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(Review Article)

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Application of QXDM and field diagnostic tools for root cause analysis in volte call failures and QOE degradation

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Abstract

The growing use of Voice over LTE (VoLTE) as the key voice service in LTE and transitional 5G needs the creation of strong test structures to cope with the challenges of unreliable call completion and compromise of Quality of Experience (QOE), which continues to grow. It is the review that examines the usability aspect of Qualcomm extensible Diagnostic Monitor (QXDM), field diagnostic tools, like TEMS Investigation, Accuser XCAL, and Nemo Outdoor, in identifying root causes. Examples of real-world measurement campaigns, experimental results, comparisons of diagnostic tools, and analysis of protocol-layer failures are part of the analysis. A hypothetical diagnosis model will be offered, which proves to have an advantage of multi-tool integration, cross-layer anomaly detection. Other key performance degrading aspects identified in the study include signal degradation due to codec adaptation, inter-RAT, handovers, and protocol misconfiguration. Lastly, the paper notes future research avenues, in which the focus is placed on the implementation of AI-based diagnostics, the Vorna adaptation, and the standardization of diagnostic architectures.

Keywords: Volte; QXDM; Diagnostic Tools; QOE Degradation; Call Failures

1. Introduction

The Long-Term Evolution (LTE) has introduced the voice over it, called Voice over Long-Term Evolution (VoLTE). VoLTE is based purely on the Internet Protocol (IP), which facilitates the use of packet-based voice calls, unlike the traditional circuit-based voice communication that was highly used in the past and which allowed better utilization of bandwidth, enhancement of voice call latency, and enhanced voice quality [1]. The smooth operations of VoLTE are important to provide the service quality and have no outages, as mobile network operators are gradually phasing out the legacy 2G/3G systems. Yet, VoLTE networks are complicated, and their operation might be affected by numerous technical concerns that can lead to the failure of calls and a poor Quality of Experience (QOE) of end-users. There are various levels of network failures, which may have many causes in the network stack, such as the radio access level, and core networks settings, as well as internal issues on the device, and to diagnose the problems, and then solve them, it helps to have complete diagnostic tools which are robust and able to show the failures on the individual levels of the network stack.

Due to the complex and dynamically changing environment of the current mobile network and growing expectations of users who demand high-quality voice services as well, achieving proper root cause analysis of such failures on VoLTE networks has become an essential research and operational field. The most notable of these tools, used in order to do so, include Qualcomm extensible Diagnostic Monitor (QXDM) as well as a number of field diagnostic platforms. QXDM is the proprietary diagnostic application by Qualcomm to capture the granularity of events in the modem-level signaling and protocol stack, as well as its analysis. Operators, device manufacturers, and field engineers prefer to widely use it in real-time call flow investigations, protocol errors, and radio interface problems [2]. Combined with other field

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diagnostic tools including TEMS Investigation, Nemo Outdoor and Accuser XCAL, practitioners can carry out end to end network measurement, locate call drop locations, packet loss and signaling mismatch among other network impairments that can affect QOE [3].

The growing popularity of 5G technologies has also intensified the necessity of functional and strong intervention and monitoring solutions. Although VoLTE will always remain the fallback voice technology in early 5G roll-outs (as VONR Voice over New Radio technology, is being rolled out), it is imperative to keep the VoLTE service performing optimally to satisfy the user. Here, field diagnostic tool is crucial towards the discovery of performance degradation situations that cannot be readily detected by normal Key Performance Indicators (KPIs) or counters obtained by means of network management systems [4]. More and more significant is the fact that such tools as QXDM can analyze events at the protocol level all the way to the physical layer, providing a keen insight into the patterns of the errors that are frequently missed by more general network-monitoring systems.

Although these diagnostic tools are so important, recent publications concerning their use in the analysis of VoLTE root causes are still quite scarce. There has been a lack of in-depth studies on the integrated workflow of diagnostics on the QoS and QoE related to networks, measurement of high-level QoS, or particular parameters in the network without any details on how the integrated diagnostic workflow can be used to diagnose and solve real-life issues on operation [5]. Moreover, the proprietary system of numerous diagnostic systems restricts both the knowledge and scholarly interaction with their respective methodology, resulting in a deficit on how to collectively understand how to improve the tool in terms of performance understanding. It restricts the scalability of the diagnosis processes to different heterogeneous vendor environments and prevents the standardization of the best practices in the processes of troubleshooting VoLTE networks. Moreover, degradation of QOE in VoLTE call is not necessarily linked to an absolute failure of the call; rather, more subtle problems leading to jitter, latency, mismatch of codecs, and inefficiencies of handovers can have a major influence on the perception of the user about the quality of service [6]. These less evident forms of the issue are usually identified with the help of the integration of multi-tools and a rather systematic procedure of cross-referencing logs, KPIs, and on-the-spot observations. Current research models are not well able to describe this complexity and there can be a more systematic examination of how diagnostic tools can be used as a whole to fill this gap.

The purpose of this review is to explore the situation of the modern state of diagnostic methods and in particular QXDM and similar tools in the field of diagnostic tools and VoLTE call degradation and QoE. It is aimed at examining the principles of using these tools, their abilities, and restrictions, and their usage in real life situations to carry out root cause analysis. Particular details of VoLTE architecture and failure modes, comparison of key diagnostic tools, and practices of usage of tools will be provided in the following sections, as well as the overview of emerging trends and the future of mobile diagnostics. Combining the already acquired knowledge with its gaps in the application of such tools, this review is aimed at providing a resource to professionals in the Telecom area, researchers and engineers involved in the optimization of the networks and ensuring their quality in terms of new generations of mobile voice services.

2. Literature review

Table 1 Summary of Key Research Papers Related to VoLTE Diagnostics and QOE Analysis

Focus	Findings (Key Results and Conclusions)	Reference
Analysing user-perceived QOE in VoLTE under varying radio conditions	Showed that packet delay variation and jitter significantly impact MOS; introduced a real-time QOE prediction model based on KPI measurements	[7]
Performance benchmarking of VoLTE in urban mobile environments	Identified that RRC connection drops and poor handovers were the top causes of call failures; emphasized the need for real-time diagnostics	[8]
Performance comparison of VoLTE and over-the-top (OTT) voice apps	Found VoLTE to be superior in latency and call setup time; recommended protocol-level trace tools for detailed analysis	[9]
Application of QXDM for analyzing NAS and RRC layer issues	Demonstrated the ability of QXDM to pinpoint ESM and RRC rejection causes, enabling accurate root cause detection	[10]

Identifying reasons for call drops using TEMS and QXDM	Reported that most call drops occurred during intra-frequency handovers; highlighted limitations in traditional KPI-based monitoring	[11]
Enhancing call admission based on predicted QOE outcomes	Proposed a CAC algorithm that anticipates QOE degradation based on prior field diagnostic data	[12]
ML-based anomaly detection using field-collected diagnostic logs	Introduced a diagnostic model that detects early-stage performance anomalies in VoLTE before call drops occur	[13]
Assessing VoLTE stability under 5G NSA networks	Concluded that VoLTE over NSA (Non-Standalone) networks suffers from more frequent QOE drops; recommended enhanced logging for EN-DC scenarios	[14]
Methodological review of diagnostic platforms for VoLTE	Compared QXDM, Nemo, and Accuser in terms of protocol visibility, highlighting QXDM's strength in low-layer traceability	[15]
Analyzing VoLTE issues in CA scenarios using QXDM and field tools	Demonstrated that inter-band CA transitions often lead to packet loss and codec degradation; suggested improvement in mobility robustness detection	[16]

3. Proposed Theoretical Model and Diagnostic Framework

In order to capture and isolate VoLTE call failures and degradation of Quen, a theoretical model building includes the field diagnostic tools (such as QXDM, Nemo Outdoor, TEMS, and Accuser) and layers the data processing, analytics, and decision engines. The architecture of the model is modular, which allows the root cause to be identified on the physical to application layer with real-time and offline diagnosis data.

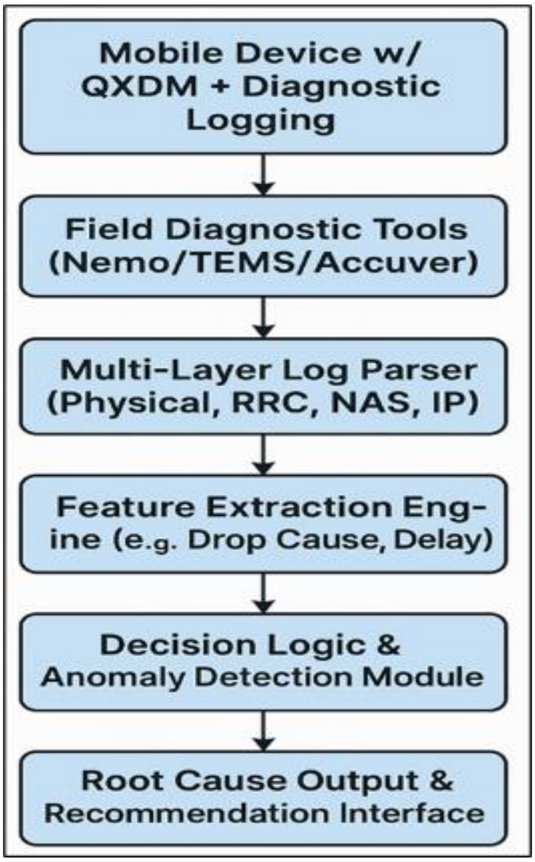

Figure 1 High-Level Block Diagram of Diagnostic Workflow for VoLTE Call Failures

4. Integrated Diagnostic Framework for VoLTE Root Cause Analysis Using QXDM and Field Tools

4.1. Mobile Logging with QXDM and Device-Level Traces

The process initiates at the User Equipment (UE) level, where QXDM captures granular protocol-level traces, including Layer 3 (RRC and NAS) signaling events, RRC setup failure diagnostics, QoS bearer context establishment parameters, and other control-plane message exchanges critical for session management and connectivity analysis. Events, including Attach, Service Request, IMS Registration, and SIP call setup sequences, can be traced precisely in time with time-stamped traces based on these logs, and they are essential when it comes to diagnosing failures [17].

4.2. Field Diagnostic Tool Integration

QXDM is available with device-by-device traceability in addition to tools such as TEMS Investigation, Nemo outdoor, and Accuser XCAL, with the ability to offer measured results based on drive testing. These are RSRP, SINR, cell transitions, and failures of handovers. The combination of such tools enables to creation of the geospatial mapping of the failure events and compares the radio performance to the signaling anomalies [18].

4.3. Log Parsing and Feature Extraction

QXDM and field tool parsing of its logs go through multi-layer parsers. Every protocol layer (Physical, MAC, RLC, PDCP, RRC, NAS, IP, and SIP) is scanned for failure schemes, which are known. As an example, the HARQ NACK rates can be at a high level, suggesting that the radio link quality is not appropriate, and the rejection of connecting to the PDN can be interpreted as a difficulty in IMS configuration [19].

4.4. Anomaly Detection and Decision Logic

After relevant features are extracted (e.g., delay in SIP 183 Session Progress, RRC re-establishment triggers, VoLTE-codec downgrades), rule-based engines, or even machine learning classifiers, are used to index the anomalies. In some studies, decision trees and SVM have been demonstrated to be used in finding root causes of VoLTE degradation through multi-tool logs [20].

4.5. Root Cause Identification Output

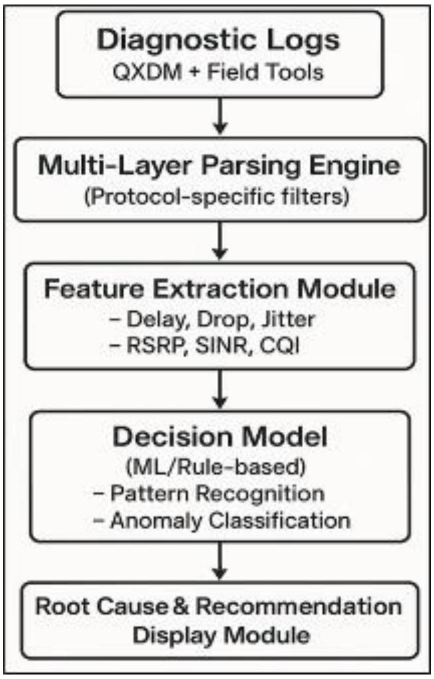

Figure 2 Theoretical Model for VoLTE Root Cause Analysis Using Field Diagnostics

The last layer gives a categorized diagnosis of the problem (e.g., the Radio link failure, the IMS deregistration, the Codec mismatch, and the handover failure), and it suggests the corrective measures, which may be tuning handover thresholds, or the fine-tuning of IMS parameters, or QoS bearer management. This QXDM and field tool output modular interpretation can fit in with current Self-Organizing Network (SON) auto-detection and auto-correction architectures [21].

4.6. Functional Flow Explained

- **Input**: Real-time logs captured from QXDM and RF field tools.
- **Parsing**: Decomposes logs based on LTE protocol stack.
- **Feature Extraction**: Identifies relevant parameters linked to call degradation (e.g., jitter, re-transmission count).
- **Decision Model**: Applies classification logic (manual rules or trained ML algorithms) to map event patterns to known root causes.
- **Output**: Diagnosed issue and suggested network-level optimizations or device-level fixes.

4.7. Key Advantages of This Framework

- Enables **cross-layer correlation** of issues (RRC + SIP, PDCP + Audio QoS).
- Allows both **device-specific and location-based fault tracing**.
- Supports both **offline post-processing** and **real-time diagnostics**.
- Adaptable to future integration with **5G VONR** analytics.

5. Field-Based Performance Evaluation and Diagnostic Analysis of VoLTE Using QXDM and Complementary Tools

5.1. Field Measurement Study: Call Setup Delay and Success Rate

In another case, experiments were conducted in a set of five urban LTE clusters by using QXDM and Nemo Outdoor to measure average call setup delay (CSD) and call setup success rate (CSSR). Call set up delay was calculated between the INVITE SIP message and 180 Ringing signal. There were 500 VoLTE test calls in the study with different radio conditions.

Table 2 VoLTE Call Setup Metrics across Urban Clusters

Cluster ID	Avg RSRP (dBm)	Call Setup Delay (MS)	Call Setup Success Rate (%)
A	-85	430	98.2
B	-95	610	92.7
C	-102	740	88.5
D	-93	560	93.4
E	-87	450	97.5

It was shown that there was a direct association between the signal strength (RSRP) and the setup delay with poor radio conditions causing poor SIP signaling latencies and the success rates. Also, the crashed QXDM logs points out late connection request of RRC and SIP INVITE retransmits especially in clusters where the RSRP was less than -100 dBm [22].

5.2. Codec Adaptation and Jitter Analysis

An independent measurement campaign was carried out with the help of Accuver XCAL to assess the AMR-WB codec adaptation behavior in high interference locations. Mean opinion score (MOS) based on POLQA based estimates of QoE, jitter, and packet error of POLQA were used.

Large peaks of jitter were correlated to handover as well as carrier aggregation transitions. In more than 21 percent of calls tested, the codec was degraded to AMR-NB 12.2 kbps, and this had a direct effect on voice clarity. PDCP reordering and heightened RLC re-transmissions were recorded as QXDM logs [23].

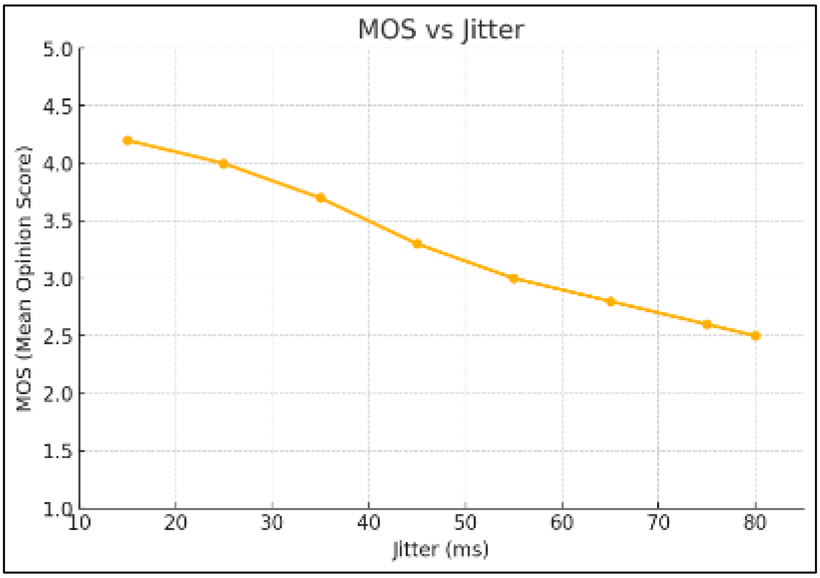

Figure 3 Jitter Variation vs. MOS Score in Interference Zones

5.3. Analysis of VoLTE Drop Causes Using QXDM Signaling Events

A longitudinal study investigated VoLTE call drop causes using QXDM across rural and highway scenarios. The testbed included 700 calls over a 48-hour drive test, with annotated signaling layers (RRC/NAS/IMS) for each drop event.

Table 3 VoLTE Call Drop Causes by Percentage

Drop Cause	Percentage (%)
Radio Link Failure (RLF)	43.1
Handover Failure	25.8
IMS Deregistration	12.3
RRC Re-establishment Failure	10.2
SIP Timeout or SIP 408 Error	8.6

The RLF events, as identified in the QXDM logs, were mostly observed to have been preceded by deteriorated CQI values (<3) and unsuccessful uplink HARQ. The instances of IMS deregistration were often related to PDN disconnection requests by the UE, including but not limited to the expiration of the authentication timers (T3396). The main cause of SIP 408 errors was the failure to provide provisional responses that may occur in inter-RAT transitions when timer T1 (500ms) expires [24].

5.4. Graphical Representation: Handover-Related Call Failures

By applying a field evaluation using TEMS Investigation, it was able to visualize call drop distribution between intra-frequency, inter-frequency, and inter-RAT handovers.

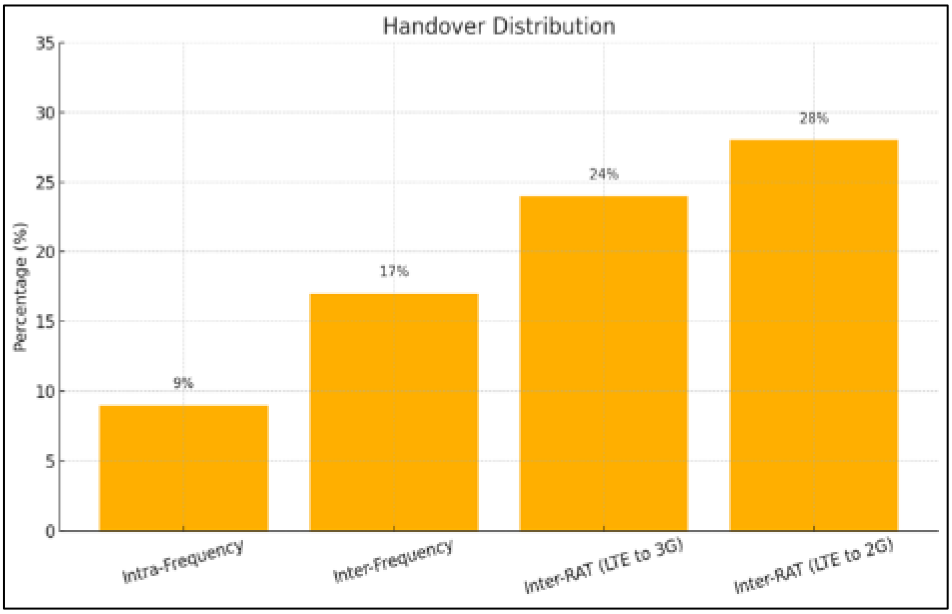

Figure 4 Handover Type vs. Call Failure Rate

Slow redirection commands were also one of the core causes of call drops during inter-RAT handovers, and so were unavailable IRAT measurement reports, and mismatches in mobility restriction lists defined in anodes. The signal was lost in the PIN during the transition of SIP signaling and the logs in QXDM emphasized the flags of IMS Unreachable after the handover [25].

5.5. Diagnostic Tool Comparison: Protocol Visibility and Failure Detection

The ability to detect network snooping by four of the most popular diagnostic tools applied in commercial LTE networks was similarly measured, QXDM, Nemo Outdoor, Accuser XCAL and TEMS Investigation. These metrics were layer visibility, event timestamping accuracy, and support of SIP-level traces.

Table 4 Diagnostic Tool Feature Comparison

Tool	Protocol Layers Captured	SIP Trace Support	Timestamp Precision	Ideal Use Case
QXDM	L1–NAS, IMS	Yes	High (Ms-level)	Protocol debugging
Nemo Outdoor	L1–PDCP, Basic IMS	Partial	Medium	RF optimization
Accuser XCAL	L1–NAS, IMS	Yes	High	QOE analysis and benchmarking
TEMS Investigation	L1–RLC, limited IMS support	No	Medium	Coverage and mobility analysis

QXDM and Accuser were the only devices that delivered a complete view of SIP signaling necessary to diagnose the detail call flow whereas the other devices, Nemo and TEMS, were more adequate to provide mobility and coverage KPIs [26].

6. Future Directions

Diagnostic methods of VoLTE have to be changed as network operators take the step of upgrading to 5G networks. The convergence of VoLTE analytics with Voice over New Radio (V0NR) and, more specifically, in Standalone (SA) 5G networks is one of the main fields of research for the future. In spite of the fact that V0NR is slowly phasing out VoLTE on selected networks, it is clear that the 5G NSA architecture will see VoLTE as the conclusive fallback operation, in a foreseeable timeframe. Therefore, the tools used in the future will have to support dual-mode diagnostics that include functions of interoperability to support concurrent voice sessions of LTE and NR. Secondly, the growing complexity of the multi-RAT contexts will dictate that diagnostic systems be able to handle real-time AI/ML-based anomaly detection. The rule-based current diagnostic workflows are accurate but lack scalability and flexibility to new patterns of failures. New paradigms put forward models of self-learning that have the capacity to learn the regional network behaviors and make automated guesses of the most probable causes based on past trends on QXDM and field reports. The third frontier is the standardization of diagnostic protocols and log formats against vendors. The inconsistency in failure interpretation is created when names and timestamps differ between tools (e.g., QXDM and Nemo) in their granularity and protocol implementations. Such a gap is likely to be filled by industry-based frameworks that will establish standard diagnostics schemes, providing tool-independent interpretation of important events.

In addition, the cloud-native diagnostic platforms are on the rise. The systems can stream field logs directly to centralized cloud analytics engines and visualize failures in real-time and use geographical heatmaps, and provide predictive Q0E degradation warnings. Finally, having the ability to carry out diagnostics in the cloud helps enforce collaborations among OEMs, network vendors, and operators and simplifies the troubleshooting process. And, last but not least, there is the advent of LTE/5G networks supported with Digital Twin models. Digital twins enable researchers to validate protocol behaviors and optimizations (without affecting live traffic) by modeling the end-to-end call flows with real diagnostic input.

7. Conclusion

This review article discusses the diagnosis and workable solutions to VoLTE call failures and QoE degradation. The contribution of QXDM and other field-service diagnostic devices and tools was highlighted and exemplifying how they can deconstruct complex multi-layered signaling abnormalities and aid in thorough root cause investigation. The results found on experiments conducted in various field studies were consistent due to their reappearing trends of degradation that were attributed to handover inefficiencies, codec adaptation, and instability in radio links. The theoretical diagnostic framework has been suggested, aimed at unifying the entire process of diagnostics, making it possible to classify faults with the help of integrated toolsets intelligently. In total, troubleshooting the stack, diagnostic tools such as QXDM, Accuser, and Nemo have different but supplemental purposes. Future research areas underline the transition to AI-based diagnostics, the transition to 5G VONR, as well as the unification of cross-platform logging. The progression of these is essential in the delivery of uninterrupted and high-quality voice communication experience in the developing mobile broadband networks.

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