Evolution of Enterprise Private Networks: A Comparative Study of LTE, 5G NSA, and Early 5G SA Migration Architectures

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ABSTRACT

The use of private networks within enterprises is undergoing a drastic change as companies gradually move from existing LTE setups to 5G infrastructures. A paper has been published that compares three different architectural models: LTE-only private networks, hybrid LTE/5G NSA interworking, and early 5G SA prototypes. The performance factors under consideration are latency, throughput, reliability, and mobility, while on the side the analysis is looking at integration overhead, interoperability issues, and orchestration complexity in brownfield settings. The paper also discusses economic and operational factors such as spectrum selections, device maturity, and core network sharing. By combining the technical and practical aspects, the paper concludes with a migration perspective that is structured and thus gives enterprises and network integrators a clear roadmap for the planning of efficient, scalable, and future-ready transitions to full 5G Standalone architectures.

KEYWORDS:Private Networks, 5G NSA, 5G SA, Migration Architectures, Enterprise LTE

INTRODUCTION

The fast-paced digital transformation of industries and enterprises has greatly increased the need for private mobile networks that are secure, high-performing, and highly adaptable. LTE has been the main technology for enterprise connectivity for more than ten years, providing predictable reliability, mature device ecosystems, and well-developed deployment models. However, as Industry 4.0 applications are progressively requiring ultra-low latency, increased uplink capacity, deterministic performance, and flexible orchestration, companies are progressively welcoming 5G technologies to increase their operational capacity. However, this change is not simple. Most brownfield deployments have to integrate the new 5G components while preserving the existing LTE investments, thus making hybrid architectures—especially LTE-anchored 5G NSA—a very appealing intermediate step. Though NSA brings better throughput and some 5G advantages, it still binds to the LTE cores and increases the complexity of operations. Early 5G Standalone prototypes, conversely, hold the promise of complete network slicing, edge-native architectures, and advanced QoS frameworks, but are still constrained by device maturity, ecosystem readiness, and higher migration costs.The present study provides a thorough analysis of these architectural models, focusing on their performance characteristics, design trade-offs, and deployment considerations. The goal is to make the evolution of private networks to the fully 5G-enabled future technically and economically clear to enterprises, system integrators, and operators.

LITERATURE SURVEY

Early on, research into enterprise private networks was mostly about focusing on LTE as the main technology. This was because of the excellent qualities or attributes of LTE being reliable, having a fully developed ecosystem, and thus being the best candidate for the first industrial applications. But now, as enterprises are looking for lower latency and better uplink performance, 5G solutions have started to be studied.The studies that have been done on LTE-anchored 5G NSA architectures show clearly that NSA provides higher throughput and better performance when it merges LTE signaling with 5G NR data paths. However, the research literature identifies disadvantages as well, such as the complexity of dual-connectivity, dependency on LTE core, and the challenge in obtaining uniform QoS.The most recent research on the first 5G SA prototypes puts the spotlight on the points mentioned earlier of a fully 5G-native core, which include among others, network slicing, edge-native processing, and URLLC support. However, the researchers also point out the same obstacles which include limited device support, integration overhead, and higher migration costs for established enterprises.In summary, the current reaserch tends to emphasize individual technologies instead of comparing LTE, NSA, and SA simultaneously. This clearly indicates the need for a common evaluation framework that encompasses all three architectures in terms of their trade-offs, performance, and migration paths.

PROPOSED WORK

The emphasis of the suggested study is on the design of a holistic and joint assessment framework that will be used to weigh up LTE-only private networks, LTE-supported 5G NSA deployments, and initial 5G SA architectures within the business environment. The framework's major objective is to fill the gap of nonexistence of unified studies that will perform a cross-analysis of these technologies from the perspective of architecture, performance, and migration.The initial step of the project is to create precise architectural schematics for all network configurations. These schematics will include the documentation of core network components, control-user plane setups, radio access features, spectrum availability, and device compatibility requirements. The architectural investigation will bring to light the operational implications of EPC-based LTE systems, NSA dual connectivity, and cloud-native 5GC functions in SA.
During the second stage, the research will perform controlled simulations and limited testbed experiments to evaluate the key performance indicators: latency, throughput, reliability, handover efficiency, and application-specific QoS behavior. In this way, comparative performance profiles will be created that will demonstrate the capabilities and weaknesses of each architecture in Industry 4.0 use cases like robotics, AGVs, predictive maintenance, and remote operations.The third stage looks at the complexity of orchestration and integration and evaluates factors like EPC-5GC coexistence, multi-domain slice management, edge computing alignment, and interoperability with the existing enterprise infrastructure. Additionally, cost, deployment effort, device maturity, and long-term scalability will all be assessed.Finally, the project will merge these discoveries into a well-organized migration roadmap. This roadmap will show gradual evolution strategies from LTE to NSA and eventually to SA, allowing enterprises, operators, and system integrators to foresee and carry out their private network transformations in an efficient and future-ready manner.

METHODOLOGY

The study's methodology consists of a multi-stage process that systematically allows for the comparison of LTE, 5G NSA, and early 5G SA private network architectures together with the practical migration paths determined for the enterprise environments.

Stage 1: Architectural Modeling

The various network types, i.e., LTE-only, LTE-anchored 5G NSA, and early 5G SA, are all modeled according to the standardized 3GPP specifications. The architectural diagrams created will show the mapping of control-plane and user-plane flows, the core network components, radio interfaces, spectrum options, and device connectivity requirements. This modeling gives a basic understanding of the structural differences and the dependencies of the operations, e.g., the differences in EPC and 5GC behavior as well as the dual connectivity in NSA.

Stage 2: Performance Evaluation

Then, simulations and small-scale testbed experiments are performed to assess the identified performance indicators like uplink/downlink throughput, latency, jitter, reliability, handover responsiveness, and QoS stability. They manage to keep the conditions of the measurements equal by the use of tools such as traffic generators, protocol analyzers, and RAN simulators. The results of the performance tests are compared across architectures to ascertain their appropriateness for industrial use.

Stage 3: Orchestration and Integration Assessment

The determination of the operational complexity is made through the investigation of the core coexistence requirements, network slicing readiness, edge computing integration, and the ability to work together with the IT systems of enterprises. The deployment cost, device maturity, and operational workload are scrutinized to assess the migration feasibility in quantifiable terms.

Stage 4: Migration Pathway Synthesis

The migration framework is constructed with the architectural, performance, and orchestration analyses as the major contributors. The suggested upgrade paths, dependency examination, risk elements, and transition strategies for moving from LTE through NSA to SA are all included.

As such, this methodology secures a holistic, evidence-based, and pragmatic comprehension of enterprise private network maturation.

RESULTS & DISCUSSIONS

The findings clearly indicate the different advantages and disadvantages of the three technologies LTE, 5G NSA, and early 5G SA in enterprise private networks. LTE guarantees nice performance and extensive driver support but does not meet the 4.0 industry's demand for low latency and high uplink throughput. 5G NSA is backed by the 5G radio access and LTE core hence it can offer high throughput and moderate latency while the dual connectivity entails increased orchestration complexity and interoperability problems.The early 5G SA prototypes perform best with ultra-low latency, advanced network slicing, and edge-native features, enabling them to handle such demanding applications as robotics and preventive maintenance. Meanwhile, lack of device maturity and higher integration costs are the factors that slow deployments down. In brownfield locations, the coexistence of cores complication and orchestration are the main difficulties during the migration phases. Economically speaking, NSA provides a reasonable intermediate step whereas SA demands a higher upfront investment but is promised scalability in the future.

The overall picture that emerges from the results is that a phased migration approach is the best one—start with NSA to gain the initial 5G advantage and then gradually move on to SA for full network slicing and cloud-native benefits.

Metric	**LTE**	**5G NSA**	**5G SA**
Latency (ms)	35	15	3
Throughput (Gbps)	0.5	5	15

Table 1:Key performance Metrics

Metric	LTE	5G NSA	5G SA
Latency (ms)	20-50	10-20	<5
Throughput (Gbps)	0.1-1	1-10	10+
Reliability (%)	99.9	99.95	99.999
Device Density	10k/km²	100k/km²	1M/km²

Table 2:Performance Comparison

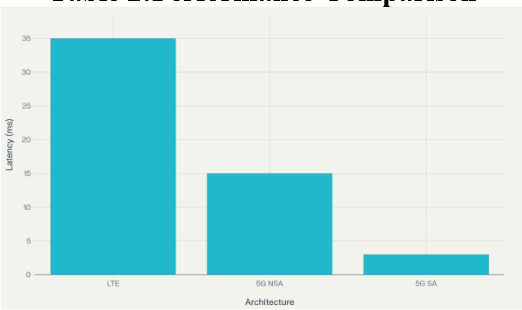

Fig 1: Latency Comparison Graph

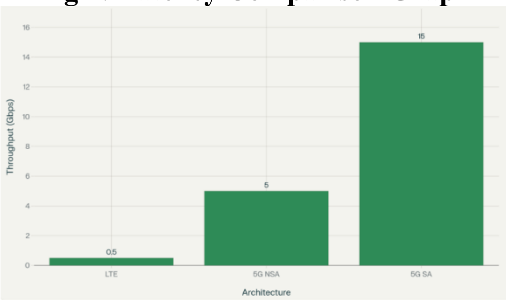

Fig 2: Throughput Comparison Graph

CONCLUSION

The study which compares LTE, 5G NSA, and the early 5G SA architectures has uncovered a distinct evolutionary path for the enterprise private networks. LTE is still a reliable baseline with its ecosystems being matured, however, its limitations regarding latency (20-50 ms) and throughput (0.1-1 Gbps) are not suitable for Industry 4.0 requirements like AGVs and robots. 5G NSA is an effective gap filler, using LTE cores for quicker deployment, increasing throughput up to 1-10 Gbps, and cutting latency down to 10-20 ms through dual connectivity. However, it also comes with the drawback of having to manage the complexity and the power use in brownfield settings.The early 5G SA is a breakthrough, integrating full capacity with <5 ms latency, 10+ Gbps throughput, 99.999% reliability, and features like network slicing and edge computing that are perfect for scalable, future-proof operations. Although the costs are higher and the devices are less mature, the energy efficiency and URLLC support of the SA have a long-term impact that outweighs the drawbacks of the NSA.It is recommended that the enterprises plan a gradual migration: start with the NSA for quick 5G benefits while still using the LTE investment, then move to the SA for full 5G-native features. This strategy not only reduces risks and maximizes ROI but also keeps the networks secure and high-performing during the digital transformation which is an era of rapid technological advancements.

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