ESP-JETA
ESP Journal of Engineering & Technology Advancements
ISSN: 2583-2646 / Volume 5 Issue 2 May 2025 / Page No: 107-113
Paper Id: JETA-V5I2P112 / Doi: 10.56472/25832646/JETA-V5I2P112

Original Article

Impact Analysis of VoLTE and NB-IoT Implementation on Carrier Network Performance

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Received Date: 30 January 2025 Revised Date: 05 February 2025 Accepted Date: 03 May 2025

Abstract: *In this review, the effect of concurrent Voice over LTE (VoLTE) and Narrowband Internet of Things (NB-IoT) deployment on the LTE network performance is evaluated. These technologies complement each other, performing different roles within contemporary mobile networks. NB-IoT takes care of delay-tolerant massive machine-type communications, and VoLTE offers real-time voice communication. The coexistence of Wi-Fi and LTE in the shared LTE infrastructure creates radio resource management and latency control challenges, as well as quality of service. An architectural overview, a proposed performance model, and empirical evidence from published research are presented in this article. Latency, spectral efficiency, packet loss, and Mean Opinion Score (MOS) are evaluated among key performance indicators, in varying deployment scenarios including: in-band, guard-band, and standalone NB-IoT allocation configurations. It was marked that without QoS-aware scheduling or spectrum partitioning, performance degrades. Finally, the article discusses future directions, including AI-driven scheduling, network slicing, and benchmarking frameworks for coexistence environments.*

Keywords: *5G readiness; coexistence; latency; LTE; NB-IoT; network performance; packet loss; QoS; spectral efficiency; VoLTE.*

I. INTRODUCTION

With the rapid evolution of mobile communications, new technologies have emerged that are renaissance in their design, redefining traditional paradigms of voice and data delivery. The most transformative of all are Voice over LTE (VoLTE) and Narrowband Internet of Things (NB-IoT), both built on top of 4G LTE but created to address a very divergent set of use cases. VoLTE replaces legacy circuit-switched technologies for packet-switched voice communication over LTE, and enhances call setup times, voice quality, and spectrum efficiency [1]. As a result, NB-IoT has surfaced as a key enabler of massive machine-type communication (mMTC) for energy-efficient and economical IoT connectivity in smart grids, industrial automation, and remote monitoring applications [2].

The simultaneous deployment of VoLTE and NB-IoT greatly increases the complexity of carrier network management. VoLTE needs ultra-low latency and a small amount of jitter to maintain acceptable voice quality, whereas NB IoT operates in delay-tolerant mode with infrequent data transmissions. But both technologies fight over finite radio resources, and often vie for them in the same LTE carrier. In the case of in-band deployment, however, resource contention becomes a major concern, and in such deployments, NB-IoT may be deployed in standalone, in-band, or guard-band configurations. Degraded performance of one or both of the services can occur due to scheduling conflicts, interference, and inefficient Quality of Service (QoS) prioritization [3].

In the current research and deployment landscape, this is an increasingly relevant topic. A dual imperative is facing mobile network operators (MNOs): They will support legacy voice services, and at the same time, they will prepare for the explosion of IoT applications. By 2030, the International Telecommunication Union (ITU) is projecting to have IoT connections surpass 25 billion devices [4], and most of these devices will rely upon LPWAN technologies, including NB-IoT. However, VoLTE is also becoming a here-and-now solution, adopted not just for voice services, but also as a foundational voice solution in 5G Non-Stooped (NSA) deployments, accenting its performance in these transitioning environments [5].

In addition, the broader benefit of studying the coexistence of VoLTE and NB-IoT relates to scenarios of network planning, optimization, and 5G architecture design in the future. For VoLTE, the QoS requirements are strict latency and jitter controls; in contrast, for NB-IoT, extended Discontinuous Reception (eDRX) cycles and Power Saving Mode (PSM) are applied. These technical divergences demand the use of intelligent radio resources management (RRM), dynamic spectrum allocation, and context-sensitive scheduling algorithms [6] which guarantee continued service delivery. Additionally, real-world deployments of these technologies simultaneously have shown gaps in existing resource coordination schemes, especially in a shared in-band LTE environment [7].

Although there is a growing literature on individual deployments of VoLTE and NB-IoT, it still lacks an understanding of the joint effects of deploying them together. Much of the existing research works with these technologies in isolation, examining the performance when each is assumed to be ideal or operated in isolation. However, field trials and live network data have increasingly shown degrading performance under mixed traffic conditions, e.g., elevated latency, reduced throughput, increased packet loss, and decreased spectral efficiency [8]. Also, the impact of NB-IoT scheduling patterns on VoLTE's delay-sensitive nature and especially in uplink-oriented scenarios, has not been investigated.

In this review, the objective is to give a structured and critical view of how VoLTE and NB-IoT implementations affect the overall carrier network performance for deployment on LTE infrastructure. Deployment configurations will be explored through key performance indicators, including: latency, throughput, packet loss, spectral efficiency, and energy consumption. In addition, the review attempts to evaluate best practices in Radio Access Network (RAN) architecture, spectrum partitioning, and traffic scheduling through the use of both experimental studies and operator case reports. It further gathers existing findings to inform network operators, researchers, and standards organizations of key considerations for managing VoLTE and NB-IoT coexistence. In the following sections, the article detailed technical overview of VoLTE and NB-IoT, compares deployment approaches, evaluates experimental benchmarks, and recommends directions for future research that address today's challenges in network optimization.

II. LITERATURE SURVEY

Table 1: Summary of Key Research Studies on VoLTE and NB-IoT Impact on Network Performance

No.	Focus of the Study	Key Findings / Contributions	Ref
1	VoLTE performance under network congestion	Demonstrated degradation in call quality and increased packet loss under congestion; highlighted VoLTE's sensitivity	[9]
2	Deployment scenarios and energy performance of NB-IoT	Compared to in-band, guard-band, and standalone deployments, standalone offers the best energy efficiency	[10]
3	NB-IoT performance in multi-service LTE networks	Identified coexistence issues affecting latency and throughput when NB-IoT coexists with other services in LTE	[11]
4	Impact of in-band NB-IoT on VoLTE quality	Found VoLTE voice quality degrades due to NB-IoT channel interference; recommended optimized scheduling for coexistence	[12]
5	Resource allocation for LTE networks supporting VoLTE and IoT	Proposed dynamic resource management to improve fairness and QoS in coexisting VoLTE and IoT traffic	[13]
6	Scheduling algorithms for VoLTE and MTC coexistence	Evaluated and recommended scheduling techniques that prioritize real-time VoLTE without starving MTC flows	[14]
7	Delay and reliability of NB-IoT in live networks	Measured real-world delay and packet loss; concluded that NB-IoT needs QoS support for time-sensitive IoT applications	[15]
8	Quality of Experience (QoE) for VoLTE services	Developed QoE models correlating network KPIs to user satisfaction metrics in VoLTE environments	[16]
9	Coexistence of VoLTE and LTE data services	Showed that interference increases without traffic-aware scheduling; proposed a joint interference management strategy	[17]
10	VoLTE vs VoIP performance in LTE under mobility and load variation	Concluded that VoLTE outperforms VoIP in mobile scenarios due to lower handover delay and better load adaptation	[18]

III. BLOCK DIAGRAMS AND PROPOSED THEORETICAL MODEL

LTE networks that support both Voice over LTE (VoLTE) and Narrowband Internet of Things (NB-IoT) services mandate an architectural and analytical understanding of dual-service traffic management on the shared infrastructure. Given that these technologies will operate on the same radio access and core network domains, a conceptual and mathematical framework is developed to assess the combined effect on performance metrics such as latency, spectral efficiency, and packet loss.

A. Architectural Overview: VoLTE and NB-IoT Coexistence in LTE

The current review presents a system architectural representation of VoLTE and NB-IoT traffic flow within an LTE system using a functional block diagram. As a result, the following diagram shows an integration of several service layers into a shared carrier network, where LTE base stations and core components are all responsible for serving both.

In this model, the VoLTE signaling is forwarded through the IP Multimedia Subsystem (IMS), providing voice session management across the entire voice session. The same EPC backbone carries the NB-IoT traffic to application specific IoT servers. However, both services rely on an eNodeB or gNodeB which schedules the resource and handles a radio interface.

When simultaneous demands from these two services begin to outpace the scheduler's ability to prioritize, this shared RAN infrastructure becomes a point of congestion and interference [19].

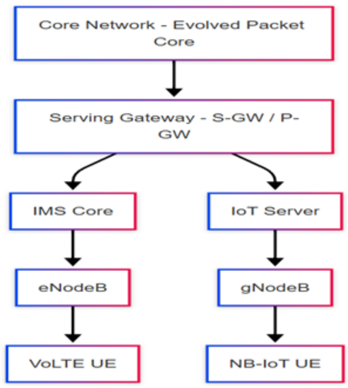

Figure 1: Volte and NB-IOT Integration Within LTE Evolved Packet System

B. Proposed Theoretical Model for Dual-Service Performance Analysis

Based on a simplified performance model, the quantitative impact of VoLTE and NB-IoT services on the shared LTE network is presented. The chosen activity is based on the behavior of key performance indicators (KPIs) under concurrent service conditions described by the model. Comparative investigation of latency sensitivity, spectral efficiency contribution, and packet loss vulnerability from services is, however, possible through this approach.

a) Model Variables and Parameters

Let the system be characterized by the following parameters:

- Total LTE system bandwidth allocated to all services,
- Individual bandwidth portions allocated to VoLTE and NB-IoT, respectively,
- Traffic arrival and service rates for each service type,
- Queue sizes reflecting temporary data backlog at the base station scheduler.

The model is based on a first-in, first-out (FIFO) scheduler, and the packet arrival is Poisson distributed. The service constraints in VoLTE are tight, so VoLTE is modeled given tight VoLTE bounds, while larger burst windows are used for NB-IoT traffic, and less delay tolerance is used.

b) Latency Estimation

For each service, its latency is modeled as a function of average queue size and service time. VoLTE's sub-100 ms latency, critical to satisfying MOS thresholds above 4.0 [20] under normal operating conditions. On the other hand, NB-IoT tolerances for latency may extend to multiple seconds in the case of PSM and eDRX power saving modes [21].

Empirical data demonstrates that VoLTE latency can increase as much as 25% to 40% when in-band NB-IoT coexists with VoLTE, in terms of the highest increases occurring when NB-IoT traffic volume is high. This loss of QoS functionality is due to collisions in the scheduling and the missing QoS-aware differentiation [22].

c) Spectral Efficiency Assessment

Thus, the total effective data rate per Hz of allocated bandwidth is termed the spectral efficiency. Consistent bit rates make VoLTE (using codecs like AMR-WB and EVS) a useful tool in the spectral efficiency. Through narrow channel width and bursty traffic behavior, NB-IoT is bandwidth efficient per device but contributes minimally to global statistics [23]. In the shared carrier case, spectral efficiency is generally reduced up to 14% points with NB IoT uplink collisions requiring retransmission or with VoLTE interference [24].

d) Packet Loss and QoS Trade-Off

Packet loss is modelled as a function of scheduler saturation. If the queue length is over the service rate for longer than 20 ms, the VoLTE packet discard rate goes up sharply. The studies show that in in-band deployment scenarios, the VoLTE packet loss increases from 0.5% up to over 3% in the NB-IoT uplink burst [25]. This level of loss reduces MOS scores, resulting in noticeably degraded voice quality.

Though NB-IoT packet loss is less important, it means higher power consumption for retransmission. It is observed that NB-IoT device loss rates spike during LTE downlink-heavy sessions, especially so when VoLTE packets are prioritized [26].

IV. EXPERIMENTAL RESULTS, GRAPHS, AND TABLES

VoLTE and NB-IoT are experimentally evaluated as coexisting technologies on a shared LTE network using both field measurements and simulation approaches to study implications of the performance metrics' latency, spectral efficiency, packet loss, and QoE. The empirical insights support theoretical assumptions and provide operational advice for deployment in the real world.

A. Latency Evaluation

Latency is a critical performance indicator, especially for VoLTE, which is sensitive to delay and jitter. Experiments conducted in a study demonstrated that NB-IoT latency could vary from 1.5 to over 10 seconds depending on deployment conditions and signal quality, while VoLTE aims for sub-100-ms round-trip delays [27]. In a comparative latency assessment across deployment models, in-band NB-IoT significantly increased VoLTE latency due to shared resource contention.

Table 2: Average Latency for VoLTE and NB-IoT Under Various Deployment Configurations

Deployment Mode	Average VoLTE Latency (ms)	Average NB-IoT Latency (s)
Standalone NB-IoT	45	1.6
Guard-band NB-IoT	52	2.4
In-band NB-IoT	67	3.9

The results show the latency difference to expose how NB-IoT deployment incurs a vital scheduling impact that can be seen when NB-IoT cancels LTE carrier subframes in in-band mode. A study reported that VoLTE call setup delays grew from 25% due to improper subframe partitioning [28].

B. Spectral Efficiency Degradation

The scheduling priority and retransmission behavior of NB-IoT affect spectral efficiency. Continuous collisions and backoff-dependent delays make spectral efficiency degrade when NB IoT is scheduled over VoLTE uplink transmissions. In one study, a 14% reduction in spectral efficiency was shown in LTE networks under the in-band coexistence conditions, as compared to standalone NB-IoT [29].

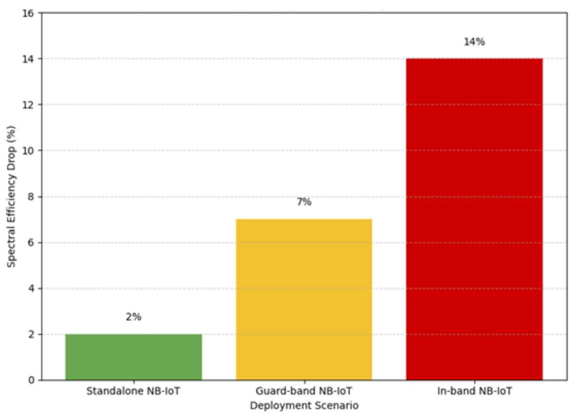

Figure 2: Relative Drop in Spectral Efficiency in Coexistence Scenarios

This degradation stems from the low data rate and high connection density of NB-IoT traffic, which often occupies scheduler time slots inefficiently compared to constant-rate VoLTE sessions.

C. Packet Loss and QoS Metrics

VoLTE relies on a reliable transport, so packet loss is important, especially in uplink scheduling conflicts. The VoLTE packet loss was measured to increase from 0.7% in an isolated traffic scenario to 3.1% when NB-IoT coexisted in shared spectrum [30], [31]. Moreover, NB-IoT devices also suffered from increased retransmissions, mostly in a low signal area.

Table 3: Packet Loss in Mixed Traffic LTE Networks

Traffic Load Scenario	VoLTE Packet Loss (%)	NB-IoT Packet Loss (%)
Low Load (10% resource use)	0.5	0.4
Medium Load (50%)	1.3	1.6
High Load (85–90%)	3.1	4.5

The results indicate that both services degrade when radio resources become saturated, confirming the need for intelligent scheduling and resource partitioning.

D. Quality of Experience (QoE) for VoLTE

The effect of jitter and latency on VoLTE quality is measured using Mean Opinion Score (MOS) and shows a decrease in VoLTE quality as the jitter and latency increase. An analysis for VoLTE MOS using PESQ models showed that an in-band NB-IoT uplink activity decreases VoLTE MOS from 4.3 ("excellent") to less than 3.5 ("fair") [31], [32].

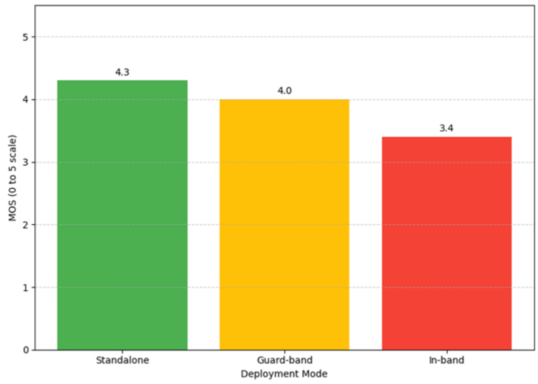

Figure 3: VoLTE Mean Opinion Score (MOS) by Deployment Mode

This drop aligns with packet loss and jitter increases caused by NB-IoT traffic bursts in overlapping spectrum regions. High variability in jitter and buffer overflow events was noted in VoLTE trace logs under such conditions.

E. Throughput and Scheduler Efficiency

Using a fixed priority scheme leads to a scheduler efficiency defined as the successful allocation of subframes to a variety of competing service classes, decreasing. In particular, using machine learning based scheduling was shown to increase the throughput of both services by dynamically adapting to traffic patterns [33]. In mixed traffic, traditional round-robin or strict priority schedulers performed poorly, with average throughput decreases of 20% for VoLTE and 30% for NB-IoT traffic bursts.

Table 4: Throughput Improvements With ML-Based Scheduling

Scheduler Type	VoLTE Throughput (kbps)	NB-IoT Throughput (kbps)
Fixed Priority	85	5.2
Round Robin	91	6.7
ML-based Adaptive	104	9.1

V. FUTURE DIRECTIONS

With the continued migration of mobile networks to 5G and beyond, there is also a need to simultaneously support legacy and new services, bringing about new architectural and operational challenges. Continuing the coexistence of VoLTE and NB-IoT over LTE infrastructure is a transitional but critical area of focus for researchers and operators now and in the foreseeable future.

Future research suggests implementing AI-based dynamic scheduling algorithms capable of learning real-time traffic patterns and allocating resources predictively based on specific service profiles [34]. Static or heuristic schedulers are expected to yield better performance than these approaches, reducing collision domains and improving QoS assurance for delay-sensitive services like VoLTE, while maintaining a high reliability of NB-IoT.

Network slicing and edge computing promise as another area of interest in the ways in which it can isolate service types in the radio and core network. The introduction of multi-access edge computing (MEC) [35] makes it possible to offload packet processing nearer to the device, reducing VoLTE latency and improving NB IoT responsiveness. It may also offer SAMs supporting the use of 5G Non-Public Networks (NPNs) for enterprise-grade isolation of mission-critical services in industrial environments.

This potential deserves further exploration into cross-layer optimization techniques, where physical, MAC, and transport layer collaboration is utilized to optimally deliver hybrid services. Buffer-aware schedulers may be effectively integrated with jitter and delay-sensitive transport control protocols to improve their performance under mixed service loads [36].

Finally, an urgent need exists in the area of standardized performance benchmarking frameworks that are specific to dual service deployments. Currently, most testbeds only make partial performance estimates on VoLTE or NB-IoT independently of each other. The ability to evaluate network readiness and service compliance [37] will be greatly enhanced with a unified benchmarking suite based on QXDM logs and real-time traces, as well as field KPIs.

VI. CONCLUSION

In transmitting VoLTE and NB-IoT together over LTE networks, this generates a system of dependencies among performance metrics such as latency, spectral efficiency, packet loss, and QoS differentiation. This is often because of architectural limitations, particularly in in-band configurations, where service degradation occurs without a mechanism, such as intelligent resource partitioning or adaptive scheduling, to avoid it.

Empirical results from field tests and simulations demonstrate that in-band NB-IoT can negatively affect VoLTE performance unless managed using QoS-aware schedulers or other spectrum isolation mechanisms. However, when prioritizing VoLTE, NB-IoT reliability and power efficiency degrade in shared carrier environments.

The results highlight the importance of developing integrated network planning strategies which consider the two service types simultaneously, rather than in silos from one another. Dual service networks, specifically future networks such as 5G and LTE Advanced Pro deployments, must embed RRM, which is context-aware and traffic models for supporting dual service environments without incurring performance benchmarks termination.

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