

Towards Network Data Analytics in 5G Systems and Beyond

Marcos Lima Romero and Ricardo Suyama

Abstract—Data have become a critical asset in the digital economy, yet it remains underutilized by Mobile Network Operators, unlike Over-the-Top players that lead global market valuations. To move beyond the commoditization of connectivity and deliver greater value to customers, data analytics emerges as a strategic enabler. Using data efficiently is essential for unlocking new service opportunities, optimizing operational efficiency, and mitigating operational and business risks. Since Release 15, the 3rd Generation Partnership Project (3GPP) has introduced the Network Data Analytics Function (NWDAF) to provide powerful insights and predictions using data collected across mobile networks, supporting both user-centric and network-oriented use cases. However, academic research has largely focused on a limited set of methods and use cases, driven by the availability of datasets, restricting broader exploration. This study analyzes trends and gaps in more than 70 articles and proposes two novel use cases to promote the adoption of NWDAF and explore its potential for monetization.

Keywords—NWDAF, Data Analytics, Machine Learning, 5G

I. INTRODUCTION

With the evolution of mobile networks, particularly 5G, Mobile Network Operators (MNOs) are handling vast amounts of data daily, which could serve as the foundation for advanced Artificial Intelligence (AI) and Machine Learning (ML) models. However, operators are often overwhelmed by Over-the-Top (OTT) applications and struggle to take advantage of these data. Many MNOs continue to treat their services as commodities, focusing solely on connectivity and leaving the added value to OTT providers [1]. This approach limits their competitiveness in the face of digital transformation and highlights the need for a significant shift in data management and network automation. Using data analytics, MNOs could introduce new value-added services to end users, unlock additional business opportunities, and mitigate operational risks.

Since Release 15 in 2017 [2], the 3rd Generation Partnership Project (3GPP) has been exploring new ways to enhance data analysis in the 5G system. The Network Data Analytics Function (NWDAF) was proposed as a solution to centralize data collection and ML models within the Core Network, with the goal of providing analytics and predictions to other network functions (NFs), application functions (AFs), and operation and maintenance (OAM) functions. NWDAF has evolved over successive releases, starting with a single use

case focused on network slicing support, and now includes more than 23 use cases in the latest Release 19 [3].

This work helps to bridge the gap between 3GPP efforts and academic research, offering a consolidated view of NWDAF's current state, highlighting areas for further research, and exploring its untapped potential for use cases and monetization in the evolving telecom landscape. The main contributions are as follows:

- Present the latest advancements in 3GPP standards for NWDAF.
- Summarize the current academic state-of-the-art in the implementation of the NWDAF.
- Propose novel use cases that could promote the adoption of NWDAF and explore its potential for monetization.

The following sections are organized as follows: Section II presents the evolution of NWDAF through 3GPP releases. Related works are discussed in Section III. The methodology used to search for relevant papers is outlined in Section IV. Sections V and VI discuss the results of the literature review and identify its gaps and propose new use cases. Finally, Section VII concludes the paper and provides future research directions.

II. NWDAF ROLE IN 3GPP

NWDAF started as a concept in the first 3GPP 5G release, Release 15, and was first introduced in the 5G system architecture specification in TS 23.501 [2]. The initial use case for NWDAF involves interaction with the Policy Control Function (PCF) to provide information about the network slice load level. This service was later detailed in 2018 in TS 29.520, also in Release 15 [4].

The architecture for NWDAF was first discussed in 2019 within the Enablers for Network Automation of 5G (eNA) work of the System Architecture working group (SA2), leading to TS 23.288 [5] in Release 16. The signalling flow was introduced later, in 2022, with Release 17 in TS 29.552 [6]. In the Service-Based Architecture (SBA), NWDAF was defined to operate using subscribe-notify or request-response modes. The use cases also evolved over the years, as shown in Fig. 1. In Release 15, there was one use case; in Release 16, 10 use cases [5]; in Release 17, 15 use cases [7]; in Release 18, 21 use cases [8]; and, as of now, Release 19, 23 use cases [3]. For ongoing Release 20, a new use case is suggested. Table I shows the use cases and a segregation into four main categories: Slice, Network, Service, and User.

The Slice category includes the earliest use case, in which the PCF requests slice load level information. The Network

Marcos Lima Romero, e-mail: marcos.romero@ufabc.edu.br; Ricardo Suyama, e-mail: ricardo.suyama@ufabc.edu.br; CECS, UFABC, Santo André-SP. This work was partially supported by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) – Financial Code 001, by Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) - grant #2020/09838-0, and the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) - grant #311380/2021-2.

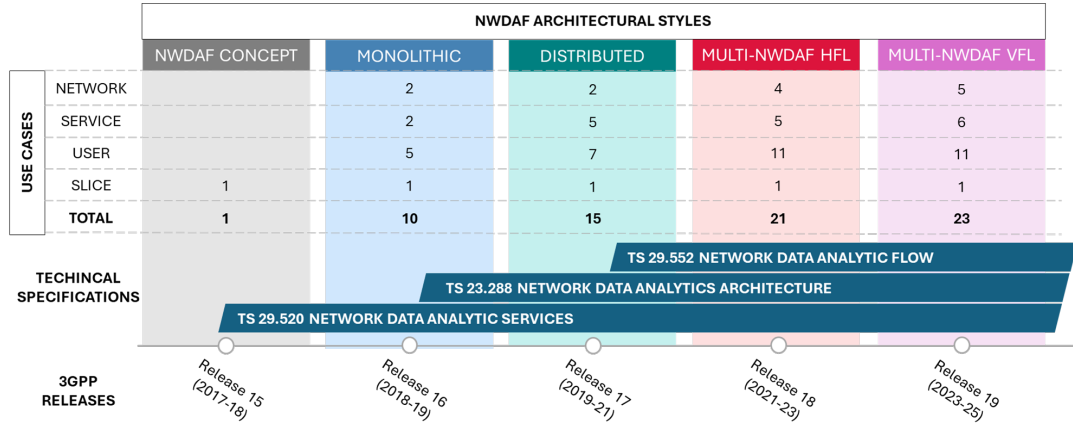


Fig. 1. Evolution of NWDAF over 3GPP Releases.

 TABLE I
 USE CASES BY CATEGORY AND 3GPP RELEASE

Release	Category	Use Case
15	Slice	Slice Load level information
16	Network	NF Load Information
		Network Performance information
		Observed Service Experience
	Service	QoS Sustainability
		UE mobility information
		UE communication information
		Expected UE behavioural parameters
		UE Abnormal behaviour information
17	User	User Data Congestion information
		Session Management Congestion Control Experience
		Redundant Transmission Experience
		DN Performance
	Service	WLAN Performance
		Dispersion
18	Network	PFD Determination
		PDU Session Traffic
		End-to-end data volume transfer time
	User	Movement Behaviour
		Location Accuracy
		Relative Proximity
19	Network	Signalling Storm
	Service	QoS and Policy Assistance
20	Network	Abnormal UPF traffic pattern

category comprises use cases related to statistical analysis and prediction of NF loads, as well as performance metrics associated with the use of resources from the access network. In Release 18, two additional use cases were introduced under this category: the determination of Packet Flow Descriptions (PFDs) and the analysis of Packet Data Unit (PDU) session traffic associated with User Equipment (UE). Furthermore, Release 19 expands this category by introducing use cases for predicting signalling storms, with the goal of preventing abnormalities.

The Service category encompasses use cases focused on Quality of Service (QoS) and Quality of Experience (QoE). These include observed service experience as delivered by a specific slice or application, QoS sustainability, characterized by changes in QoS levels across time and location, along

with associated thresholds, and session management congestion control for specific Data Network Names (DNNs) or slices. Additional scenarios include redundant transmission experiences for Ultra-Reliable Low Latency Communication (URLLC) services, user plane performance evaluation for Edge Computing applications, and QoS and policy assistance mechanisms to support the selection of optimal QoS parameter sets aligned with expected QoE requirements.

The User category includes use cases centered on UE-related behaviours and performance. In Release 16, use cases were defined to address UE mobility and communication patterns, as well as detection of expected and abnormal behaviour and user data congestion. Release 17 introduced use cases concerning WLAN performance metrics for UEs, as well as the dispersion of UEs with respect to data volume, mobility patterns, and session management transactions. Release 18 extended this scope further by incorporating use cases related to end-to-end data volume transfer time statistics or predictions between UEs and applications, movement behaviour, location accuracy, and relative proximity between UEs.

Currently, 3GPP is starting the discussions of Release 20 and delegates are proposing a new use case, the NWDAF-assisted analytics, detection, and control of User Plane Function (UPF) traffic patterns. The main goal is to mitigate potential abnormal UE or application traffic that may lead to degradation of UPF performance.

The releases also supported evolutions in the NWDAF architecture, starting with a monolithic structure in Release 16. Release 17 introduced a distributed architecture, dividing NWDAF into two components: the Analytics Logical Function (AnLF) and the Model Training Logical Function (MTLF). It also defined new functions to support NWDAF: the Analytics and Data Repository Function (ADRF), the Data Collection Coordination Function (DCCF), and the Messaging Framework Adapt Function (MFAF), as shown in Fig. 2. Release 18 brought significant architectural enhancements, including support for roaming, Horizontal Federated Learning (HFL), multi-vendor ML model sharing, and NWDAF performance monitoring (e.g., analytics and ML model accuracy). Finally, in Release 19, SA2 is focusing its efforts on introducing Vertical Federated Learning (VFL) as a feature to NWDAF.

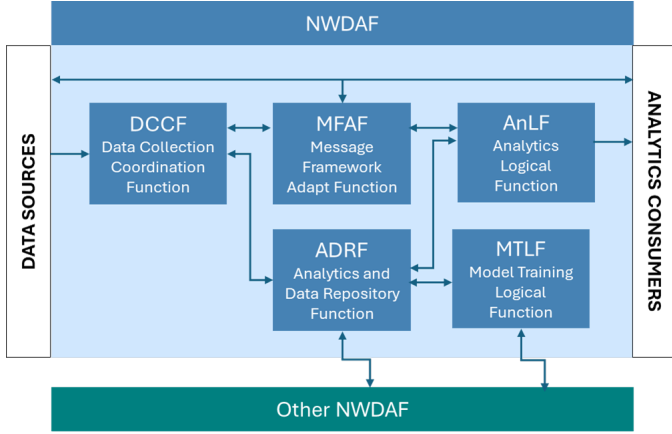


Fig. 2. NWDAF Architecture as specified in 3GPP Release 19.

III. RELATED WORK

Following 3GPP standardization is not always straightforward. Not only are specifications typically developed approximately five years ahead of actual implementation, but the volume of information and complexity of standards have been increasing substantially every year. Providing the academic community with an overview of ongoing discussions among rapporteurs is a significant and valuable effort that helps align standardization with the state-of-the-art.

Some works in the literature analyze 3GPP standards focused on AI and Data Analytics but fail to simultaneously address advancements in NWDAF use cases, architecture evolution, implementations by researchers, and used datasets. Related works can be cited, as presented in Table II. This work offers a contribution to the existing literature by presenting the architecture and use cases through Release 19 and the future directions of Release 20, focusing exclusively on NWDAF. Additionally, it provides comprehensive coverage of existing implementations and datasets employed in related research, and also proposes new use cases.

TABLE II
COMPARISON OF RELATED SURVEYS REGARDING NWDAF

Reference	3GPP Release	Focus on NWDAF	Implementations	Datasets
[9]	16	●	○	○
[10]	17	●	●	○
[11]	17	●	●	●
[12]	18	●	○	○
[13]	18	●	○	○
[14]	19	●	●	○
This work	20	●	●	●

Symbol legend: ● Full coverage, ● Partial coverage, ○ Not covered

IV. METHODOLOGY

A preliminary search for the term “NWDAF” within titles, abstracts, and keywords in the Scopus database returned 95 articles, of which 79 were indexed in the IEEE Xplore digital library. To maintain methodological consistency, without losing generality, this study confined its literature retrieval to IEEE Xplore. After a screening process involving both

abstracts and full texts, a total of 23 articles were selected for detailed analysis.

These selected studies were systematically examined across key dimensions: implementation approaches, primary use case domains, availability of code and datasets, and the machine learning algorithms employed. This analytical framework facilitated the identification of prevailing trends and highlighted existing research gaps in the current landscape of NWDAF.

V. DISCUSSION

The analysis presented in Table III highlights the rapid evolution and experimentation of NWDAF in 5G networks. A clear trend is the increasing use of open source 5G core projects such as Free5GC¹ for the latest releases of 3GPP and Open5GS², OpenAirInterface (OAI)³ for older releases. The Release 16 references in earlier studies reflects the foundational phase of NWDAF exploration, while more recent articles have adopted Release 17 and Release 18, signaling growing maturity and integration of advanced analytics capabilities in the 5G ecosystem. However, no studies have yet registered any use of Release 19 or more.

One of the most prominent observations is the emphasis on user-centric and network-centric analytics. Although some work focuses on predicting user behaviour and improving QoE, others prioritize network-level anomaly detection and performance monitoring. This division reveals the dual role that NWDAF is expected to play: both as a feedback loop for optimizing user services and as a control loop for self-healing and resource optimization in the network.

The application of ML in the surveyed works is notably diverse. Traditional models such as Decision Trees, Random Forests, and XGBoost, often used for anomaly detection, coexist with deep learning techniques, including Long Short-Term Memory (LSTM), Recurrent Neural Networks (RNNs) for time-series prediction, and even transformer-based models like Large Language Models (LLMs) for intent discovering. This heterogeneity reflects the exploratory nature of the field, where the optimal ML approach remains an open research question. These trends underscore the increasing complexity of data sources and highlight the necessity for flexible, adaptive analytics frameworks in NWDAF.

Datasets play a pivotal role in NWDAF research, forming the foundation upon which most studies are built. A combination of real, synthetic, and benchmark datasets is commonly employed, and several works explicitly share their datasets to promote reproducibility.⁴ The availability of specific types of datasets often influences the choice of use cases, as researchers tend to prioritize those for which data are more accessible.

For instance, although the slice load level use case has been included in the 3GPP specification since Release 15, only one study to date has attempted its implementation. This underscores how research efforts are often guided by the availability of datasets and the feasibility of simulating specific scenarios. Furthermore, since network slicing is not yet

¹<https://free5gc.org/>

²<https://open5gs.org/>

³<https://openairinterface.org/>

⁴<https://romerocode.github.io/towards-network-data-analytics-in-5g/>

TABLE III
ARTICLES BY RELEASE, TESTBED, USE CASE, DATASET AND CODE AVAILABILITY, AND ML ALGORITHM

Reference	Release	Testbed	Slice	User	Network	Service	Dataset	Code	ML Algorithm
[15]	16	Open5GS			✓		✓		
[16]	16	Open5GS		✓			✓		LSTM
[17]	16	Open5GS			✓		✓		K-Means
[18]	16	ANChOR		✓					
[19]	16	OAI		✓	✓		✓		GBM, Random Forest, Catboost, XGBoost
[20]	16		✓	✓	✓		✓		GBM, Random Forest, Catboost, LSTM
[21]	16			✓	✓		✓		Linear and Logistic Regression, XGBoost, LSTM, RNN
[22]	16			✓		✓			Fuzzy
[23]	17	OAI		✓	✓		✓		LSTM, SVM
[24]	17	OAI		✓			✓	✓	LSTM
[25]	17	Free5GC		✓	✓				Linear Regression, Random Forest, Decision Tree
[26]	17	Free5GC		✓				✓	SARIMA
[27]	17	Free5GC		✓			✓	✓	Decision Tree, Random Forest, MLP
[28]	17	Free5GC			✓			✓	LSTM
[29]	17			✓			✓		RNN, LSTM, GRU
[30]	17								Decision Tree, SVM
[31]	17						✓		MLP, CNN
[32]	18	Free5GC		✓			✓	✓	LSTM
[33]	18	Free5GC		✓	✓				
[34]	18	Free5GC		✓			✓		Bagging Predictor
[35]	18			✓	✓		✓	✓	LLM
[36]	18			✓			✓		AGP, Autoencoder, Random Forest, OneClassSVM, Isolation Forest
[37]	18						✓		MLP

widely deployed in commercial mobile networks, data scarcity remains a major barrier. A study by Ericsson [38] indicates that most enterprises are expected to begin to trial network slicing by 2026, highlighting the gap between standardization and real-world adoption. Consequently, obtaining sufficient and realistic data for experimental purposes continues to be a significant challenge in this domain.

Additionally, the limited sharing of code artifacts reveals a notable gap in the field. None of the most widely used 5G open source projects have yet officially deployed NWDAF to their official repositories, emphasizing the need for a development of community-driven toolchains to facilitate NWDAF experimentation. Currently, only a small number of projects make their implementations publicly available.⁴

VI. NEW PROPOSED USE CASES

After an analysis of existing use cases and research gaps, two new use cases for NWDAF are proposed:

NWDAF-assisted Charging Bypass Fraud Detection: Charging bypass occurs when users exploit zero-rated traffic configurations or other vulnerabilities to access services that should be charged [39]. NWDAF can help detect such anomalies by continuously analyzing user behaviour patterns, correlating service usage with charging records, and identifying inconsistencies. Using ML models trained on fraud scenarios, NWDAF can identify suspicious activity and trigger alerts or policy adjustments in near real-time.

NWDAF Open Gateway Network Interface: NWDAF acts as a centralized analytics engine to mediate interactions

between Open Gateway APIs⁵ and NFs, with great monetization potential. With the support of MFAF, it can align business-oriented API requests with real-time network data. Telefónica has expressed interest in expanding the role of NWDAF to meet Open Gateway use cases⁶, although these initiatives are still exploratory, with no standardized approach or comprehensive studies available. A related idea is explored in [40], where NWDAF supports only performance API metrics. The proposed use case goes further by advocating for a standardized integration of CAMARA project⁷ endpoints with NWDAF, enabling API exposure that is both network-aware and dynamically adaptive.

VII. CONCLUSION

Through a comprehensive review of 3GPP specifications and the academic state-of-the-art on network data analytics in 5G and beyond, this study identified key trends in NWDAF research and highlighted existing gaps between standardized definitions and real-world implementations. More than 70 papers were initially surveyed, with 23 selected for in-depth analysis regarding implementation, datasets, and ML algorithms. The findings serve as a valuable starting point for new researchers entering the field and propose novel use cases that can be further explored in future works.

⁵<https://www.gsma.com/solutions-and-impact/gsma-open-gateway/>

⁶<https://www.telefonica.com/en/mwc/agora-2025/5g-innovation-and-monetization-network-data-analytic-function-nwdaf-potential>

⁷<https://github.com/camaraproject>

REFERENCES

- [1] H. S. Kim, Y. Jang, S. H. Lee, and S. Kim, "How to relieve mobile network overload from mobile over-the-top (ott) traffic: Proposing a user-based content-sharing solution," *Telecommunications Policy*, p. 102931, 2025.
- [2] 3GPP, "System architecture for the 5G System (5GS)," Technical Specification (TS) 23.501, 3rd Generation Partnership Project (3GPP), Dec. 2017. Version 15.0.0.
- [3] 3GPP, "Architecture enhancements for 5G System (5GS) to support network data analytics services," Technical Specification (TS) 23.288, 3rd Generation Partnership Project (3GPP), Mar. 2025. Version 19.2.0.
- [4] 3GPP, "5G System; Network Data Analytics Services; Stage 3," Technical Specification (TS) 23.520, 3rd Generation Partnership Project (3GPP), Jun. 2018. Version 15.0.0.
- [5] 3GPP, "Architecture enhancements for 5G System (5GS) to support network data analytics services," Technical Specification (TS) 23.288, 3rd Generation Partnership Project (3GPP), Jun. 2019. Version 16.0.0.
- [6] 3GPP, "5G System; Network Data Analytics signalling flows; Stage 3," Technical Specification (TS) 29.552, 3rd Generation Partnership Project (3GPP), Mar. 2022. Version 17.0.0.
- [7] 3GPP, "Architecture enhancements for 5G System (5GS) to support network data analytics services," Technical Specification (TS) 23.288, 3rd Generation Partnership Project (3GPP), Mar. 2021. Version 17.0.0.
- [8] 3GPP, "Architecture enhancements for 5G System (5GS) to support network data analytics services," Technical Specification (TS) 23.288, 3rd Generation Partnership Project (3GPP), Dec. 2022. Version 18.0.0.
- [9] Q. Duan, "Intelligent and autonomous management in cloud-native future networks—a survey on related standards from an architectural perspective," *Future Internet*, vol. 13, no. 2, p. 42, 2021.
- [10] K. Koufos, K. El Haloui, M. Dianati, M. Higgins, J. Elmighani, M. A. Imran, and R. Tafazolli, "Trends in intelligent communication systems: Review of standards, major research projects, and identification of research gaps," *Journal of Sensor and Actuator Networks*, vol. 10, no. 4, p. 60, 2021.
- [11] E. Coronado, R. Behraves, T. Subramanya, A. Fernandez-Fernandez, M. S. Siddiqui, X. Costa-Pérez, and R. Riggio, "Zero touch management: A survey of network automation solutions for 5g and 6g networks," *IEEE Communications Surveys & Tutorials*, vol. 24, no. 4, pp. 2535–2578, 2022.
- [12] Y. Niu, S. Zhao, X. She, and P. Chen, "A survey of 3gpp release 18 on network data analytics function management," in *2022 IEEE/CIC International Conference on Communications in China (ICCC Workshops)*, pp. 146–151, IEEE, 2022.
- [13] M.-A. Garcia-Martin, M. Gramaglia, and P. Serrano, "Network automation and data analytics in 3gpp 5g systems," *IEEE Network*, vol. 38, no. 4, pp. 182–189, 2023.
- [14] C. Sun, T. Cui, W. Zhang, Y. Bai, S. Wang, and H. Li, "On the combination of ai and wireless technologies: 3gpp standardization progress," in *2024 IEEE/CIC International Conference on Communications in China (ICCC Workshops)*, pp. 523–528, IEEE, 2024.
- [15] A. Chouman, D. M. Manias, and A. Shami, "Towards supporting intelligence in 5g/6g core networks: Nwdaf implementation and initial analysis," in *2022 International Wireless Communications and Mobile Computing (IWCWC)*, pp. 324–329, IEEE, 2022.
- [16] D. M. Manias, A. Chouman, and A. Shami, "A model drift detection and adaptation framework for 5g core networks," in *2022 IEEE International Mediterranean Conference on Communications and Networking (MeditCom)*, pp. 197–202, IEEE, 2022.
- [17] D. M. Manias, A. Chouman, and A. Shami, "An nwdaf approach to 5g core network signaling traffic: Analysis and characterization," in *GLOBECOM 2022-2022 IEEE Global Communications Conference*, pp. 6001–6006, IEEE, 2022.
- [18] M. Quadri, C. Roseti, F. Zampognaro, and L. Serranti, "Data collection using nwdaf network function in a 5g core network with real traffic," in *2023 International Symposium on Networks, Computers and Communications (ISNCC)*, pp. 1–7, IEEE, 2023.
- [19] K. Abbas, T. A. Khan, M. Afaq, and W.-C. Song, "Ensemble learning-based network data analytics for network slice orchestration and management: An intent-based networking mechanism," in *NOMS 2022-2022 IEEE/IFIP Network Operations and Management Symposium*, pp. 1–5, IEEE, 2022.
- [20] K. Abbas, T. A. Khan, M. Afaq, J. J. D. Rivera, and W.-C. Song, "Network data analytics function for ibn-based network slice lifecycle management," in *2021 22nd Asia-Pacific Network Operations and Management Symposium (APNOMS)*, pp. 148–153, IEEE, 2021.
- [21] S. Sevgican, M. Turan, K. Gökarslan, H. B. Yilmaz, and T. Tugcu, "Intelligent network data analytics function in 5g cellular networks using machine learning," *Journal of Communications and Networks*, vol. 22, no. 3, pp. 269–280, 2020.
- [22] R. Vidhya, P. Karthik, and S. Jamadagni, "Anticipatory qoe mechanisms for 5g data analytics," in *2020 International Conference on COMMunication Systems & NETWORKS (COMSNETS)*, pp. 523–526, IEEE, 2020.
- [23] A. Mekrache, K. Boutiba, and A. Ksentini, "Combining network data analytics function and machine learning for abnormal traffic detection in beyond 5g," in *GLOBECOM 2023-2023 IEEE Global Communications Conference*, pp. 1204–1209, IEEE, 2023.
- [24] A. Nadar and J. Härrä, "Enhancing network data analytics functions: Integrating aiaas with ml model provisioning," in *2024 22nd Mediterranean Communication and Computer Networking Conference (MedComNet)*, pp. 1–4, IEEE, 2024.
- [25] A. A. Bayleyegn, Z. Fernández, and F. Granelli, "Real-time monitoring of 5g networks: An nwdaf and ml based kpi prediction," in *2024 IEEE 10th International Conference on Network Softwarization (NetSoft)*, pp. 31–36, IEEE, 2024.
- [26] R. Bolla, C. Lombardo, P. Bono, N. S. Martinelli, R. Bruschi, and B. Siccardi, "An open-source prototype of network data analytics function for next-generation 5/6g environments," in *2023 IEEE Globecom Workshops (GC Wkshps)*, pp. 720–725, IEEE, 2023.
- [27] L. A. de Oliveira, E. F. Silva, and M. A. R. Dantas, "A nwdaf study employing machine learning models on a simulated 5g network dataset," in *2024 IEEE Symposium on Computers and Communications (ISCC)*, pp. 1–6, IEEE, 2024.
- [28] P. Rajabzadeh and A. Outagarts, "Federated learning for distributed nwdaf architecture," in *2023 26th Conference on Innovation in Clouds, Internet and Networks and Workshops (ICIN)*, pp. 24–26, IEEE, 2023.
- [29] K.-H. Chen and H.-S. Huang, "Meta-nwdaf: A meta-learning based network data analytic function for internet traffic prediction," in *2022 23rd Asia-Pacific Network Operations and Management Symposium (APNOMS)*, pp. 01–04, IEEE, 2022.
- [30] C.-H. Chen and H.-S. Huang, "C-nwdaf: Designing a cloud-based multi-model architecture for network data analytics function," in *2023 9th International Conference on Applied System Innovation (ICASI)*, pp. 196–198, IEEE, 2023.
- [31] W. Zhang, C. Sun, X. Wang, L. Li, T. Cui, and H. Li, "5gc enabled lightweight federated learning under communication quality constraint," in *2024 IEEE/CIC International Conference on Communications in China (ICCC)*, pp. 1633–1638, IEEE, 2024.
- [32] Y. Jeon and S. Pack, "Hierarchical network data analytics framework for 6g network automation: Design and implementation," *IEEE Internet Computing*, 2024.
- [33] H. Jeong and S. Pack, "An implementation study of 3gpp network data analytics function on kubernetes," in *2024 15th International Conference on Information and Communication Technology Convergence (ICTC)*, pp. 1931–1933, IEEE, 2024.
- [34] J. M. Oliveira, J. Almeida, E. D. B. e Silva, L. F. R. Moreira, R. Moreira, F. O. Silva, D. F. Macedo, and J. M. Nogueira, "Anomaly detection employing a 5g core data analytics framework," in *2024 IEEE 13th International Conference on Cloud Networking (CloudNet)*, pp. 1–9, IEEE, 2024.
- [35] K. B. Kan, H. Mun, G. Cao, and Y. Lee, "Mobile-llama: Instruction fine-tuning open-source llm for network analysis in 5g networks," *IEEE Network*, 2024.
- [36] C. Zhang, G. Shan, and B.-h. Roh, "Fair federated learning for multi-task 6g nwdaf network anomaly detection," *IEEE Transactions on Intelligent Transportation Systems*, 2024.
- [37] C. Zhou and N. Ansari, "Securing federated learning enabled nwdaf architecture with partial homomorphic encryption," *IEEE Networking Letters*, vol. 5, no. 4, pp. 299–303, 2023.
- [38] P. Linder and J. Marcus, "5g network slicing: Bridging the gap between csp readiness and enterprise expectations," 2025. [Online] Available: <https://www.ericsson.com/en/blog/north-america/2025/bridging-the-gap-for-5g-network-slicing>.
- [39] F. Wills, "Fighting telecom fraud – the new (old) trend for 2025!," 2025. [Online] Available: <https://www.enea.com/insights/telecom-fighting-fraud-in-2025/>.
- [40] B. Turkovic, R. van de Vlasakker, S. Potnuru, R. S. Schwartz, L. D'Acunto, O. Held, S. Karasek, R. Kusumakar, A. Cremona, and R. Fardanian, "On-demand network qos adaptation for automated tele-operated driving," in *Proceedings of the 3rd International Workshop on Testing Distributed Internet of Things Systems, TDIS '25*, (New York, NY, USA), p. 19–22, Association for Computing Machinery, 2025.