services is to provide a trusted electronic identity and easy access to e-infrastructure services.

The infrastructure is based on **eduID.cz, the Czech academic identity federation** whose members use shared information about the identity of their users to facilitate their access to various network services. Every full member of the federation can have either or both of the following roles:

- An **identity provider** (IdP) administers user names, passwords and other user data and makes selected information available to service providers.
- A **service provider** (SP) runs a web application or network service and uses information about users' identity and other properties, if applicable, to control access to it.

The IdP role is performed by 40 public and private colleges and universities, 49 institutes of the Czech Academy of Sciences, 86 libraries, 12 hospitals, 8 other research organizations, 2 international research groups and several museums, archives and regional authorities. A number of other institutions are in the process of joining. Users are also able to authenticate by means of the mojeID.cz service or social connectors (Apple, Facebook, GitHub, Google, LinkedIn, Microsoft, ORCID). This functionality, which allows 'sponsoring', replaced the discontinued eduID.cz Hostel IdP service. Service providers include CESNET and many Czech universities as well as most major providers of electronic information resources and services for universities in the Czech Republic: GRADA BookPort, GTS Alive – ISIC, Cheap Library, Single Information Gateway of the National Library of the Czech Republic, Mefanet, TECHEM.cz and others.

The eduID.cz federation also participates in the international academic **eduGAIN interfederation**. The participation of eduID.cz in eduGAIN makes it possible for Czech universities to access the services of ACM, Annual Review, BMJ, Cambridge Core, Elsevier, EBSCO, Emerald, Harvard University Press, IEEE, JSTOR, Karger, Ovid, Proquest, Thomson Reuters, Wiley, Springer, Taylor & Francis, Oxford University Press, Proquest RefWorks and Web of Science.

Members of the eduID.cz federation were provided with access to the resources of JoVE, Ex Libris Alma and ČSN Online, the 'Works Unavailable in the Market' services of the National Library, the Moravian Library and the Library of the Czech Academy of Sciences and information resources of the Czech National Bank. Members of eduID.cz can also take advantage of standardized federated authentication using Seamless Access at IOP Publishing, AIP Publishing, Emerald and Mendeley. Access to e-books and e-journals licensed by both the university and the library was tested in collaboration with Tomáš Baťa University in Zlín and the National Library of Technology by interconnecting user accounts and the library.

A new web service for metadata management was prepared in production mode for federation members under the eduID.cz federation. The application also allows managing internal federations for individual organizations.

230
identity providers

perun

The federation was joined by 45 new organizations in 2021. A total of 10 organizations use infrastructure managed by CESNET.

In the field of PKI, the CESNET CA began issuing certificates using federated authentication and a private certificate authority was created for the University of Western Bohemia for the university's internal needs. The TCS service for issuing personal and server certificates will warn about domain expiration, which will help organization administrators validate domains regularly without any interruption in the issuance of certificates by the vendor.

The eIDAS service continued in its production mode and was used by 10 organizations. Based on further negotiations with PostSign, the RemSig system can now be used not only by Association members but also by other organizations that are associated with CESNET. Processes were defined for user support, which was integrated with the Association's operational support. Other activities included preparations for supporting unqualified certificates and RemSig training for its current and prospective customers.

Authentication and Authorization Infrastructures (AAIs)

The new AAI Department took charge of the development and operation of authentication and authorization infrastructures for a number of scientific computing infrastructures:

- Czech national e-infrastructure run by CESNET
- SURF, Dutch national education and research network (surf.nl)
- UmbrellaID, a digital identity for photon and neutron users (umbrellaid.org)
- FENIX Research Infrastructure, an association of supercomputing centres (fenix-ri.eu)
- MyAccessID, an association of supercomputing centres
- MyAcademicID, a project for student mobility (myacademic-id.eu)
- European Life Science Research Infrastructures (lifescience-ri.eu)
- European Consortium for the Development of Fusion Energy (euro-fusion.org)
- eduTEAMS service (eduteams.org)
- GÉANT (geant.org)

The AAIs are based on the custom Perun AAI system, which is developed in collaboration with Masaryk University.

In the second half of 2021, the AAI Department took preparatory steps to create a unified AAI for the e-INFRA CZ e-infrastructure, which is operated jointly by a consortium consisting of CESNET, CERIT-SC (MUNI) and IT4Innovations (VSB). The steps will culminate in January 2022 in the transfer of existing IT4Innovations users to CESNET's Perun system, IT4Innovations' switch to Perun for new user applications and the creation of a new instance of the Perun Proxy IdP for e-INFRA CZ to which the web services of MetaCentrum and CERIT-SC will be switched.

User collaboration and multimedia

cesnet meetings

THE CESNET MEETINGS VIDEO CONFERENCING AND WEB CONFERENCING SERVICES WERE AMONG THE MOST POPULAR IN THE WHOLE PORTFOLIO OF SERVICES PROVIDED BY CESNET. USERS CREATED MORE THAN 260,000 MEETINGS IN 2021, IN WHICH 2,800,000 USERS SPENT ALMOST 3,400,000 MAN-HOURS.

CESNET's streaming infrastructure continued to experience increased use in 2021, due especially to remote teaching. **The total number of sessions (viewed broadcasts) exceeded 3,000,000 and about 1.2 PB (petabytes) of data was streamed to the network.** A higher number of recorded lectures was reflected in an increased amount of stored data. Managed recordings exceed 60 TB in total, which means about 40,000 to 50,000 hours.

In addition to the operation of the infrastructure itself, the Association's activities focused primarily on supporting user events held in hybrid mode.

We continued developing tools for high-definition video and high-quality audio streaming with the lowest possible latency. **UltraGrid version 1.7** was prepared for release. Its most significant new properties were support for NAT traversal using both Port Mapping Protocol and Port Control Protocol and support for client-server mode in addition to conventional peer-to-peer mode. Support for the processing and streaming of 360° video was prepared in UltraGrid, including custom GPU-accelerated implementation of the composition of video from multiple cameras. In addition, the new release of UltraGrid introduced support for the NDI 5 video-over-IP transport mechanism or support for the Apple M1 ARM architecture.

260 000
meetings and conferences

A total of
3 400 000
man-hours

Cooperation with large research infrastructures

THE CESNET E-INFRASTRUCTURE IS PART OF RELEVANT EUROPEAN E-INFRASTRUCTURES, FORMING A COMMUNICATIONS AND INFORMATION ENVIRONMENT FOR NATIONAL LARGE INFRASTRUCTURES IN OTHER SCIENTIFIC FIELDS AND FACILITATING THEIR COOPERATION WITH THEIR FOREIGN PARTNERS:

GÉANT – the European backbone communications infrastructure ensures interconnection of European national research and education networks and connection to similar infrastructures on other continents. Collaboration in the operation and development of this infrastructure in 2021 took place under the GN4-3 project (856726; H2020 programme), the aim of which is to improve the quality of European research, support its scientific excellence, provide access to research data and make the data reusable. CESNET is primarily involved in project activities relating to the building of specialized network environments (for example, for transfers of precise time and stable frequency or QKD), network security or AAI matters. Together with other GÉANT members, we participate in building a high-capacity communications infrastructure and coordinating the use of AAI mechanisms for EuroHPC.

EGI.eu – the European infrastructure for distributed computing coordinates national activities for the implementation of grid technologies at European level. Collaboration among members of this infrastructure takes place in particular within the intentions of the EOSC-Hub H2020 programme. CESNET's collaboration involves participating in all primary operational activities, ensuring the operation of the national EGI grid node and providing computing resources comprising both its own computing capacities and those of the Institute of Physics of the Czech Academy of Sciences. As part of the collaboration, CESNET is responsible for providing resources and support to users from the virtual organizations ELIXIR (bioinformatics), Auger (cosmic radiation), Belle (particle physics) and CTA (gamma astronomy) and to COVID-19 research projects (EGI COVID-19 support initiatives). It also provides direct support to Czech user groups wanting to utilize the pan-European grid.

ELIXIR is a European bioinformatics infrastructure that combines advanced computing environments, data resources and unique tools for the purposes of bioinformatics research across Europe. CESNET contributes to the development of the European infrastructure under the Technical Services activity of the ELIXIR Compute Platform, focusing on the establishment of a common framework for the provision of computing services and services related to data storage, and to the building of ELIXIR AAI. CESNET is also directly involved in national activities in this field – it is one of the founding members of the **ELIXIR CZ** infrastructure, which provides an advanced computing environment, data resources and unique tools to the bioinformatics science community in the Czech Republic and in Europe, and participated directly in two projects for the operation and development of this infrastructure in 2021: **Czech National Infrastructure for Biological Data** (LM2018131) under the Large Infrastructure Projects for R&D&I programme and **ELIXIR-CZ:** Capacity Building (CZ.02.1.01/0.0/0.0/16_013/0001777) under the Research, Development and Education operational programme.

QUAPITAL is a Central European partnership for secure communications with quantum-level security and a QUAPITAL quantum internet. The initiative's goal is to build a quantum-compatible infrastructure interconnecting quantum experiments between various research facilities throughout Central Europe.

National large research and development infrastructures

In addition to the above mentioned close collaboration with national e-infrastructures and participation in the ELIXIR CZ large infrastructure, CESNET also holds continuous debates with representatives of other large infrastructures included in the Czech Republic Roadmap for Large Research, Experimental Development and Innovation Infrastructures for 2016 to 2022, provides for their information and communications technology needs and offers collaboration in addressing them. Examples include:

- Cooperation between the Institute of Molecular Genetics of the Czech Academy of Sciences and CESNET on the operation of the European Chemical Biology Database (ECBD)
- Organization of four seminars/consultations for research infrastructure representatives under e-INFRA CZ and in collaboration with the Technology Centre of the Czech Academy of Sciences on the topic of research data and their storage, accessibility and processing
- Collaboration between e-INFRA CZ, ELIXIR CZ and EATRIS on procuring high-performance computer technology for the Institute of Molecular and Translational Medicine of the Faculty of Medicine and Dentistry of Palacký University in Olomouc, which is in charge of the national coordination and processing of data from SARS-CoV-2 testing

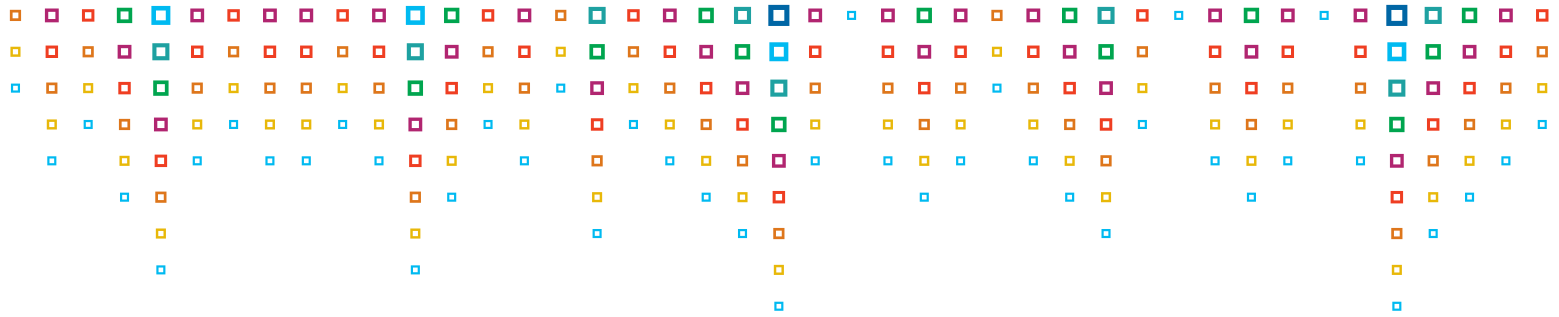
EOSC

The European Commission's goal for scientific data is to lower the barriers to free access to data (while adhering to the principles of personal data protection) in order to support their practical application. The tool for achieving the accessibility, interoperability and reusability of data obtained from publicly funded research and development should be the European Open Science Cloud (EOSC). The EOSC AISBL international association was established in 2020 to coordinate involved entities' activities in the field. Its members include several organizations from the Czech Republic and CESNET has been mandated by the Ministry of Education, Youth and Sports to represent the Czech Republic.

The EOSC is developed under multiple international projects; CESNET specifically participates in the following:

PaNOSC Photon and Neutron Open Science Cloud	The project is aimed at creating federated services over existing metadata catalogues and data archives for easy data accessibility, interoperability and reusability (FAIR). It is also concerned with scientific data analysis with the aim of offering services that will help users work with primary data. All services should be fully integrated into the EOSC catalogue. CESNET participates in the project as a third party for EGI.eu.
EOSC-synergy European Open Science Cloud – Expanding Capaties	The project aims to coordinate the development of a European open environment for scientific data and their processing, which should promote mutual collaboration between infrastructures at national and European level. The EOSC-synergy project is developed by the national EOSC centre.

CS3MESH4EOSC Interactive and agile/responsive sharing mesh of storage, data and applications for EOSC	The aim of the project is to develop a platform for easy and user-friendly data sharing and transfers between sync'n'share systems. Another project focus is controlled access to applications integrated into sync'n'share systems. CESNET's participation in the project concerns, most significantly, the development and implementation of a federated authentication and authorization infrastructure.
EGI-ACE EGI Advanced Computing for EOSC	The project is aimed at developing services operated by the EGI infrastructure as part of EOSC activities. This concerns both fundamental services for the EOSC (AAI, accounting, monitoring) and computing services used by scientific groups. CESNET is involved in the fields of AAI (integrating the Perun system with EGO Check-In), operational security and use of EGI FedCloud cloud services; moreover, it assumes responsibility for the operation of the Jupyter Notebook EGI service.
DICE Data resources and Interoperable services for EOSC	The DICE project is part of the development of a European data storage and management infrastructure and provides user groups with fundamental data resources. CESNET offers the archiving capacity of its object storage under the project in the form of Virtual Access and uses the project for fundamental integration with EUDAT services.
C-SCALE Copernicus – eoSC Analytics Engine	The C-SCALE project is aimed at developing a platform for the analysis of Earth observation data provided by the Copernicus project within the European Open Science Cloud (EOSC) environment. CESNET is primarily involved in the establishment of a federation of partners operating extensive archives of remote sensing products. To a lesser extent, CESNET is engaged in building an expert community and providing access to computing resources in the EOSC environment under the C-SCALE project.
EOSC FUTURE	The project is aimed at operating and developing services for the EOSC; CESNET is involved as a third-party under EGI.eu in the fields of operational security (CSIRT, training, monitoring) and AAI (Identity Management).



National data infrastructure

The specific implementation of the Open Science concept in the Czech Republic is described in 'EOSC Implementation in the Czech Republic', a strategic document issued by the MEYS in 2021. Association representatives participated in the creation of the document as members of the advisory group. EOSC implementation in the Czech Republic aims to create national data infrastructures as an environment for the storage, accessibility and further processing of FAIR (Findable, Accessible, Interoperable, Reusable) data in the Czech Republic, comprising a national repository platform, a metadata repository, science branch repositories and a national EOSC secretariat. In this concept, CESNET and e-INFRA CZ are expected to participate in the creation of the national repository platform and support for the national EOSC secretariat.

Research, development and innovation

THE DEVELOPMENT OF CESNET E-INFRASTRUCTURE REQUIRES AN INNOVATIVE APPROACH. THAT IS WHY THE ASSOCIATION, IN ADDITION TO BUILDING AND OPERATING ITS E-INFRASTRUCTURE, IS ALSO ENGAGED IN RESEARCH AND DEVELOPMENT IN THE FIELD OF INFORMATION AND COMMUNICATIONS TECHNOLOGY, MOST IMPORTANTLY IN THE AREAS MENTIONED BELOW.

Optical transport systems

CESNET has long looked into the software management of optical networks, transfer of precise time and stable frequency, quantum transfer of cryptographic keys and use of optical networks as physical quantity sensors.

CESNET e-infrastructure security

CESNET has long been committed to e-infrastructure security. In addition to developing tools for ensuring user privacy and security of their data or tools for sharing information on security incidents, we have also been intensively developing tools for network monitoring and detection of operating anomalies as potential sources of attack. The Association continues to develop its own **DDoS protector**.

Network identity

In the field of identity management and access control, CESNET and Masaryk University jointly develop **Perun**, a system that allows organizing users into virtual organizations and groups, allocating resources and controlling access to them.

New applications

CESNET constantly looks at possible applications of its e-infrastructure in new fields such as medicine, culture or architecture. Research in the area includes the development of two platforms, a hardware platform named **MVTP** and a software platform named **UltraGrid** (in collaboration with Masaryk University), for working with high-definition video (up to 8K) while maintaining low latency. Furthermore, the Association is also heavily engaged in the digitalization and presentation of cultural heritage objects and the internet of things.

Projects undertaken in 2021

International projects

Project title	Subsidy provider	Programme
Advanced time/frequency comparison and dissemination through optical telecommunication networks	EURAMET	EMPIR
An interdisciplinary Digital Twin Engine for science	EU	Horizon Europe
Clock Network Services - Design Study	EU	H2020
Copernicus - eoSC AnaLytics Engine	EU	H2020
Data Infrastructure Capacity for EOSC	EU	H2020
EGI Advanced Computing for EOSC	EU	H2020
EOSC-FUTURE	EU	H2020
European Open Science Cloud - SYmbiosis for New and Established Research Groups Yield	EU	H2020
GN4-3 Research and Education Networking - GÉANT	EU	H2020
High Performance Language Technologies	EU	Horizon Europe
Integrating and managing services for the European Open Science Cloud	EU	H2020
Interactive and agile/responsive sharing mesh of storage, data and applications for EOSC	EU	H2020
leveraging the European compute infrastructures for data-intensive research guided by FAIR principles	EU	Horizon Europe
Photon and Neutron Open Science Cloud	EU- EGI.EU	H2020
PRIVacy and homomorphIc encryption for artificiaL intElliGencE	European Defence Agency	H2020-Future Disruptive Defence Technologies
Sharing and Automation for Privacy Preserving Attack Neutralization	EU	H2020
Special projects for advanced research and technology in Europe	EU	H2020

National Projects

Project title	Subsidy provider	Programme
Adaptive Protection against DDoS Attacks	MoI CR	VI – Czech Republic Security Research 2015–2022
Acceleration Platform for Virtual Switches	TA CR	TH – EPSILON Applied Research and Experimental Development Support Programme (2015–2025)
Acceleration platform for low-latency exchange trading	TA CR	FW – TREND Industrial Research and Experimental Development Support Programme
Encrypted Traffic Analysis Using Network Flows	MoI CR	VJ – Strategic Support for Security Research Development in the Czech Republic 2019–2025 (IMPAKT 1)
Czech National Infrastructure for Biological Data	MEYS	LM – Large Research Infrastructure Projects
Remote Collaboration in Artist Education Using Modern Transmission Technology	TA CR	TL – ÉTA Social Sciences and Arts Applied Research, Experimental Development and Innovation Support Programme (2018–2023)
Distributed DDoS Mitigation in a Critical Infrastructure Environment	TA CR	VB – Security Research Programme of the Czech Republic 2021–2026: Developing, Testing and Evaluating New Security Technologies (SECTECH)
e-INFRA CZ: Modernization	MEYS	EF – Research, Development and Education Operational Programme
e-infrastruktura CZ	MEYS	LM – Large Research Infrastructure Projects
ELIXIR-CZ: Capacity Building	MEYS	EF – Research, Development and Education Operational Programme
FlowTest: Testing Network Monitoring Devices	MoI CR	VB – Security Research Programme of the Czech Republic 2021–2026: Developing, Testing and Evaluating New Security Technologies (SECTECH)
Network Cybersecurity in the Post-Quantum Era	MoI CR	VJ – Strategic Support for Security Research Development in the Czech Republic 2019–2025 (IMPAKT 1)
National Cybersecurity Competence Centres	TA CR	National Cybersecurity Competence Centre
Presentation and Protection of 3D Digital Objects in Museum Collections	MoC CR	DG – National and Cultural Identity Applied Research and Experimental Development Support Programme for 2016 to 2022 (NAKI II)
Smart ADS	TA CR	TH – EPSILON Applied Research and Experimental Development Support Programme (2015–2025)
Virtual Digital Wardrobe	TA CR	TL – ÉTA Social Sciences and Arts Applied Research, Experimental Development and Innovation Support Programme (2018–2023)

National Projects

Project title	Subsidy provider	Programme
Cyber Threat Intelligence System Development and Pilot Operation	MoI CR	VH – Security Research for State Needs Programme 2016–2021
Use of Digital Models for the National Infrastructure of Memory Institutions	TA CR	TL – ÉTA Social Sciences and Arts Applied Research, Experimental Development and Innovation Support Programme (2018–2023)
Equipment for Low-latency Transmissions of JPEG XS Video	TA CR	FW – TREND Industrial Research and Experimental Development Support Programme

We would like to thank all subsidy providers for providing the funds for undertaking the projects.

Research and development outcomes

Research activities in 2021 resulted in eight papers in peer-reviewed scientific journals, twenty-two papers in collections, one book, nine functional specimens, nine pieces of software and two datasets.

In addition, two new patents were granted:

- CESNET, z. s. p. o. Connection for high-speed checksum computation by a CRC circuit connected directly to a data packet transfer bus. Inventors: Lukáš KEKELY, Jakub CABAL. No.: 308855 granted by CZ001 – Industrial Property Office, 2 June 2021.
- Brno University of Technology and CESNET, z. s. p. o. Distributed fibre optic sensory system. Inventors: Petr Münster, Josef VOJTĚCH, Tomáš Horváth. No.: 308822 granted by CZ001 – Industrial Property Office, 5 May 2021.

2
new patents

CESNET Development Fund

In late 2020, the Development Fund Board prepared and launched the first round of a tendering procedure for projects for 2021. In connection with the fact that an associated member was accepted by the General Assembly, Development Fund documents were edited to allow associated members to take part in the next tendering procedure.
The following topic areas were chosen in cooperation with the Association:

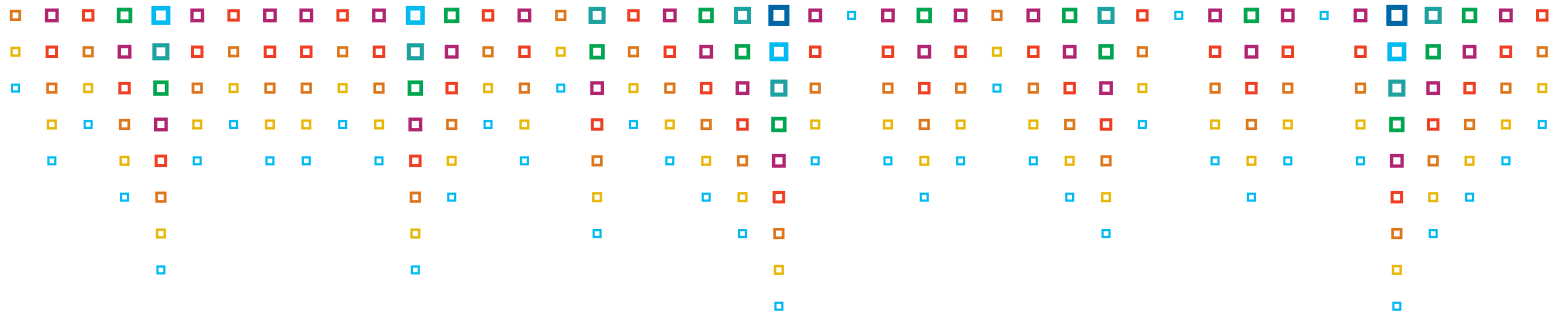
- Utilization and advancement of CESNET e-infrastructure services and modern information and communications technologies in teaching and learning processes, creative and scientific research work and management of public universities and the Czech Academy of Sciences
- Advanced applications utilizing the CESNET e-infrastructure

Five rounds of opposition procedures for completed projects were also carried out over the course of 2021 – a total of **14 projects were completed successfully**. Due to the epidemic situation, there was no public presentation of the results of any project by the researchers. The Development Fund Board recommended a broader presentation of the results of three projects at an expert forum so as to allow other Association members to benefit from them. Final reports for projects carried out under the CESNET Development Fund are available on the Association's website at fondrozvoje.cesnet.cz.

The tendering process resulted in the submission of 16 projects. **Twelve of those projects were accepted for co-funding**, including eight projects admitted after revision. An overview of accepted projects is shown in the table below.

Project number	Project holder	Project title
671R1/2021	University of Pardubice	Datel – Data and Telephone Circuit Documentation Application
672/2021	Czech Academy of Sciences	Fibre Optic Amplifier for Wavelengths beyond the L Band
674/2021	Masaryk University	Deployment of the Data Stewardship Wizard DMP Tool in the Czech Public University Environment
675R1/2021	Masaryk University	Using Container Technology and Orchestration in e-INFRA for SaaS Academic Development
676R1/2021	Masaryk University	Authentication Gateway for Academia
677/2021	VSB – Technical University of Ostrava	Interoperability between an Experimental LoRaWAN Network and 5G Technology using CESNET Infrastructure
678/2021	VSB – Technical University of Ostrava	Concept of Security Incident Resolution in the Environment of VSB – Technical University of Ostrava
679R1/2021	Masaryk University	Analysis of Mass Spectrometry Data using Machine Learning
680R1/2021	Masaryk University	Integration of Services Run by MetaCentrum into a Unified Platform for the Management of Provided IT Services at MU
682R1/2021	Czech Technical University	FEEL: FEderatEd Learning for network security
684R1/2021	Jan Evangelista Purkyně University	Using IoT to Collect, Evaluate and Monitor Water Consumption at the Pasteurova Campus of Jan Evangelista Purkyně in Ústí nad Labem
686R1/2021	Czech Technical University	Video Stream Hunter

Public relations



THE YEAR 2021 WAS AFFECTED BY THE COVID-19 PANDEMIC, TOO, SO MOST WORK, STUDY AND CULTURAL ACTIVITIES STILL TOOK PLACE ONLINE. WE ORGANIZED A WHOLE RANGE OF EVENTS FOR THE USER COMMUNITY AND THE EXPERT AND GENERAL PUBLIC.

At the beginning of the year, we **continued with our successful Security Fest – an online screening of the film Caught in the Net** followed by a debate with the film director and our cybersecurity expert Jan Kolouch. The screening was primarily intended for students and teachers from colleges of education in Liberec, Hradec Králové and Ústí nad Labem and the Ambis college. The film and the debate were attended by more than 1,200 students and teachers.

The traditional **Network and Services Security Workshop**, focusing on the operation and security of networks, services and internet applications, was held in early February. The workshop was attended by over 400 participants online. The project's follow-up international workshop focused on cybersecurity in Europe.

March was characterized by CESNET's celebrations of its 25th anniversary. We held a brief online meeting at which CESNET's leading personalities met with Pavel Doleček, deputy minister of education and head of the ministry's higher education, science and research section; representatives from universities, colleges and institutes of the Czech Academy of Sciences; and representatives from other major institutions. After a brief summary of the Association's activities and a presentation of its latest plans, the attendees drank a toast, remotely, sipping on a cocktail mixed specifically for the anniversary.

Another annual **CESNET e-infrastructure Conference** was held over three days in April. It involved lectures and practical examples presenting the broad range CESNET's services and research activities. The conference was enriched by papers of distinguished experts from the pan-European Géant and EOSC e-infrastructures.

In June, we met at an **online workshop on IPv6 and more** and organized an **OCRE workshop on the cloud and infrastructure services** of major commercial providers offered under framework agreements under the OCRE project.

At the beginning of the new school year, we participated 'live' in the Researchers' Night, whose theme was Time, and held another Forensic Training session.

Another annual run of The Catch competition, this time under the title of 'Lost Civilization', was held as part of the Cybersecurity Month. Over 600 contestants took part in it, trying to solve the difficult problems. All of the problems were successfully solved by 30 entrants.

Traditionally, we were a technology partner of many events such as the Linux Day, OpenAlt, IS2 – Information Security Summit or Contemporary Libraries. CESNET presents the latest news, employee activities and achievements and information on upcoming events by means of its website, social media and its Newsletter.

CESNET administers the websites of Large Research Infrastructures of the Czech Republic and the e-INFRA CZ consortium. CESNET published **18 press releases** and registered **281 media outputs** in 2021.

Jan Gruntorád was inducted into the Internet Hall of Fame.

Lecture on cyberbullying

Researchers' Night at CESNET

Andrea Kropáčová was inducted into the Cybersecurity Hall of Fame.

CESNET celebrated its 25th anniversary.

1996
- CESNET founded
- Academic network transfer from CTU to the new entity
- CESNET is a founding member of the NIX.cz association

1997
- TEN-34 backbone network with a transmission speed of 34 Mbps launched

1998
- CESNET is a founding member of the CZ.NIC association, administrator of the national cz domain
- Metacentrum incorporated into CESNET

1999
- CESNET built TEN-155 CZ network with connection to the European TEN-155
- The experimental IPv6 ATM network started

2000
- CESNET divested its commercial network
- Network reinforcement on the Prague-Brno line to 2.5 Gb/s
- IP telephony project launched

2001
- CESNET2 backbone network with 2.5 Gb/s line capacity
- Central authentication and authorisation system created

2002
- Backbone network transition to fibre optics completed
- Development of CzechLight and COMBO devices launched
- Connection to the Géant network at 10 Gb/s

2003
- IPv6 deployment in production environment
- CESNET CA certification authority established

2004
- Network reinforcement on the Prague-Brno line to 10 Gb/s
- CESNET-CERTS security team established
- Eduroam network launched

2005
- Network core upgraded to DWDM with 10 Gb/s channels
- Intercontinental FullHD video transmission
- UltraGrid technology introduced

2006
- CESNET, ACOnet (Austria) and SANET (Slovakia) networks interconnected
- The first public video conference in HD quality in the Czech Republic and one of the first in the EU.

2007
- First spin-off INVEA-TECH, a. s., established
- First 4K (UHD) video transmissions between Prague, Seattle, Chicago, San Diego, Tokyo and Amsterdam

2008
- Establishment of the eduID.cz federation
- CSIRT.CZ team launched
- Adobe Connect web conferences launched

2009
- MetaCentrum declared a national grid infrastructure
- First tests of the 40 Gb/s backbone network
- MVTP platform created

2010
- CESNET included in the Czech Large Infrastructure Roadmap
- CSIRT.CZ declared a national CSIRT team
- CESNET interfaces natively with Google's IPv6 protocol

2011
- Metacentrum offers computing on GPU graphics cards
- Mentat and Warden systems development launched
- Optical time transfer Prague – Vienna
- CSIRT.CZ handed over to CZ.NIC

2012
- First lines increased to 100 Gb/s
- First data storage facility in Plzeň opened

2013
- The association entered the EUXIR.CZ infrastructure
- Data repositories launched in Brno and Jihlava
- FLAB forensic laboratory opened
- LHCONE network connection for CERN-CZ

2014
- The association entered the FENIX security project
- COMBO-100G card introduced
- ownCloud service launched
- Eduroam launched at train stations

2015
- Hadoop cluster for big data launched
- Experimental 400Gb/s transmissions
- Mentat system launched

2016
- CESNET network connected at 100 Gbps to GÉANT infrastructure
- Virtualisation platform launched
- Presentation of the restored Ikaria XB1 film &#8211

2017
- Suite of security services expanded
- Prague circuit Zikova-BIOCEV (Vestec) – ELI (Dolní Břežany) commissioned
- Provision of penetration and stress tests (FLAB)

2018
- Transition to object storage started
- Eduroam network significantly expanded in secondary and primary schools

2019
- Next generation backbone network designed
- Building of eIDAS services for remote electronic signing started

2020
- e-INFRA CZ launched
- CESNET accepted as a member of EOSC (European Open Science Cloud)

Financial performance

FINANCIAL PERFORMANCE IN 2021

CESNET'S ACTIVITIES ARE DIVIDED INTO TWO CATEGORIES IN ACCORDANCE WITH ITS STATUTES: PRINCIPAL ACTIVITY AND SUPPLEMENTARY (ECONOMIC) ACTIVITY.

Principal Activity

As part of its Principal Activity, the Association continued to build a qualitatively new CESNET e-infrastructure to provide a comprehensive set of services to Association members and other entities eligible for connection to the CESNET network.

The Association also participated in international research projects under the Horizon 2020 programme, national projects supported by the Ministry of Education, Youth and Sports, the Technology Agency of the Czech Republic, the Ministry of the Interior and the Ministry of Culture and projects supported by CESNET's Development Fund Board, as already mentioned in the previous section of the Annual Report.

The Association's Principal Activity in 2021 generated an accounting profit of approximately CZK 15,771,000 before tax. Revenues from the Association's Principal Activity amounted to approximately CZK 569,696,000; expenses were approximately CZK 553,925,000.

The income tax base for the Principal Activity in 2021 was positive, amounting to approximately CZK 24,108,000.

Economic Activity

The Association's Economic Activity in 2021 consisted primarily in holding a prevailingly bond-based portfolio of the Development Fund Board, comprising financial resources obtained by selling the commercial part of the CESNET network in 2000, and in managing financial resources in other funds.

The Association's Economic Activity in 2021 generated an accounting profit of approximately CZK 679,000. Revenues from the Association's Economic Activity in 2021 amounted to approximately CZK 72,675,000; expenses on the Economic Activity were approximately CZK 71,996,000. The income tax base for the Association's Economic Activity in 2021 was positive, amounting to approximately CZK 674,000.

Total accounting and tax profit or loss

CESNET had a total accounting profit before tax of approximately CZK 16,450,000 in 2021.

The Association's total income tax base was approximately CZK 24,782,000. The Association's total corporate income tax for 2021 is approximately CZK 4,711,000, resulting in a post-tax profit of approximately CZK 11,739,000.

Conclusion

In the past year, CESNET managed the entrusted funds responsibly and properly, meeting all of its obligations resulting from legislation, decisions of the Ministry of Education, Youth and Sports of the Czech Republic and concluded contracts.

BDO Audit s. r. o., an audit firm having its registered office at V Parku 2316/12, Praha 4, Chodov, Chamber of Auditors authorization No. 018, audited the annual financial statements and expressed the following opinion:

'In our opinion, the financial statements give a true and fair view of the assets and liabilities of CESNET, interest association of legal entities, as at 31 December 2021 and its expenses and revenues and its financial performance for the year (January 2021 - December 2021) then ended in accordance with the Czech accounting standards'.