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The rise of softwarization and cloudification in network functions presents a vast opportunity for the next generation of mobile networks. However, to fully exploit the potential of flexible network architectures to meet the ever-increasing service demands and requirements, it is crucial to effectively integrate Network Intelligence (NI) solutions into production infrastructures. While standardization efforts in this area are still in their infancy, cutting-edge initiatives are taking the native NI orchestration into account. In this paper, we present a general model for the representation of NI instances that facilitates their integration into network environments. We showcase the practical viability and benefits of this approach by analyzing two state-of-the-art Network Intelligence algorithms implemented in an open-source data flow programming framework

Resumen ejecutivo

El surgimiento de la softwarización y cloudificación en las funciones de red presenta una gran oportunidad para la próxima generación de redes móviles. Sin embargo, para aprovechar al máximo el potencial de las arquitecturas de red flexibles y satisfacer las demandas y requisitos de servicio cada vez mayores, es crucial integrar de manera efectiva soluciones de inteligencia de red (NI) en las infraestructuras de producción. Si bien los esfuerzos de estandarización en esta área aún están en sus primeras etapas, las iniciativas de vanguardia están teniendo en cuenta la orquestación nativa de NI. En este trabajo, presentamos un modelo general para la representación de instancias de NI que facilita su integración en entornos de red. Mostramos la viabilidad práctica y los beneficios de este enfoque mediante el análisis de dos algoritmos de inteligencia de red de última generación implementados en un marco de programación de flujo de datos de código abierto.

Abstract

The rise of softwarization and cloudification in network functions presents a vast opportunity for the next generation of mobile networks. However, to fully exploit the potential of flexible network architectures to meet the ever-increasing service demands and requirements, it is crucial to effectively integrate Network Intelligence (NI) solutions into production infrastructures. While standardization efforts in this area are still in their infancy, cutting-edge initiatives are taking the native NI orchestration into account. In this paper, we present a general model for the representation of NI instances that facilitates their integration into network environments. We showcase the practical viability and benefits of this approach by analyzing two state-of-the-art Network Intelligence algorithms implemented in an open-source data flow programming framework.

1. Introduction

The deployment of fifth-generation (5G) and upcoming sixth-generation (6G) mobile networks has prompted the wireless communications community to explore new architectures that support softwarization and cloudification trends. To achieve this, advanced Artificial Intelligence (AI) and Machine Learning (ML) algorithms are necessary, which will be executed by heterogeneous orchestrators and controllers to manage various microdomains or network slices. These algorithms are collectively known as Network Intelligence (NI) and are capable of dynamically taking actions in response to fluctuations in network activities or service requests.

NI instances will be deployed throughout the network to solve a variety of networking tasks, such as end-to-end orchestration, network service monitoring, and analysis, among others. Each instance will adhere to numerous Key Performance Indicator (KPI) targets, including Quality of Service (QoS) or Quality of Experience (QoE) guarantees, maximization of infrastructure and resource reuse across different tenants or network services, and full network automation to achieve zero-touch network and service management.

In the context of Radio Access Network (RAN) virtualization, the concept of the RAN Intelligent Controller (RIC) has emerged, which provides a centralized abstraction of the network. Operators can design, implement, and deploy custom control-plane Virtual Network Functions (VNFs) to perform RAN optimization via closed control loops at different timescales aided by ML. This is fundamental since present implementations of algorithms that perform RAN optimizations are far from optimal[1] .

However, the current architectural and VNFs design does not provide specifications or guidelines to include NI yet. Moreover, the present efforts promoted by major standardization bodies towards the integration of NI in next-generation network architectures are still in their infancy [2].

There are proposals for a NI-native mobile network architecture that goes beyond current standardization trends [3]. For instance in [4], the authors outlined general requirements and specifications for NI design that stem from data management, diverse control timescales, and network technology characteristics. We also derived initial principles for the design of an NI Orchestration layer that focuses on proposals for the interaction loop between NI instances and the NI Orchestrator and a unified representation of NI algorithms.

So, building on the concepts introduced in[5] and exploiting a unified representation of NI algorithms to integrate NI in the context of vRAN orchestration and control problems. Mappings between the N-MAPE-K loop proposed as the unified NI representation presented in[6] and NI algorithms is possible. It can be shown

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[1] A. Banchs et al., "Network Intelligence in 6G: Challenges and Opportunities", ser. MobiArch '21, pp. 7-12, 2021.
[2] Y. Wang, R. Forbes, C. Cavigioli, H. Wang, A. Gamelas, A. Wade, et al., "Network management and orchestration using artificial intelligence: Overview of etsi eni", IEEE Communications Standards Magazine, vol. 2, no. 4, pp. 58-65, 2018.
[3] Architectural framework for machine learning in future networks including IMT-2020, 2019.
[4] M. Camelo et al., "Requirements and Specifications for the Orchestration of Network Intelligence in 6G," 2022 IEEE 19th Annual Consumer Communications & Networking Conference (CCNC), Las Vegas, NV, USA, 2022, pp. 1-9, doi: 10.1109/CCNC49033.2022.9700729.
[5] M. Camelo et al., "Requirements and Specifications for the Orchestration of Network Intelligence in 6G," 2022 IEEE 19th Annual Consumer Communications & Networking Conference (CCNC), Las Vegas, NV, USA, 2022, pp. 1-9, doi: 10.1109/CCNC49033.2022.9700729.
[6] M. Camelo et al., "Requirements and Specifications for the Orchestration of Network Intelligence in 6G," 2022 IEEE

that such architecture promotes the reuse of NI components, such as monitoring ones, among heterogeneous algorithms used inside each micro-domain. We implement the unified framework in Zenoh-flow, a dataflow-based programming platform that is especially suited to support the operation of AI algorithms with different time scales such as end-to-end deadlines, automatic timestamps, or feedback support.

In summary, the integration of Network Intelligence (NI) into mobile networks is essential to support the softwarization and cloudification trends of 5G and 6G. So a NI-native architecture that goes beyond current standardization trends and provides a structured approach to AI assimilation in networking systems, greatly simplifying future innovations in NI for beyond-5G and 6G networks is needed.

2. Network Intelligence for vRAN

vRAN technology is widely recognized as an essential tool for meeting the increasing demand for mobile services at a low cost for mobile operators. By centralizing softwarized base stations into a common computing infrastructure in the cloud (typically at the edge) via NFV, vRAN offers significant benefits such as resource pooling, simpler update roll-ups, and cheaper management and control. This can lead to significant cost savings, such as a 10-15% reduction in capital expenditure per km2 and 22% in CPU usage.

vRAN has attracted significant attention from academia and industry, with initiatives such as OpenRAN, O-RAN, and Rakuten's vRAN driving progress towards fully programmable, virtualized, and open RAN solutions based on general-purpose processing platforms.

Recent innovations in the context of open RAN include the introduction of programmable components, such as the near-Real-Time (RT) RIC and non-RT RIC proposed by the O-RAN alliance. These logical controllers create a centralized view of the network by consuming monitoring data generated from the network infrastructure. The algorithms running on these controllers are empowered by AI and ML techniques, introducing a data-driven approach to optimize network performance automatically in a closed-loop fashion.

The non-RT RIC is integrated into the network Service Management and Orchestration (SMO) layer and operates on a timescale larger than 1 second. Its main goal is to support intelligent RAN optimization by providing policy-based guidance, ML model management, and enrichment information to the near-RT RIC function. In contrast, the near-RT RIC enables near real-time control and optimization of the RAN and its resources via fine-grained data collection and actions over open interfaces and with control loops in the order of 10ms-1s.

While the near-RT RIC hosts xApps designed to collect near real-time information and provide control over the RAN, the non-RT-RIC hosts rApps that offer value-added services to support and perform RAN optimization and operations. Both functions are essentially custom logic to perform RAN optimization, operating at different time scales. When empowered by AI/ML algorithms, they match the definition of NI. However, to integrate NI natively in next-generation network architectures, a large range of NI instances will need to interact seamlessly to perform at their best and exchange data and information to mutually improve both their learning and decision-making processes.

19th Annual Consumer Communications & Networking Conference (CCNC), Las Vegas, NV, USA, 2022, pp. 1-9, doi: 10.1109/CCNC49033.2022.9700729.

For this reason, it is essential that NI for vRAN optimization can support closed-loop control, be defined via a well-defined modeling order, and create components that are easily extended, re-usable, and easily migrated among platforms that support NI by design. Overall, vRAN technology and the integration of AI and ML techniques have the potential to revolutionize mobile services, leading to cost savings, improved performance, and greater efficiency.

3. A unified framework for Network Automation

To ensure that diverse NI algorithms such as those presented above can coexist and run effectively in the same mobile network infrastructure, we need to abstract their complexity and produce a homogeneous representation of their multi-timescale operation. To address this challenge, we propose a split between the NI algorithms' requirements and the interactions between their different components. We will discuss this approach in detail next.

3.1. Requirements

Typical vRAN orchestration algorithms such as vrAIn[7] or SPB-vRAN[8] introduce two main functional requirements: monitoring capabilities and resources allocation capabilities. The first requirement specifies the need for NI solutions that provide monitoring capabilities to obtain information about the current state or context of the system. Given this requirement, our analysis has identified relevant metrics such as CPU load, wireless channel conditions (SNR, CQI), traffic demands (as Buffer State Reports from the terminals and downlink buffer occupancy), or power consumption measurements. This also describes the need to integrate sensing capabilities in vRAN systems. RAN systems should provide APIs to access raw data from all the layers in the radio stack. We remark that Open RAN solutions specified by O-RAN are a key enabler to this end.

From this requirement, one functional and one nonfunctional requirement may be derived. On the one hand, there is the need to reduce the dimensionality of the state/context space and provide an expressive latent representation that is relevant to take appropriate actions. On the other hand, it should be stated that advanced NI solutions that allow dynamic change of sources and time scales in the monitored data at runtime.

The last pillar of requirements is the allocation of resources and policies. We conclude that NI solutions should offer the ability to allocate resources dynamically. Specifically, computing resources and radio resources.

3.2. The common framework

To enable the coexistence and effective functioning of various NI algorithms, a common framework to map the most common features of these algorithms it is required. This framework shall also integrate them into the overall architecture, and design the necessary interfaces for interaction with their environment.

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[7] J. A. Ayala-Romero et al., "vrAIn: Deep Learning based Orchestration for Computing and Radio Resources in vRANs", IEEE Transactions on Mobile Computing, pp. 1-1, 2020.

[8] J. A. Ayala-Romero, A. Garcia-Saavedra, X. Costa-Perez and G. Iosifidis, "Bayesian online learning for energy-aware resource orchestration in virtualized rans", IEEE INFOCOM 2021 - IEEE Conference on Computer Communications, pp. 1-10, 2021..

To achieve this goal, the work in [9] adopts a methodology already used by the MAPE-K feedback loop, which is one of the most influential reference control models for autonomic and self-adaptive systems. This methodology allows for the classification of algorithms that run at NI instances based on how they interact with other network elements, thereby creating a unified approach to categorizing NI algorithms. However, given that the original MAPE-K framework has limitations in the context of mobile network functionalities supported by NI, in [10] they propose changes to the legacy MAPE-K to address the specificities of the network environment.

There, the authors present Network MAPE-K (N-MAPE-K), which extends MAPE-K along two dimensions. Firstly, the purpose of the NI is considered, which can be either training or inference for the operation of the network, following the MLOps paradigm. Secondly, the nature of the NI algorithm is distinguished between supervised learning and reinforcement learning. For the latter, the knowledge module is integrated with a training definition that specifies aspects such as input data shape, batches, used loss function (which could be dynamically adjusted), and state/action representation. Additionally, the effector and sensors can also be redirected to a digital twin element if required by the specific NI instance.

By applying this framework, as already presented in[11], vRAN algorithms can be represented in a unified way.

4. Conclusion

We discussed several technical aspects related to the field of network intelligence and virtualized radio access networks (vRAN). We covered topics such as the functional and non-functional requirements for vRAN orchestration algorithms, the need for a unified framework to map and integrate NI algorithms into the overall architecture, and the importance of considering the specificities of the mobile network environment when designing such frameworks. We also touched on the potential benefits of using reinforcement learning-based algorithms for resource allocation in vRAN systems. Overall, our discussion highlighted the complex and ever-evolving nature of the field of network intelligence and its critical role in optimizing the performance and efficiency of modern communication networks.

[9] M. Gramaglia et al., "Network Intelligence for Virtualized RAN Orchestration: The DAEMON Approach," 2022 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit), Grenoble, France, 2022, pp. 482-487, doi: 10.1109/EuCNC/6GSummit54941.2022.9815816.
[10] M. Gramaglia et al., "Network Intelligence for Virtualized RAN Orchestration: The DAEMON Approach," 2022 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit), Grenoble, France, 2022, pp. 482-487, doi: 10.1109/EuCNC/6GSummit54941.2022.9815816.
[11] M. Camelo et al., "Requirements and Specifications for the Orchestration of Network Intelligence in 6G," 2022 IEEE 19th Annual Consumer Communications & Networking Conference (CCNC), Las Vegas, NV, USA, 2022, pp. 1-9, doi: 10.1109/CCNC49033.2022.9700729.