NOKIA BELL LABS

Advancing AI: Networks and LLMs

A new paradigm for network management and troubleshooting

White paper

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Introduction:
From complex networks to AI-native operations

For more than a century, networks have become increasingly integral, essential, and even vital to modern society. The ability of humans to communicate with each other has always been fundamental, not just to survive, but to thrive as a society.

Networks are systems that enhance the ability for humans to communicate. One of the first electrical-based networks was the telegraph system, introduced in the 1830s, making possible the sending of messages in the form of Morse code. The invention of the telephone in 1876 led to the creation of a new telecommunications network that enabled humans to talk to each other from any distance —first through wires (copper then fiber) and subsequently via various wireless access technologies (AMPS, TDMA, CDMA, GSM, UMTS, LTE, 5G and WiFi).

Through the years, this voice-based network evolved to support other modes of person-to-person communications in the form of text, images and video and eventually expanded to provide advanced capabilities such as screen sharing, whiteboarding, and so on. In parallel, the network also evolved to support what is now known as the internet and all that humans can do via the World Wide Web and stand-alone apps.

The network has become indispensable to everyday life and to today's enterprises and the global economic structure that it empowers. Given the criticality of the network, it is imperative to minimize downtime. Network reliability is crucial. Any disruption of service could lead to loss or delay of revenue for businesses or, in the case of emergency services, potential loss of life. Indeed, the goal should be zero network downtime.

The introduction of large language models (LLMs) is turning out to be the start of the AI revolution—a technology revolution that will change life in ways that humanity has never experienced. LLMs are not just making search engines more user-friendly with human-sounding chatbots. LLMs have the potential to redefine how systems operate and how they are managed. And networks are prime candidates for this transformation—all types of networks, e.g., wired, wireless, optical and fixed networks across all physical and geographic scope, including networks for data centers.

As networks evolve, they become both more capable and sophisticated as well as more complex. The number of configuration parameters, key performance indicators (KPIs), logs, alarms, alerts, etc. has exploded. Networks have also become more heterogeneous. Thus, troubleshooting issues in a network today require tools with much greater intelligence than in the past.

LLMs, especially reasoning AI models, are demonstrating remarkable performance against the latest benchmarks. And the expectations are that they will continue to improve dramatically.

How can language models help address increasing network complexity? First, consider applying the innate conversational nature of LLMs to networks. What if in the future, engineers or technicians can manage a network by simply talking to it? Or texting with it? Reasoning models make this possible. And with this possibility comes a complete redefinition of network operations and management.

Secondly, much of the data used to troubleshoot networks can be considered as a form of language augmented with multimodal data—from logs to alerts to combinations of KPIs. Add trouble tickets with structured fields along with free-form inputs into the mix, and these are the wide-ranging types of data that LLMs are good at sorting through and making sense of. LLMs can examine large volumes of this set

of cross-sectional and time series data coming from various components across the network including customer relationship management (CRM) data and come to some recommendation or prediction – whether it is for anomaly detection, root cause analysis, zero-touch ticket assignments, next-best step, etc.

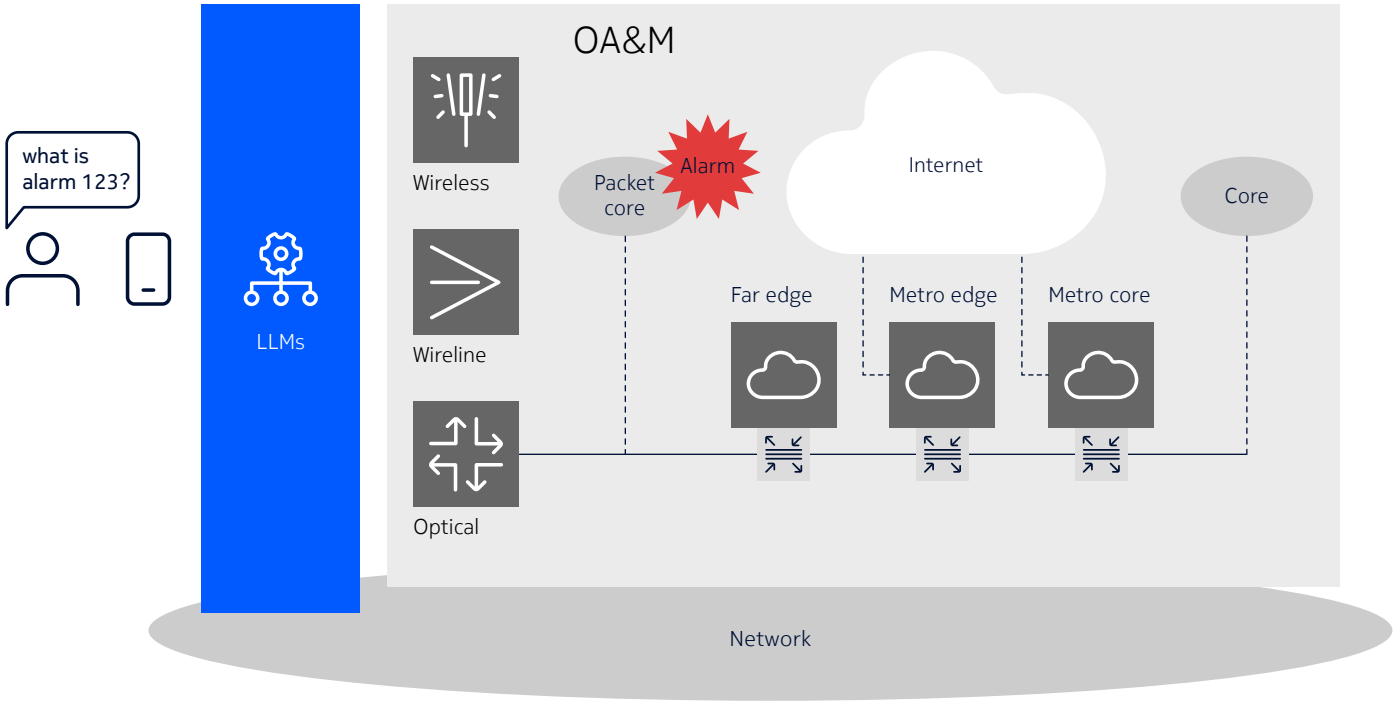
LLMs could become an excellent collaborator for troubleshooting problems by providing a conversational interface to retrieving relevant information from documentation or databases. LLMs could also be advantageous for recognizing anomalies, predicting root causes, being a sounding board to brainstorm and reason through potential solutions, or by autonomously recommending actions to take next.

The aid that LLMs can provide would be profound in:

1. Reducing trouble-ticket resolution time
2. Reducing time needed from domain experts
3. Enabling lesser-experienced engineers to resolve network issues
4. Initiating predictive maintenance.

This vision for a revolutionary new way of managing and operating networks could ultimately lead to new ways of doing business including new business models and new paths to revenue.

Figure 1. Revolutionizing network operations and management with LLMs



Goals:
Outcomes that cut down time and speed resolution

The goals of leveraging LLMs for networks are to address the increasing complexity of these systems as well as to utilize AI to revolutionize the way they are managed and operated.

The goals include:

1. Minimize downtime
2. Reduce the time it takes to resolve issues
3. Reduce the time required by domain experts
4. Improve the customer experience by providing and supporting easy, conversational interactions with the network by engineers and technicians
5. Furthering the automation of:
    a. Anomaly detection
    b. Root cause determination of issues
    c. Solution recommendations
    d. Progress toward self-healing.

Key to this transformation is the use of LLMs that can reason. For greater capabilities, these LLMs can also be utilized as components of AI agents with the following capabilities:

1. Reasoning
2. Planning
3. Autonomy
4. Real-time, continuous data collection from a diverse array of sources
5. Self-checking and self-correction
6. Problem solving
7. Hallucination mitigation.

This paper will describe the state-of-the-art (SOTA) building blocks followed by two Nokia solutions: Network LLM (Talk to your network) and Augmenting Network Troubleshooting and Problem Resolution Using LLMs.

Tenets:
Design principles for sage, scalable network AI

We identify eight tenets that are essential for redefining how networks are managed and operated, as well as improving troubleshooting and problem resolution.

1. **Ease of use** – a conversational interface requiring little technical skill to query or manage a network can revolutionize telecommunications

2. **Multimodal integration and contextual awareness** – seamless integration and reasoning across multiple modalities are needed to provide context-aware insights or actions
3. **Hallucination mitigation** – accurate results and outcomes from LLMs for networks are essential; hence, hallucinations must be minimized
4. **Explainability** – trust and assurance of LLMs' results and outcomes for networks is possible if they are explainable
5. **Robustness and reliability** – highly reliable results and outcomes, including in edge cases, are required for the viability of LLMs used in networks
6. **Scalability and real-time performance** – LLMs must be able to scale to support a wide variety of network components across a diverse number of tasks over multiple geographical locations
7. **Data privacy and security** – network data is sensitive and must be protected
8. **Costs** – As networks become AI-native with AI and AI agents embedded throughout the system, the cost of AI models will be a critical issue, and solutions to minimize costs, including the use of SLMs and MLMs, will be required.

Language models, LLMs along with their smaller counterparts Medium Language Models (MLMs) and Small Language Models (SLMs), can transform networks in profound ways. These AI models are ideal for processing multi-modal, cross-sectional, and time-series data.

State of the business: Alliances, benchmarks and early operator moves

To ensure the best results, LLMs should understand and have specific knowledge about networks. Understanding networks can come from training or fine-tuning LLMs with both internal and external documents that describe the network, e.g., equipment manuals, standards documents, etc. Understanding can also come from submission to or retrieval of documentation by LLMs during inference time, e.g., via retrieval-augmented generation (RAG) techniques.

In 2024, SK Telecom, Deutsche Telekom, e& Group, Singtel and Softbank formed the Global Telecom AI Alliance (GTAA) joint venture to create telco-specific LLM solutions [1]. The GTAA members want to use LLMs to identify and solve telco-specific business issues using local languages, as well as industry-specific terms and their own internal business jargon, none of which can be done quickly or easily with generic LLMs.

The GTAA's founders have announced a joint venture agreement to co-develop and launch a multilingual telco large language model (TLLM), which will work for Korean, English, German, Arabic, and Bahasa, among other languages. Customer care is an initial focus for GTAA members, but they want to go further. They have a vision for personalized services that will drive a third-party application ecosystem. They want to leverage LLMs to not just lower OPEX, but to create new business models for new revenue.

Benchmarks are needed to evaluate the performance of LLMs for telco use. In furtherance of this goal, the Global System for Mobile Communications Association (GSMA) first published its open-telco benchmarks on Hugging Face's website, February 25, 2025 [2]. Launched by GSMA's Foundry, they describe the challenges faced by telcos in using LLMs as:

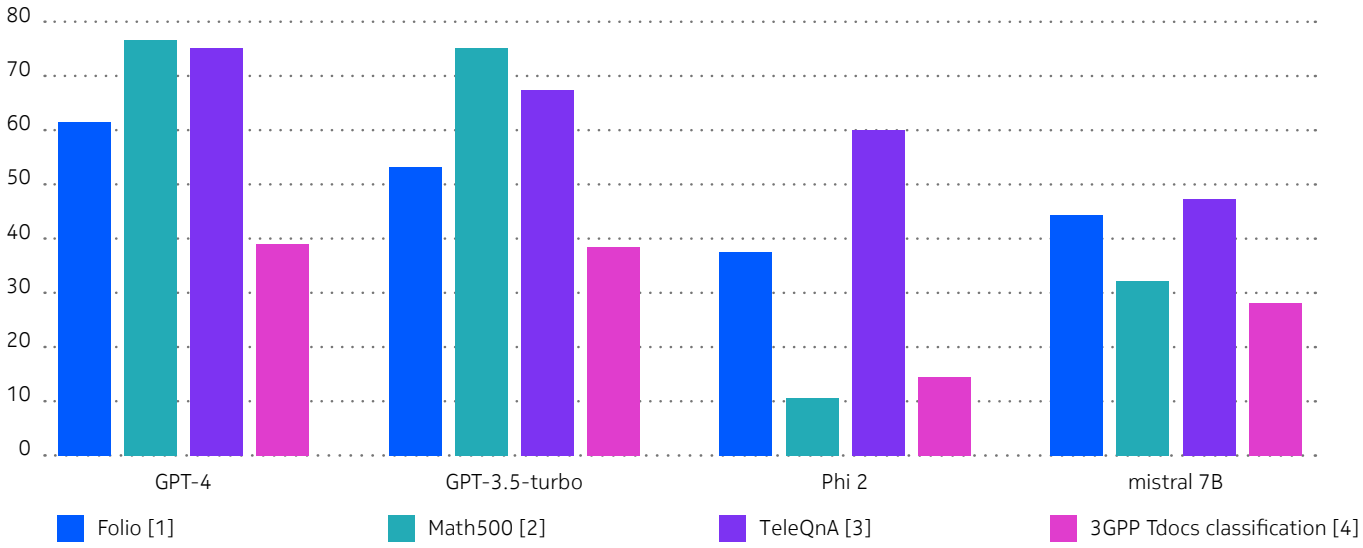
- Misinterpretation of telecom standards and policies
- Errors in network optimization and automation
- Ineffective fault detection and incident resolution
- Challenges in AI-powered customer experience and service management.

The GSMA Open-Telco LLM Benchmarks assess LLMs using four key datasets:

1. TeleQnA – Telecom domain knowledge and technical understanding
2. 3GPPTdocs Classification – Standards comprehension and documentation parsing
3. MATH500 – Mathematical reasoning and modeling
4. FOLIO – Logic and reasoning

There is a leaderboard on the Hugging Face website for AI models that have been tested against these benchmarks [3]. See figure 2 below for the initial benchmark results.

Figure 2. GSMA Open-Telco LLM Benchmarks results



These are expected to improve over time and to track additional AI models. But, clearly there is room for improvement.

Telecommunication providers are already moving forward with utilizing LLMs. For instance, SK Telecom is working with Anthropic to fine-tune a generative-AI assistant named Claude "to best meet the needs of telcos," according to a press release from Anthropic [4][5]. Anthropic "will leverage SKT's domain experience in telecommunications in order to make the model optimized for a wide variety of telco applications, including customer service, marketing, sales, and interactive customer applications." The goal is also for the model to support Korean, English, Japanese and Spanish. SKT has also invested $100 million into Anthropic [6].

Launched in 2023, AT&T utilizes OpenAI's GPT for its "Ask AT&T" chatbot [7]. This chatbot helps AT&T's software developers become more productive. It also simplifies and translates customer and employee documentation from English to other languages.

According to AT&T, they plan to use LLMs in the future to upgrade legacy software, make their care representatives more effective at supporting customers, and give employees quick and simple answers to human resources questions.

Network LLM: A conversational control plane for operations

Applying AI to network operations has been underway for a while. The incorporation of LLMs will revolutionize the way network management is conducted using natural language conversations. This enables a new "Talk to Your Network" paradigm for network operations.

Research applying LLMs to networks include:

- "Large Language Model (LLM) for Telecommunications: A Comprehensive Survey on Principles, Key Techniques, and Opportunities" [8]

  This paper describes a number of use cases in which LLMs can be employed in networks. These include traffic classification, network attacks classification, subscriber feedback classification, network QnA, automated network configuration and troubleshooting, and network optimization.

- "Large Language Models for Networking: Applications, Enabling Techniques, and Challenges" [9]

  This paper describes the application of LLMs to four network domains: design, configuration, diagnosis, and security. The insight is that language understanding and tool usage are both required for network LLMs. They present a novel framework allowing interactions between end-users and a chatbot that demonstrates the embodied intelligence of a network that they call ChatNet, which is a domain-adapted network LLM framework with access to various external network tools.

- "NetConfEval: Can LLMs Facilitate Network Configuration?" [10]

  This paper evaluates the efficiency of LLMs to improve and automate the tasks of network configuration. The authors introduce a benchmark suite, NetConfEval, which evaluates LLM performance across tasks such as converting requirements to formal specifications, generating API calls, developing routing algorithms, and producing protocol configurations. Based on their findings, they propose design principles for LLM-based network configuration systems and demonstrate two GPT-4 prototypes.

- "Neural language models for network configuration: Opportunities and reality check" [11]

  This paper provides an overview of progress on language models for computer language and projects its potential impact for automated network configuration. It surveyed recent advances in deep learning applied to programming languages, for the purpose of code verification, synthesis and translation. In particularly, they reviewed the training requirements and expected performance, and qualitatively assess whether similar techniques can benefit corresponding use cases in networking.

- "TelecomGPT: A Framework to Build Telecom-Specific Large Language Models" [12]

  This paper presents a novel pipeline that adapts general-purpose LLMs into telecom-specific models by leveraging specially curated datasets for pre-training, instruction tuning, and alignment tuning. Additionally, it introduces three new benchmarks—Telecom Math Modeling, Telecom Open QnA, and Telecom Code Tasks—to comprehensively evaluate performance in telecom contexts, including math modeling, open-ended question answering, code generation, and more. Their fine-tuned model,

TelecomGPT, significantly outperforms state-of-the-art LLMs like GPT-4, Llama-3, and Mistral in telecom math modeling while achieving competitive results on other evaluation tasks.

Augmenting network troubleshooting and problem resolution using LLMs

LLMs are great for providing a universal conversational interface to anything, including networks. But they can be used for even more than that. LLMs are AI models that can understand anything that can be considered a language.

Network troubleshooting data presents itself in various linguistic forms, including system logs, alerts, and KPIs. When combined with trouble tickets—containing both structured data fields and unstructured text inputs, this creates a diverse dataset that LLMs excel at processing and interpreting. These models demonstrate a remarkable capability to analyze vast amounts of both cross-sectional and temporal network data, while also incorporating CRM information. This comprehensive analysis enables LLMs to generate valuable insights, whether for identifying root causes, anomaly detection, automatically assigning tickets, or suggesting optimal next actions in the troubleshooting process.

LLMs make possible a holistic solution for examining the network end-to-end in troubleshooting, rather than the current siloed and fragmented collection of separate tools that we have today for different data types and node-by-node analysis.

Lessons learned: Limitations and future directions

LLMs can be used today for customer care, network operations, and troubleshooting. In these areas alone, significant gains in productivity and savings are possible. We do, however, need to recognize and address existing limitations of LLMs that can impact their usefulness in real-world deployments when integrated into network products and solutions. The following lists some of the limitations that must be addressed in order to effectively apply LLMs to networks.

1. Technical limitations
    a. Token limits that restrict processing of large network configurations or logs at once
    b. Reasoning with SLMs and MLMs for costs minimization
2. Accuracy and reliability
    a. Risk of AI hallucinations in mission-critical network operations
    b. Need for formal and continuous validation of AI-generated network recommendations
    c. Lack of guaranteed deterministic behavior
3. Security and privacy concerns
    a. Risk of exposing sensitive network configuration data
    b. Data privacy compliance requirements when processing network data
4. Domain-specific challenges
    a. Need for specialized training on networking-specific terminology and concepts
    b. Need for continuous improvements in prompting techniques
    c. Complexity in handling multi-vendor network environments.

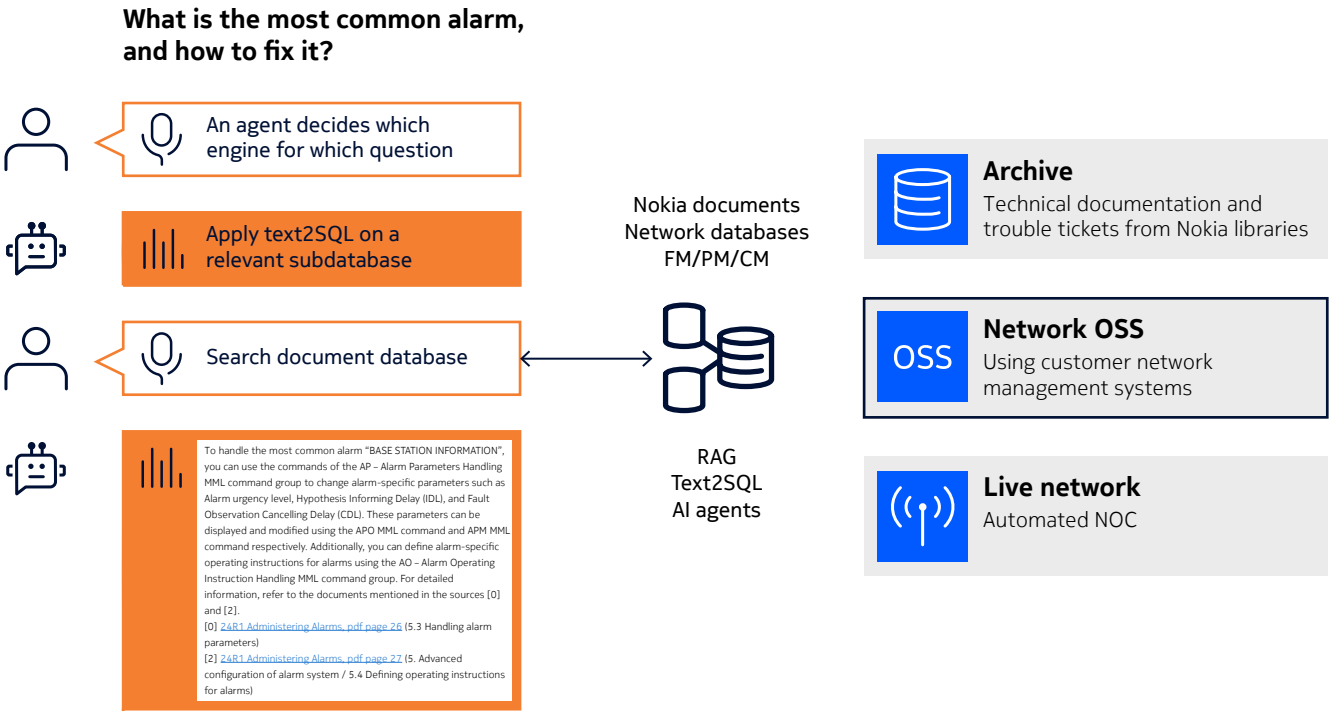
Strategic priorities: Applying LLMs to network operations

LLMs, together with Small Language Models (SLMs) and multimodal models (MLMs), can reshape how networks are managed and operated. Two near-term opportunities stand out: conversational network operations— “talk to your network”—and LLM-assisted troubleshooting that fuses diverse, language-like telemetry. Both aim to shorten time to resolution and reduce operational burdens while preserving accuracy, security and explainability.

Conversational network management

This undertaking explores the transformative potential of integrating LLMs into network management systems. By leveraging the advanced capabilities of LLMs, particularly in querying databases, network operators can interact with complex network data more intuitively and efficiently. The proposed vision includes using natural language capabilities to make an interactive automatic health check (AHC) and network digital assistant (NDA). This could, for instance, enable automatic summaries and extraction of critical attributes from network configuration databases. This approach aims to enhance user engagement, improve customer experience, and provide trustworthy, explainable answers. There are challenges and strategic priorities to be addressed, especially with respect to the complexity and size of the databases. In order to implement LLMs for network management, it is essential to generate accurate, reliable and verifiable outputs.

Figure 3. Nokia Digital Assistant with “Talk to Your Network”



LLM-augmented network troubleshooting and problem resolution

This initiative uses the application of LLMs to enhance modern network troubleshooting and problem resolution by simplifying complex tasks. Specifically, it aims to address how traditional LLMs in some domain-specific tasks generate hallucinations and generic responses that often limit their use in complex, telecommunication networks. It emphasizes the need for a specifically trained and/or fine-tuned multi-modal LLM system. This system needs to be capable of processing and integrating diverse types of structured and unstructured network data such as key performance data, system log messages, alarms and alerts, diagnostics and even ancillary data such as customer surveys and site audio and video. The solution outlines a workstream focused on unified solutions for understanding network troubleshooting, identifying anomalies, and suggesting corrective actions for resolution. The approach aims to reduce the time and effort required by our domain experts while enabling non-experts to also generate insights effectively. The solution addresses the limitations of traditional rule-based methods in dynamic heterogeneous networks (DHNs). It aims to provide adaptable tools that ensure reliable and robust network functionality.

Conclusion

The integration of LLMs into telco operations represents a revolutionary change in the management and operation of networks. By leveraging the advanced reasoning and conversational capabilities of these AI models, network operations can evolve to address increasing complexity, reduce downtime, and enhance efficiency. Our initiatives, namely conversational network management (“Talk to Your Network”) and LLM-augmented troubleshooting, aim to simplify network interactions, improve anomaly detection, and enable faster resolution of issues.

While the potential of LLMs in telecommunications is immense, challenges such as hallucination mitigation, data privacy, scalability, and domain-specific training must be addressed to ensure accuracy, reliability and security. Collaborative efforts, such as the Global Telecom AI Alliance and the development of telco-specific benchmarks, are paving the way for tailored solutions that meet the unique demands of the industry by supporting the development of LLMs that are trained specifically for networks.

Abbreviations

AHC	Automatic health check
AMPS	Advanced Mobile Phone System
AI	Artificial intelligence
CDMA	Code-Division Multiple Access
CRM	Customer relationship management
DHN	Dynamic heterogenous network
GTAA	Global Telecom AI Alliance
GSM	Global System for Mobile Communications
GSMA	Global System for Mobile Communications Association
KPI	Key performance indicator
LLM	Large language model
LTE	Long-Term Evolution
MLM	Medium language model
NDA	Network digital assistant
OPEX	Operating expense
RAG	Retrieval-augmented generation
SLM	Small language model
SOTA	State of the art
TDMA	Time-Division Multiple Access
TLLM	Telco large language model
UMTS	Universal Mobile Telecommunications System

References

1. Taffe, J., "DTW24-Ignite: Global Telecom AI Alliance lays out vision for telco LLMs," TM Forum, 19 Jun 2024. Online: https://inform.tmforum.org/features-and-opinion/dtw24-ignite-global-telecom-ai-alliance-lays-out-vision-for-telco-llms
2. Bariah, L. et al., "GSMA Open-Telco LLM Benchmarks," Hugging Face, 25 Feb 2025. Online: https://huggingface.co/blog/otellm/gsma-benchmarks
3. Open Telecom LLMs team, "GSMA Open-Telco LLM Benchmarks Leaderboard," Hugging Faces Spaces, viewed 18 Nov 2025. Online: https://huggingface.co/spaces/otellm/leaderboard
4. Anthropic, "SKT partnership announcement," Anthropic web site, 15 Aug 2023. Online: https://www.anthropic.com/news/skt-partnership-announcement

5. Kinney, S., “Three large language models (LLMs)—and how they’re being used for telco AI use cases,” RCR Wireless News, 13 Aug 2024. Online: https://www.rcrwireless.com/20240813/fundamentals/top-five-large-language-models-llms-used-for-telco-ai
6. TelcoLLM.AI, “Introducing the TELCO LLM,” TelcoLLM.AI web site, viewed 18 Nov 2025. Online: https://www.telcollm.ai/
7. Markus, A., “Ask AT&T – AT&T’s new Generative AI tool will help employees be more effective, creative, and innovative,” AT&T Blog, 20 Jun 2023. Online: https://about.att.com/blogs/2023/generative-ai.html
8. Zhou, H., et al., “Large Language Model (LLM) for Telecommunications: A Comprehensive Survey on Principles, Key Techniques, and Opportunities,” arXiv:2405.10825, 17 May 2024. Online: https://arxiv.org/abs/2405.10825
9. Huang, Y., et al., “Large Language Models for Networking: Applications, Enabling Techniques, and Challenges,” arXiv:2311/17474, 29 Nov 2023. Online: https://arxiv.org/pdf/2311.17474
10. Wang, C., et al., “NetConfEval: Can LLMs Facilitate Network Configuration?”, Proceedings of the ACM on Networking, vol 2, article 7, pp. 1–25, 13 Jun 2024. Online: https://dl.acm.org/doi/10.1145/3656296
11. Houdi, Z. B. and Rossi, D., “Neural language models for network configuration: Opportunities and reality check,” Elsevier Computer Communications, Vol. 193, 1 Sep 2022. Online: https://arxiv.org/abs/2205.01398
12. Zou, H., et al., “TelecomGPT: A Framework to Build Telecom-Specific Large Language Models,” arXiv:2407.09424, 12 Jul 2024. Online: https://arxiv.org/pdf/2407.09424

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