Design and implementation of an academic NOC using NetBox towards automation

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***Abstract*—Even smaller academic ICT infrastructures face increasing complexity, requiring reliable documentation and efficient automation. The paper presents the foundations applicable to the design of a lightweight network operations center (NOC) built on NetBox as a central source of truth with the vision of leveraging network automation. NetBox is used to collect, model, and visualize network-related information (cabling, network devices, IP addressing, services). To enable automation, we integrate NetBox with the Semaphore UI Ansible platform, creating a workflow for multi-vendor networking that includes configuration backup and orchestration. The solution was deployed and tested at the Department of InfoComm Networks, University of Žilina. Our results confirm that NetBox improves documentation accuracy, has the potential to reduce later administrative workload, and provides a foundation for automation as the main improvement for future network operations. Furthermore, building the academic NOC model enhances student engagement by bridging theoretical knowledge and operational practice. NetBox thus serves as both a documentation system and an enabler of network automation.**

Keywords—Ansible, automation, documentation, NetBox, network operations center (NOC), orchestration.

I. Introduction

The growing scale and complexity of academic IT infrastructures bring new demands on their documentation, monitoring, and daily operation. Faculty and even departmental networks no longer consist only of a few switches and servers. With the rise of virtualization, cloud services, and hybrid environments, campus infrastructures have become distributed, dynamic, and highly interdependent. These changes increase the pressure on administrators to prevent outages, ensure service continuity, and maintain reliable documentation. At the same time, academic institutions must operate with limited staff resources and still provide students with hands-on experience in managing real infrastructures.

In this context, building an academic Network Operations Center (NOC) as a Learn & Operate Hub provides us the opportunity to interconnect networking professionals and students through a model of "learning by doing". On the one hand, it supports daily tasks such as monitoring, troubleshooting, and change management. On the other hand, it serves as a training ground where students gain direct experience with operational procedures, automation frameworks, and best practices in IT service management. This dual role makes the NOC both an operational backbone and an educational laboratory.

In this environment, traditional approaches like static wikis, text documents, or spreadsheets do not provide the scalability required by modern approaches. They lack consistency, are difficult to maintain, and are very tough to integrate with automation and orchestration approaches. At least, automation in environments is no longer an optional choice. Automation is becoming the standard way to handle repetitive operations such as configuration backup, device inventory, and service deployment. And finally, it highlights how automation enhances resilience, minimizes human error, and boosts efficiency.

Our work focuses on using NetBox, an open-source IP Address Management (IPAM) and Data Center Infrastructure Management (DCIM) system, as the central source of truth and cornerstone for such an academic NOC. NetBox allows structured modeling of physical, infrastructure, network, and endpoint devices, connections, and services. And what is very important, NetBox provides an open API (Application Programming Interface) and plugin ecosystem, making it suitable for integration with other automation tools. In combination with tools like Ansible and Semaphore, it enables orchestration tasks across multi-vendor environments.

The paper presents the design and deployment of an academic NOC at the Department of IncoComm Networks, University of Žilina. The work was carried out as part of problem-based learning within the master's degree program in Applied Networking Engineering (ASI). The solution not only improves our infrastructure management but also provides students with real operational experience, directly linking course assignments with production-like tasks. By integrating NetBox with automation frameworks, students learn how to operate and extend modern network management platforms. The results show that NetBox, when extended with automation, can serve both as a documentation system and as an orchestration hub, forming the foundation of a modern, educationally driven NOC.

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II. Network Operations Center: background

A **Network Operations Center (NOC)** may be specified as a centralized facility responsible for the continuous supervision, control, and maintenance of IT and network infrastructures. Its core functions include ensuring service availability, preventing and managing outages, and coordinating incident response. In practice, NOC monitors the health of network devices, servers, applications, and communication channels. NOC also simultaneously ensures that key performance parameters such as latency, throughput, and packet loss remain within acceptable thresholds. When anomalies occur, the NOC acts as the first line of defense by detecting the incident, initiating predefined response procedures, and coordinating escalation to higher support tiers if necessary. A properly designed NOC identifies anomalies before they affect end users and ensures their resolution through predefined processes and escalation procedures [1][11].

In general, the overall benefits of deploying NOC include an increased reliability of key IT functions. It ensures consistent backup management, coordinated software updates, and structured incident/problem handling with defined workflows. The NOC also improves efficiency by concentrating on routine tasks such as monitoring, documentation, and reporting in one central unit. In addition, NOC provides clear communication with users about outages and planned changes.

The rise of cloud computing, virtualization, and software-defined networking has transformed the NOC's role. Today's NOCs are evolving from reactive surveillance centers into proactive orchestration engines capable of automating repetitive tasks, anticipating failures, and minimizing downtime. In academic contexts, a NOC exceeds its operational purpose and gains educational significance. Acting as a Learn & Operate Hub, it provides students with direct problem-based learning opportunities via real-world infrastructure tasks—bridging academic theory and hands-on practice.

The NOC consists of three fundamental blocks: people, processes, and platforms. Together, they define the organization of work, the methods of problem solving, and the suitable supporting technologies.

A. People

People represent the human resources operating within the NOC. Building NOC, we define all necessary employee roles, their respective levels of responsibility, and the work shift schedule [2][4]. The first step we need to take is to create an organizational structure. The organizational structure describes how the NOC staff will work and is primarily guided by two principal models:

- **Tiered Structure:** This model is based on a hierarchical arrangement of teams, each corresponding to a specific level of expertise. The Tier 1 (T1) team serves as the initial point of contact, handling monitoring, incident analysis, ticket creation, and customer communication. If an incident cannot be resolved by the T1 team, the ticket is escalated to a higher level (e.g., Tier 2 or Tier 3), according to the escalation policy. Each subsequent tier consists of more experienced specialists, ensuring that complex issues are addressed with the appropriate level of expertise [4]. Tier organizational structures are one of the basic structures.
- **Intelligent Swarm Structure:** The alternative model that assigns complex incidents directly to an individual or an ad-hoc team with the most relevant expertise. The objective is to bypass the traditional escalation hierarchy and route the task immediately to the most qualified person, thereby minimizing wait times. This structure is highly effective for quickly resolving a large number of simple tasks, while complex cases are promptly handled by a designated expert, reducing overall resolution time [5].

As the third model, we may define a **Hybrid Structure** model that combines the strengths of both tiered and swarm models. Routine tasks and common incidents are handled by a Tier 1 team. However, when a ticket requires specialized expertise or is identified as high priority, direct assignment to a relevant expert or a collaborative swarm team is allowed. It allows bypassing multiple escalation steps. This balances efficiency (through structured tiers) with agility (through targeted swarming).

In addition to the organizational structure, several other processes are critical for the effective operation of NOC [4][11]:

- **Defining Roles and Responsibilities:** Here, creating detailed job descriptions and responsibilities for each position is required to define. The level of involvement in each process is formally documented using a RACI Matrix (Responsible, Accountable, Consulted, Informed), which ensures a clear division of labor.
- **Staff Selection:** Employees are selected based on specific role requirements and a defined set of skills. An interest in continuous learning and a passion for IT are also considered important criteria.
- **Staff Training**: Ongoing training is an integral part of NOC operations. Employees must go through initial training before joining and must perform subsequent recurring training sessions at regular intervals.
- **Work Schedule Planning:** This involves designing work shifts. It is influenced by factors such as the number of employees, the NOC's operating hours, and staff experience levels.
- **NOC Quality Control:** Focuses on monitoring and evaluating key performance indicators (KPI), such as average ticket resolution time, process efficiency, and training quality. The data from these metrics is used to identify and rectify inefficient parts of the operation.

B. Integrating students into an academic NOC

In the concept of our Academic NOC, the involvement of students is a fundamental principle in its design. We mainly expect students who will perform internships (practice) or work on problem-based assignments (projects, master's theses). They will participate in tasks as monitoring, documentation, and first-level troubleshooting. As a model of organization, we will use a ***hybrid model***. It ensures efficient distribution of workload and provides junior staff with valuable first-line experience. We plan to formally establish a ***Junior NOC Operator*** role for student

participants. This position would be clearly defined as an integral part of the Tier 1 (T1). This placement allows students to handle initial tasks under the supervision of more experienced staff.

To ensure learning experience and operational quality, student involvement should be guided by a formal mentorship program. Each student would be assigned a dedicated mentor from the senior administrator staff. The process includes:

- **Formal onboarding**: Prior to their operational duties, each student would go through a training program to familiarize themselves with the environment, tools, and fundamental processes.
- **Regular review and feedback:** Mentors from the administrator staff (experienced teachers) will conduct regular meetings to review the student's progress, discuss cases, and provide feedback.
- **Problem-based assignments:** In addition to routine tasks, students will solve assigned, specific, project-oriented tasks that require deeper analysis and problem-solving skills.

This structured approach delivers significant advantages for both the institution and its students. From the NOC perspective, it strengthened tier 1 capacity, as simple and time-intensive tasks like monitoring and documentation can be efficiently managed by student operators, freeing up senior staff to focus on more complex issues. From the academy's perspective, the program serves as a recruitment pipeline, allowing the school to identify and support talented students. Finally, students and research bring new perspectives and the latest academic knowledge. This will lead to innovative ideas and the optimization of existing processes.

From the student perspective, working in the NOC allows students to gain practical, in-demand technical skills that provide a significant competitive advantage in the job market. The engagement allows them to apply theoretical knowledge from the classroom directly to real-world networking challenges, which can be crucial for future career opportunities.

C. *Processes*

Processes in the NOC define standardized workflows of its operation itself (i.e., monitoring, incident handling, and change management) that ensure consistency, reduce response time, and minimize the risk of errors. Processes are fundamental for the effective operation and governance of any NOC. Many organizations adopt elements of the ITIL (Information Technology Infrastructure Library) framework.

NOC should have a set of core processes developed, although, however, their implementation and scope depend on the specific environment and available resources. These essentials processes typically include event management and monitoring (defining the monitoring scope), incident management (identification, handling, and resolution of service failures), problem management (analysis and elimination of root causes), capacity management (control of performance, bandwidth, and storage resources), and change management (planning and execution of infrastructure modifications). Together, these processes provide a structured framework that supports service reliability while allowing flexibility in adaptation to the academic setting [2].

Operational procedures of NOC are described in **runbooks.** A runbook is a critical component of NOC processes. It is a collection of documents that describe step-by-step actions for common tasks such as verifying device availability, restoring a failed service, or escalating incidents. The runbook's purpose is to ensure that tasks are performed consistently and accurately, regardless of who is performing them. A well-documented runbook reduces the time needed to resolve a documented task, freeing up operators to focus on more complex issues [3].

Automation extends processes further by replacing repetitive manual steps with scripts or orchestration workflows. Typical examples include automated configuration backup, capacity checks, or service restarts.

D. *Processes in the Academic NOC*

As a basic set of processes for our Academic NOC operated by the department, we have identified and defined six essential areas that we are going to implement to ensure effective management of the IT infrastructure:

- **Logging & Monitoring:** Focuses on continuous collection and supervision of system and network events to detect anomalies.
- **Ticketing:** Provides structured recording and tracking of incidents and service requests.
- **Documentation:** Maintains accurate records of infrastructure, procedures, and troubleshooting steps.
- **Communication:** Ensures clear information flow between operators, administrators, and stakeholders.
- **Change Management:** Controls and documents planned modifications to infrastructure and services.
- **Backups:** Allows systematic creation and verification of configuration for recovery purposes.

These processes provide the operational foundation required for service reliability and continuity in our academic environment.

Regarding runbooks, we must underline that for an academic NOC, which often involves staff with varying levels of experience (including students), a quality runbook is essential for effective knowledge transfer and maintaining operational continuity.

E. *Platform*

The platform represents the technical foundation of any NOC, providing tools and systems that enable personnel to execute all NOC's operational processes efficiently. They also help with staff training, infrastructure analysis, and network processes. The platform usually comprises several categories of systems that are integrated to provide an operational environment. We have identified four basic categories of platform systems that include monitoring and management systems, ticketing systems, communication systems, and documentation systems [6].

For their deployment in our department, the platform consists of integrated open-source tools covering the four categories mentioned:

- **Network Management Systems (NMS)**: NMS systems are the central system of NOC. They are used to collect real-time data and metrics from the network and infrastructure, including logs, performance metrics, and device status. Their primary function is to provide continuous situational awareness and to automatically detect events and incidents. For years, we have relied on open-source tools like Zabbix and Syslog-ng, which provide robust, configurable monitoring capabilities. Actually, we are focusing on a promising new approach that integrates an open-source monitoring stack consisting of the OpenTelemetry Collector as a central gateway for metrics and logs, Prometheus for time-series data storage, Loki for log aggregation, and Grafana for visualization and alerting.
- **Ticketing Systems:** Ticketing systems are the operational backbone for managing the incident lifecycle. They serve as a centralized hub for organizing and tracking all requests and issues. Each incident is assigned a unique ticket, with a priority and status that helps the team members sort and manage the workload. We are looking for a final lightweight ticketing solution supporting incident registration, prioritization, and escalation.
- **Communication & Collaboration Systems:** Provides effective information exchange. These systems go beyond simple email, actually. They integrate real-time messaging, video conferencing, and file sharing. For our Academic NOC, a suitable communication platform is still under evaluation, with emphasis on open-source solutions that can be deployed and customized locally. At the same time, we consider the option of leveraging a university-wide collaboration platform based on Microsoft Teams, which would provide tighter integration with existing services.
- **Documentation Tools**: This is one of the main blocks of the NOC center that is critical for efficient NOC operation. The three main parts of documentation are: network documentation, infrastructure documentation, and user documentation. Documentation must always be up-to-date and specific so that the reader does not have to guess the necessary facts. Our approach has adopted NetBox, which provides structured modeling of devices, racks, IP addressing, and services. In our case, NetBox replaces static Wikis with a dynamic database that integrates with automation frameworks via REST API and plugins.

In addition to these categories, the platform integrates an **automation and orchestration category,** which is required for handling pipelined and automated operation tasks. For this purpose, Ansible, executed through Semaphore UI, is used to perform management of multi-vendor network devices and their configuration backups. All configurations and scripts are versioned in Git repositories, which ensures reproducibility, change tracking, and controlled deployment of updates. The combination of Ansible, Semaphore, and Git enables our academic NOC to implement standardized processes for device management while allowing students to practice automation techniques that are widely applied in industry.

Finally, the **control panel** (also named the NOC Wall) concept is also implemented. Here, the monitoring dashboards are displayed on shared screens to provide continuous situational awareness. Alarms or error notifications are visible to all operators, allowing immediate response [7].

By integrating these three fundamental blocks, extended by an automation block, we expect that our academic NOC can provide a powerful and efficient operational model that simultaneously serves the needs of our institution and the educational development of its students. And as such it provides a balance between operational needs and educational objectives.

F. Recommendations and expectations for the departmental Academic NOC

The proposed Academic NOC is deployed as Proof of Concept (POC), partially integrated into the existing departmental infrastructure and processes. This will allow controlled verification of functionality and procedures before expanding it further.

Given financial resource constraints dedicated to experiments, the preferred software stack is based on open-source technologies that are straightforward to deploy and maintain. Our focus is also on a solution that enhances current processes and must avoid introducing additional administrative overhead. Administrators should not be burdened with complex support systems; instead, the platform should streamline daily operations and enable efficient monitoring, documentation, and automation. For this purpose, we also prefer containerized deployment, using Docker, which in the near future will follow CI/CD (Continuous Integration / Continuous Deployment) pipeline and NetDevOps principles.

NOC should serve as an educational platform too. Students are expected to participate in daily operations in the role of junior operators. Due to capacity limits, the number of students present simultaneously is set to a maximum of two, which has dedicated seats reserved in the Wall room. Their involvement should follow a hybrid model, where they perform monitoring, documentation, and first-level troubleshooting, escalating complex incidents to senior staff.

From an operational perspective, the Academic NOC is designed to run during standard working hours, providing support five days a week for eight hours per day. This schedule aligns with the current staffing model while maintaining a balance between educational use and reliable service delivery.

III. NETBOX AS DOCUMENTATION AND ORCHESTRATION HUB

NetBox is an open-source network modeling and documentation tool that is designed to serve as a single source of truth for all infrastructure components, as it provides structured data, easy querying, and integration through modern APIs [7][10].

A. NetBox core functions

NetBox combines the features of IP address management (IPAM) and data center management (DCIM) with benefit that it provides a range of objects that allow for modeling the network as accurately as possible. NetBox

core functionality supports network devices, racks, network interfaces, IP prefixes, VLANs, and service object modeling. NetBox provides a relational model of the infrastructure, and its significant advantage is that it exposes all objects via REST API endpoints. This design enables the use of NetBox not only for documentation purposes but also as a backend integrated with other systems, including different automation platforms [10]. In the context of the Academic NOC, NetBox represents the primary documentation hub, ensuring consistency and accuracy of infrastructure data.

A significant advantage of NetBox is its extensibility. The platform supports plugins, custom scripts, and webhooks. Custom scripts allow automated generation of configuration templates or validation of stored data. This makes NetBox adaptable to the specific needs of an organization.

B. NetBox alternatives

Of course, NetBox is not the only DCIM tool available. Other alternatives include RackTables, openDCIM, Ralph, and iTop. RackTables and openDCIM provide straightforward documentation of physical assets such as devices, cabling, and switchboards. They are simple to operate and easy to deploy, but offer only limited IP Address Management (IPAM) features. Their lower level of detail makes them comparable to structured wikis rather than comprehensive documentation systems [9].

Ralph and iTop extend beyond physical infrastructure documentation. Ralph supports license management and offers a REST API, which makes it usable in automation workflows [9]. NetBox provides similar functionality through plugins, which cover licenses and contracts. iTop belongs to the category of Configuration Management Databases (CMDB). It emphasizes process integration and supports ticketing, service documentation, and device relationships. However, iTop lacks detailed modeling of physical devices and racks. Its strength lies in managing end devices and servers, supported by an extensive plugin ecosystem [8], [11].

Compared to these tools, NetBox combines detailed physical documentation with extensibility and automation readiness, making it a suitable choice for the Academic NOC.

IV. Proposed Implementation in Academic Environment - Case Study

A. Role of NetBox in department network management

The Academic NOC at the Department of InfoComm Networks was implemented with NetBox as the central documentation and orchestration hub. Previous documentation based on DokuWiki proved insufficient, as it lacked structure and integration with automation tools. NetBox now provides a structured inventory of devices, addressing, and services. In addition, NetBox supports validation and configuration generation, making it a foundation for automation workflows.

B. Building NetBox documentation

NetBox enables precise modeling of the IT infrastructure using objects that describe physical and logical components of networking infrastructure. In our case, documentation begins with modelling organizational structures (region, faculty, buildings, rooms), followed by devices, racks, and cabling. VPN tunnels and IP addressing were also modeled. All these objects are logically grouped according to their type. Data entry is possible through multiple methods: manual forms for small changes, bulk file imports for larger updates, and APIs for automated integration. The manual method is very demanding and is not recommended for major changes. The last two provide flexibility that allows the documentation to be gradually expanded and kept consistent. For the specific method of inserting data into NetBox, we recommend referring to the official documentation.

C. NetBox plugins

The platform can be expanded with carefully selected plugins to enhance its usability. We selected and recommended the following:

- **Topology Views** provides a graphical visualization of network topologies. The plugin looks into the database according to the set filters and draws or parts of the topology. Thanks to it, we can always have a high-quality visual representation of the network topology.
- **Reorder Racks** enables intuitive rack management via drag-and-drop. The netbox-reorder-rack plugin provides the ability to move devices in distribution racks using a "drag and drop" method. Without this, there is only a manual way.
- **Attachments** allow storing related files, such as contracts or diagrams, directly with objects. These plugins improve usability and support both operational and educational tasks.

D. Configuration templates and custom scripts

NetBox, as its advanced feature, natively supports Jinja2 configuration templates and the building of custom, NetBox internal code scripts. Templates may, for example, generate device configurations (for example, interface config) directly from stored attributes, while scripts are used to check documentation quality, enforce rules, or generate new objects. During our development, several validation scripts were created to ensure the compliance of network modelling with documentation standards. They include a custom script that compares LAG VLAN Config, i.e. it scans all LAG interfaces and reports members whose VLAN mode/untagged/tagged VLANs don't match the LAG. The second one was a custom script that checks LAG VLAN inconsistencies and copies the LAG's VLAN config to all members.

E. Automation of network processes: Configuration backup use case

To integrate automation into our NOC solution, we connected NetBox with the Semaphore UI platform, which executes Ansible playbooks, manually and even automatically. The NetBox inventory plugin provides Ansible with device lists accessed via API tokens. Further, we have also integrated Git repositories into our automation solution, serving as a version control system for both Ansible

playbooks and resulting configurations, ensuring reproducibility.

As an automation demonstration case study, an automated configuration backup was implemented (Fig. 1). The workflow first fetches the BitBucket GIT repository with the necessary files. These files contain a list of tasks and a list of devices. The script then uses the Rest API to retrieve a device list from NetBox (ansible plugin netbox was used) and executes platform-specific Ansible modules to download configurations. Finally, the script deletes old configs and stores a new one back in a Git repository. The process was tested in a GNS3 environment with Cisco IOS, Cisco IOS XE, Cisco NX-OS, and MikroTik RouterOS. Devices are accessed via SSH (SecureSHell), with Semaphore orchestrating the tasks. The workflow includes repository synchronization, configuration retrieval, and controlled update of versions. This demonstrates practical integration of documentation, automation, and orchestration in the Academic NOC.

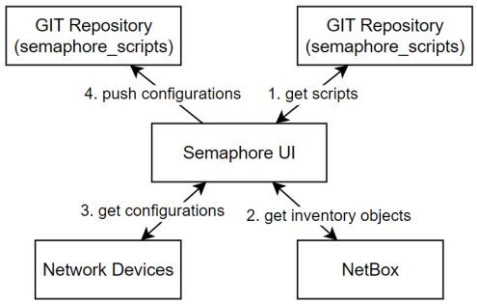


Fig. 1 Configuration backup use case

V. Conclusion

The article presents the idea, design, and initial implementation of an Academic NOC based on NetBox as the central documentation and orchestration hub. The proposed model consolidates essential NOC functions, monitoring, documentation, automation, and collaboration into a single framework, addressing both operational and educational requirements. By integrating NetBox with automation platforms such as Ansible and Semaphore UI, we demonstrated how repetitive tasks like configuration backup can be standardized and executed across multi-vendor environments.

The results from testing and initial deployment at the Department of InfoComm Networks confirm that NetBox improves documentation accuracy, streamlines daily administration, and provides a foundation for automation. At the same time, the Academic NOC model enhances student engagement by linking theoretical assignments with real operational tasks, thereby fostering problem-based learning.

In the future, our Academic NOC has the potential to evolve towards a faculty-wide platform. Further work will focus on extending automation workflows, adopting CI/CD principles, and deepening integration with monitoring and collaboration systems. This dual operational–educational approach demonstrates that even lightweight, resource-constrained environments can benefit from NOC principles while simultaneously serving as a training ground for the next generation of network engineers.

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