Performance Analysis of 5G Voice Solutions via EPS Fallback and VoNR

Matheus Fontinele De Aguiar, Jordan Kalliure S. Carvalho, Vivianne De A. Rodrigues,
Abdel Fadyl Chabi, Joao Vitor Da S. Campos, Luan R. Lopes, Janislley Oliveira De Sousa
Sidia Institute of Science and Technology
Manaus, Brazil
Email: {matheus.fontinele, jordan.carvalho, vivianne.aquino,
abdel.chabi, joao.vitor, luan.lopes, janislley.sousa}@sidia.com

***Abstract*—The rapid global adoption of 5G technology necessitates the optimization of network parameters and voice quality to ensure an unparalleled user experience. To address this, we present a comprehensive evaluation of New Radio (NR) voice solutions in the context of 5G-enabled mobile devices. In our study, we meticulously examined the call reception performance of three mobile devices, each equipped with modem chipsets from different manufacturers, within a controlled laboratory environment. Our data show that Device A and Device B, both compliant with 3GPP Release 15, display similar performance metrics despite using different modem chipsets. In contrast, device C, aligned with 3GPP Release 16, achieved a remarkable reduction in average Call Setup Time (CST) by 78.31% for Voice over New Radio (VoNR) and 95.72% for Evolved Packet System Fallback (EPS Fallback), relative to the combined CST of devices A and B. Our findings confirm that VoNR outperforms EPS Fallback in facilitating faster call setup times. This study addresses the pivotal matter of voice services over 5G during the deployment of 5G networks. It underscores the potential of emerging technologies to markedly improve user experience and reinforces the telecommunications industry's dedication to 5G service optimization.**

Keywords* — *VoNR; 5G; EPS Fallback; VoLTE; Voice Call; IMS

I. Introduction

The advent of 5G networks, facilitated by the New Radio (NR) interface, promises low latency and high throughput. As standardized by the 3rd Generation Partnership Project (3GPP), 5G networks are deployed in two distinct architectures: Non-Standalone (NSA) and Standalone (SA) [1]. In the NSA configuration, the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) works in tandem with NR, enabling E-UTRAN-NR Dual Connectivity (EN-DC) [1]. This architecture relies on a 4G network to function as the master node, responsible for signaling and control mechanisms, while the 5G network acts as a secondary node dedicated solely to data transmission [2]. To access other services the 4G architecture is required, such as the voice calls through Voice Over LTE (VoLTE) [3]. Conversely, the SA architecture involves the core of the 5G network without legacy (LTE) network presence [1].

While 5G networks do not support traditional circuit-switched services, they achieve enhanced quality of voice service and real-time functionality through Voice Over New Radio (VoNR) [4], [5]. Initially, the SA architecture employed Evolved Packet System Fallback (EPS Fallback) as an interim feature to redirect voice services to the LTE network [5]. Both NSA and SA 5G architectures facilitate access to IP Multimedia Subsystem (IMS) services [6]. This is achieved by routing data packets via Session Initiation Protocol (SIP) messages, which are used to initiate, modify, and terminate sessions for services like VoLTE and VoNR.

The commercial deployment of VoNR faces a variety of obstacles, such as interoperability, latency, and Quality of Service (QoS) issues, as highlighted in existing literature [7], [8]. Subsequent studies have specifically addressed challenges in cell boundary regions, which are notorious for their unstable signal coverage and elevated power consumption during voice calls. A recent investigation into VoNR and VoLTE considered both NSA and SA architectures, evaluating three key QoS metrics: latency, jitter, and throughput [9]. This study demonstrated superior audio call quality under VoNR, corroborating its advantages over VoLTE. Furthermore, an in-depth analysis of battery consumption in 5G SA voice calls revealed notable energy savings of up to 38.88% when compared to 4G services [10]. In terms of call quality, 5G SA calls outperformed their 4G counterparts with a significant average jitter reduction of up to 16.5 ms. Another study conducted a thorough analysis of audio calls over IMS across SA, NSA, and VoLTE architectures [11]. This research aimed to quantify the time required for audio call reception and reconnection to the home network. Notably, it was found that calls established over 5G SA networks experienced delays due to the Fallback process to the LTE network, an issue not present in NSA configurations that maintain 4G connectivity.

As demonstrated in prior research [12], conducting experiments within controlled laboratory settings can yield critical insights for validating radio voice solutions, specifically for VoLTE. Such empirical analyses contribute not only to the optimization of audio quality in VoLTE calls but also offer avenues for improvements in VoNR calls. Diverging from existing studies, the present research distinguishes itself through the deployment of rigorous, practical experiments within a controlled laboratory environment. These experiments are specifically tailored to optimize voice services performance across various mobile devices, leveraging simulated 5G network equipment for this purpose. Utilizing this methodological framework, we thoroughly assess the evolution and efficacy of voice call technologies across devices compliant with 3GPP releases 15 [1] and 16 [4]. This research aims to evaluate the Call Setup Time under two specific scenarios: EPS Fallback and VoNR. The evaluation is conducted across three mobile devices equipped with different modem chipsets

979-8-3503-2687-1/23/$31.00 ©2023 IEEE

and compliant with varying 3GPP releases.

The paper is structured as follows: Section II provides background information on 5G networks, defining key concepts regarding 5G architecture and explaining how IMS operates for both 4G and 5G networks using the SIP protocol. In Section III, the configurations for the established scenarios in both 5G architectures for voice calls are detailed. Section IV discusses the simulation outcomes and their comparative analysis. Finally, Section V presents the paper's conclusion.

II. Background

A. 5G Network

The 5G Network works in an isolated way using the architecture known as StandAlone. The 5G SA technology embraces an all-encompassing 5G Core (5GC) architecture. As illustrated in Fig. 1, within this setup, the gNodeB (gNB) undertakes the role of the base station, establishing a direct connection with the 5GC. Notably, this communication link operates independently without any reliance on 4G assistance to mediate interactions between the gNB and User Equipment (UE). This configuration empowers the gNB to seamlessly communicate with UEs within the 5G network, offering a self-sufficient and robust framework for data transmission and network management. Moreover, the 5GC introduces advanced concepts encompassing cloud-native principles, virtualization, containerization, container orchestration, and microservices. This framework enables the adoption of an Architecture Based on Services (SBA), accommodating a spectrum ranging from streamlined networks tailored for specific services and users to intricate networks demanding high performance. This adaptability enhances network flexibility and scalability [13].

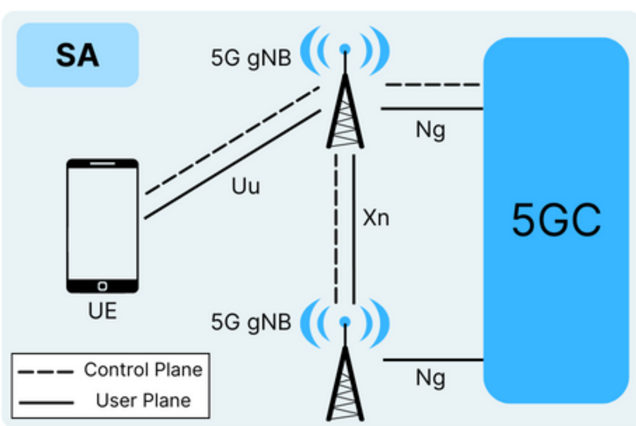

Fig. 1. SA architecture on 5G Network

B. 5G Releases 15 and 16 in 3GPP

The 3GPP global initiative ensures that emerging technologies are harmonized and compatible across radio access networks, services, system aspects, core networks, and terminals. In this context, Release 15 introduces the foundational standards for 5G. Beyond setting these new benchmarks, Release 15 also enhances communication and service functionalities in tandem with legacy systems. This release empowers industries relying on large-scale communications to enhance response times, exert finer control over device and network software updates, and manage revisions more effectively [14].

Moving forward, Release 16 [15], representing the second 5G standard, paves the way for novel 5G applications beyond conventional broadband services. The specifications and features of Release 16 not only augment the network's performance and efficiency but also introduce fresh capabilities in the RAN and core, reducing network latency and facilitating real-time applications across various sectors. Furthermore, this 5G standard promotes the utilization of high-frequency waves, reaching up to 43GHz, aiming to deliver enhanced bandwidth and reduced latency [16].

C. IMS Services and SIP messages

IMS is a standardized architecture that enables the delivery of various multimedia services, such as voice, video, and text messaging, over IP networks [17]. This architecture is organized into three key subsystems: the control layer, the transport layer, and the access layer. Within the control layer, components like the Home Subscriber Server (HSS) [18] and the Call Session Control Function (CSCF) manage call session activities. The transport layer includes elements like the Multimedia Resource Function (MRF), responsible for media manipulation, and gateways that enable connectivity to external networks.

Session Initiation Protocol acts as the cornerstone for signaling within the IMS, facilitating the initiation, modification, and termination of real-time multimedia sessions [19]. Functioning at the application layer, SIP utilizes a text-based protocol for easier field analysis [20]. The protocol ensures reliable communication pathways between two or more terminals through a comprehensive session initiation process. To initiate a SIP call, an *INVITE* request is sent by the caller, signaling their intent to start a session. SIP operates using methods and responses; methods signify specific requests, and responses provide feedback on the success or failure of these requests. This systematic approach ensures robust session control and effective communication.

D. 5G Voice Solutions

Ensuring high-quality voice services has consistently been a central objective for mobile operators [21]. As mobile communications have evolved across generations, a multitude of features has become available to users. Despite the expansion of services offered by telecommunications companies, maintaining excellent voice service quality remains a paramount concern for network operators. In the fourth generation, known as LTE (Long Term Evolution), the introduction of voice calls over IP (Internet Protocol) through the IMS marked a significant technological advancement. VoLTE calls ushered in a new user experience and demonstrated commendable interoperability with 2G/3G voice services.

The 3GPP Release 15 [1] outlines that 5G's voice service employs the IMS architecture. Unlike VoLTE, this new approach reduces interoperability with 2G/3G networks [11]. In NSA networks, voice calls route through LTE networks to establish VoLTE calls [22]. In SA networks, voice services are provided through two distinct features: EPS FallBack (EPSFB) and Voice over New Radio. The network architectures for both cases are shown in Fig. 2.

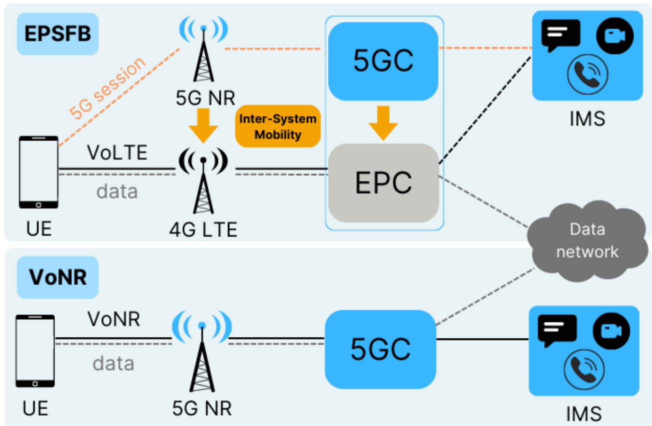

Fig. 2. EPSFB and VoNR architectures for voice call establishment

EPS FallBack serves as the initial solution for voice services in 5G networks. When this feature is employed, the 5G Core isn't responsible for voice services. In this scenario, when a UE connected to 5G needs to initiate or receive a call, redirection or handover directs the UE to the LTE network [23]. The UE establishes a VoLTE call over the LTE network. Upon call completion, the UE disconnects from LTE and reconnects to 5G. Fig. 3 illustrates the EPSFB Call Flow for voice call establishment with redirection to the 4G core.

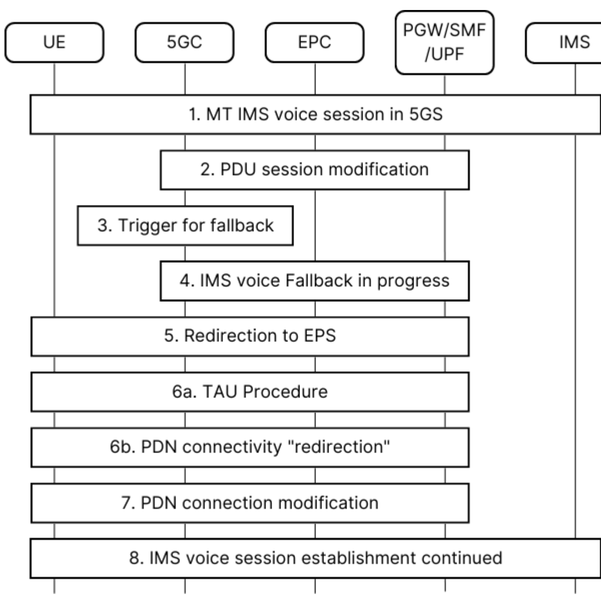

Fig. 3. MT EPSFB Call Flow

Concerning VoNR technology, its resemblance to the precursor VoLTE is evident. However, VoNR distinguishes itself by not relying on the LTE network, offering voice service via the 5G Core. While both VoLTE and VoNR adopt an IMS architecture, VoNR stands out due to its commitment to high-definition speech and video encoding, low latency, and an enriched user experience attributed to broader network coverage [24]. According to [8], VoNR notably reduces call setup time, achieving a swift 1 to 2 seconds from dialing to ringback tone. Moreover, subscribers maintain access to high-speed internet during the call session.

III. Methodology

A. Experimental Environment

The experiments were conducted in a state-of-the-art telecommunications laboratory, specifically engineered to offer a rigorously controlled setting that mitigates external network interference. Utilized for these tests was the *E7515B UXM 5G Wireless Test Platform*, a cutting-edge solution developed by *Keysight Technologies*. This versatile platform possesses the ability to simulate both LTE and 5G network environments, thereby serving as a linchpin for the activation of IMS servers and enabling the seamless registration of mobile devices within these networks. Consequently, it provides the requisite access to the corresponding service offerings.

The experimental setup can be comprehensively described as follows:

1) Hardware Setup: The *UXM 5G Wireless Test Platform* functioned as the network generator, meticulously establishing connectivity with the User Equipment's (UE) RF antennas via carefully orchestrated conducted cables. In parallel, the Test Server and Processing Computer (TSPC) were integrated through a NETGEAR ProSAFE GS108E switch. This strategic interconnection not only provided precise control over the test equipment but also ensured seamless data communication between the UXM 5G and the TSPC. A comprehensive illustration of this hardware setup is provided in Fig. 4.

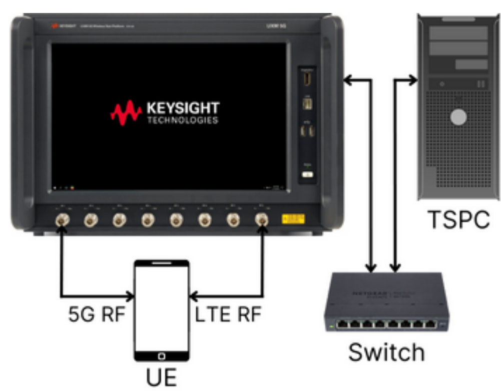

Fig. 4. Hardware Setup

2) Software Setup: The experiments leveraged the *Test Application* software, which was accessed via the TSPC. This sophisticated software suite manages the entire experimental framework, dictating simulation parameters, mediating device interactions, and initiating both voice calls and an array of additional services. Specific versions of the software employed during these experiments are detailed below:

- Test Application v22.10.70.07030
- Core Software Release 39.0.0.0
- Core Logging Tools v11.0.1
- Core Licensing & Automation Tools v10.0.1
- UXM5G Installer v2.2.16.30801

B. Experimentation Scenario

Table I displays the network parameters employed in our experiment. Consistency in LTE and NR cell setups was upheld across the VoLTE, EPSFB, and VoNR scenarios. Both LTE Band 7 with a bandwidth (BW) of 20MHz and NR Band 78 with a BW of 100MHz were utilized, while the cell power level (RSRP) was set at -67 dBm.

Table I
NETWORK PARAMETERS USED IN EXPERIMENT

	LTE Cell	**5G Cell**
Cell Band	B7	N78
Bandwidth (BW)	20 MHz	100 MHz
Duplex Mode	FDD	TDD
SCS	N/A	30 kHz
DL Freq	2655 MHz	3350.01 MHz
Channel (ARFCN)	3100	623334
RSRP	-67 dBm	-67 dBm

To meet the operational requirements of a 5G network environment, it is crucial that our experiments comply with the baseline standards delineated in 3GPP Release 15 for 5G networks. Our study involved three distinct mobile devices, each outfitted with a specialized chipset. Device A leverages a *Samsung Exynos 2100* chipset from 2021, device B employs a *MediaTek Dimensity 900* chipset from 2022, and device C utilizes a *Qualcomm Snapdragon 8 Gen 2* chipset from 2023. It is noteworthy that devices A and B are aligned with the guidelines set forth in Release 15, while device C is compliant with Release 16. Comprehensive specifications of the Devices under Test (DuT) are presented in Table II.

Establishing a connection to the IMS server is essential for every voice solution evaluated in this study. Fig. 5 provides a high-level schematic of the SIP signaling interactions between the calling and receiving parties.

The focus of our experiments is Call Setup Time (CST) [25], a crucial Key Performance Indicator (KPI) that significantly impacts user experience in voice services. We measured the CST by analyzing the delay between the *INVITE* and *180-Ringing* SIP messages, captured from User Equipment (UE) log files. The *INVITE* message is sent at call initiation, while *180-Ringing* indicates that the recipient's device is ringing.

The experiments were conducted across three distinct network scenarios described below:

- **Scenario 1 - VoLTE Call**: This scenario sets up a dedicated 4G network using the UXM 5G platform. We used only the LTE Cell parameters, as outlined in Table I. A connected EPC core housed the IMS server, allowing VoLTE calls to be initiated once the device connected to the LTE network.
- **Scenario 2 - EPSFB Call**: This scenario simulated both LTE and 5G Cells, as listed in Table I. An EPC core with an integrated IMS server was used, as depicted in Fig. 2. Devices first connected to the 5G network. On receiving a voice call, the EPSFB process kicked in, rerouting the device to the LTE network for a VoLTE call. Notably, the existing 5G connection was preserved, ensuring a smooth transition back to the 5G network after the call ended.

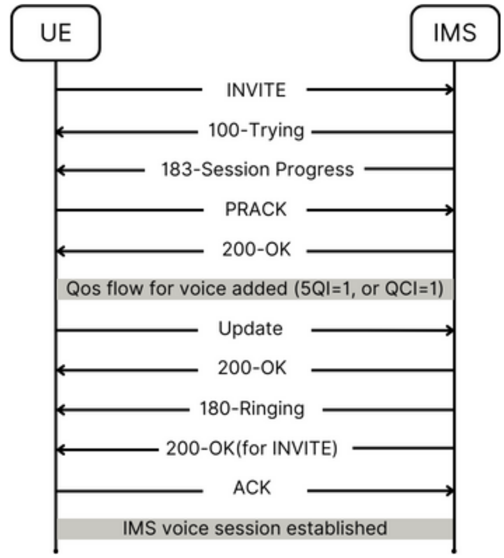

Fig. 5. IMS workflow

- **Scenario 3 - VoNR Call**: This scenario focused on building a full-fledged 5G network using UXM 5G hardware. Only the 5G Cell parameters, indicated in Table I, were implemented. Using a 5GC core with an accessible IMS server, VoNR calls were initiated as soon as the device connected to the NR network.

In all scenarios, the initiation of a Mobile Terminated (MT) voice call was orchestrated via the *Test Application*. The DuT, once connected to the equipment, responded to the call, enabling the measurement of the Call Setup Time. To ensure the experiment's precision, devices A, B, and C were connected to the equipment separately and in the same environment. For each scenario, a comprehensive set of 20 measurements was obtained. These CST measurements were consolidated and the corresponding average (AVG) are presented in Table III, accompanied by standard deviation (STDEV) values for each scenario.

IV. RESULTS AND DISCUSSION

During this research, two critical metrics have been considered: the average and standard deviation of call setup time, as shown in Table III. Fig. 6 illustrates the interrelation between VoLTE, EPSFB, and VoNR concerning the average time it takes for devices to receive the voice call, considering the delay between *INVITE* and *180-Ringing* SIP messages.

In Fig. 6, we evaluate three devices for their average call reception time. Device A demonstrates an average time of 3.395 seconds for EPSFB and 0.606 seconds for VoNR. Similarly, device B records averages of 3.199 seconds and 0.593 seconds for EPSFB and VoNR, respectively. In contrast, device C, operating under Release 16, displays markedly better performance with 0.141 seconds for EPSFB and 0.130 seconds for VoNR. These data points illustrate that devices A and B, both under Release 15, perform comparably, while device C shows a notable enhancement in performance due to its alignment with Release 16.

Table II
DEVICE TECHNICAL SPECIFICATIONS

	Device A	Device B	Device C
Chipset	Exynos 2100	Dimensity 900	Snapdragon 8 Gen 2
CPU	1x 2.9 GHz Cortex-X1 + 3x 2.8 GHz Cortex-A78 + 4x 2.2 GHz Cortex-A55	2x 2.4 GHz Cortex-A78 + 6x 2.0 GHz Cortex-A55	1x 3.2 GHz Cortex-X3 + 2x 2.8 GHz Cortex-A715 + 2x 2.8 GHz Cortex-A710 + 3x 2.0 GHz Cortex-A510
Modem-RF	Exynos® 2100 5G (integrated)	Dimensity 900 5G (integrated)	Snapdragon® X70 5G (integrated)
3GPP Release	Release 15	Release 15	Release 16
Memory RAM	8GB		
Operating System	Android 13		

Table III
MEASURED VALUES SHOWING THE TIME BETWEEN SIP INVITE AND SIP RINGING MESSAGES FOR EACH SCENARIO

	Device A			Device B			Device C		
Samples	VoLTE	EPSFB	VoNR	VoLTE	EPSFB	VoNR	VoLTE	EPSFB	VoNR
AVG	0.761	3.395	0.606	0.842	3.199	0.593	0.163	0.141	0.130
STDEV	0.026	0.091	0.071	0.043	0.103	0.033	0.011	0.016	0.011

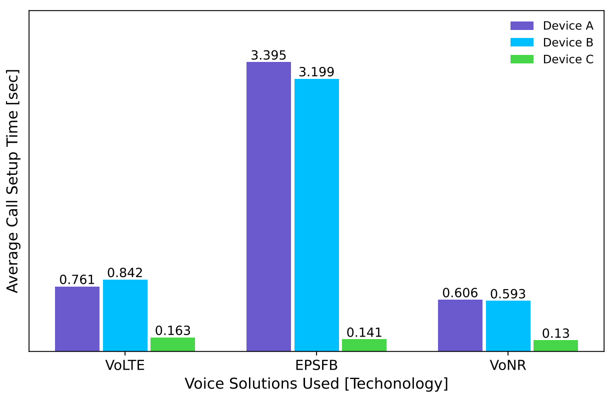

Fig. 6. Average CST obtained on each voice solution used

Device C exhibited enhanced performance, which can be predominantly attributed to its sophisticated hardware, particularly the incorporation of the latest Qualcomm modem chipset. However, it is pivotal to underscore that our findings don't hinge solely on modem-specific analysis. This clarification is crucial given that each device under review boasted an integrated modem, ran on the same operating system, and shared analogous RAM capacities. The crux of the differential performance observed in Device C stems from the technological enhancements integral to 5G, as embodied by devices adhering to the 3GPP Release 16 standards. This compliance ensures devices benefit from enriched functionalities, expedited network access, and reduced latency times. In turn, this equips them with the prowess to pioneer novel strategies and techniques for device interconnectivity within the evolving 5G network framework, such as Ultra-Low Latency Suite to help achieve unmatched 5G low-latency for hyper-responsive 5G user experiences and applications.

5G 3GPP Release 16 aims to extend Radio Access Network (RAN) capabilities and reduce latency to better accommodate real-time-sensitive services. Among the advancements is the introduction of a two-step Random Access Channel (RACH), implemented at the gNB, designed to minimize latency and control signaling overhead compared to the four-step RACH in Release 15. Additionally, Release 16 updates the IMS-to-5GC interface, transitioning from Diameter to HTTP in the 5G network service architecture.

Our findings indicate that VoNR consistently outperforms VoLTE and EPSFB in terms of audio call time delay across all tested devices. Specifically, the longest CST values were observed in the EPSFB procedure for devices A and B. This is primarily due to the multiple steps required in EPSFB, where the UE must initiate EPS Fallback, perform a Tracking Area Update (TAU), and establish a QCI bearer to route the voice call through the IMS core. In contrast, VoLTE and VoNR only necessitate SIP session establishment.

In terms of statistical dispersion, the standard deviation serves as a reliable metric. Our analysis shows that device A exhibited standard deviation values of 0.091 for EPSFB and 0.071 for VoNR. For device B, these figures were 0.103 and 0.033, respectively. Remarkably, device C demonstrated the most stable measurements with values of 0.016 for EPSFB and 0.011 for VoNR. These figures underline the enhanced consistency of results for device C.

As depicted in Fig. 6, device C, conforming to 3GPP Release 16, exhibits the least amount of call reception delay across all scenarios. This aligns well with Release 16 objectives, which prioritize reducing latency in signaling interactions between the UE and the Base Station. In summary, VoNR displays the shortest audio call delays, a distinction mainly attributable to the simplified SIP-based session initiation, contrasting the more elaborate procedures in EPSFB.

In this study, we did not evaluate additional devices compatible with Release 16, largely because such devices are currently sparse in the market. As the industry is in the early stages of adopting this standard, many of the forthcoming Release 16-compliant devices are still under development.

V. Conclusion

The evolution of mobile network technologies strives to enhance resources for delivering superior user experiences. This study offers a comprehensive evaluation of unique voice service solutions in 5G network, focusing on EPS Fallback and VoNR technologies. Conducted in a meticulously controlled setting, our experiments accurately measured two key metrics: the average and standard deviation of call setup time. Our results led to significant insights. Specifically, device C, operating on 3GGP Release 16, displayed a 78.31% reduction in VoNR CST and a staggering 95.72% reduction for EPSFB when compared to devices A and B, which operate on 3GPP Release 15. This suggests that the 3GPP Release 16 devices, particularly with VoNR features, excel in delivering superior call setup performance.

Our comprehensive analysis reveals that VoNR consistently surpasses other technologies in reducing call setup time across a variety of devices. Although Devices A and B are equipped with different modem chipsets, they exhibited similar delay values. VoLTE recorded the next lengthiest setup time, closely trailed by EPSFB. Such observations underscore the potential of VoNR to significantly ameliorate user experiences by curtailing call setup duration, irrespective of the device or scenario.

This paper focused on a study of the CST in different modem chipsets in addition to evaluating their behavior through Releases 15 and 16 of the 3GPP standard that address the issue of device heterogeneity in 5G networks, which is critical for service providers and manufacturers. For future work, we intend to broaden our analysis to encompass devices compliant with subsequent 3GPP 5G releases. Additionally, we aim to incorporate and assess other metrics of 5G voice solutions, such as 5G voice solutions, voice quality through the POLQA method, loss of packages in the data transmission flow, or verification of the delay in sending packages (jitter).

Acknowledgment

This paper is a result of the Research, Development & Innovation Project (Model 5G) performed at Sidia Institute of Science and Technology sponsored by Samsung Eletrônica da Amazônia Ltda., using resources under terms of Federal Law No. 8.387/1991, by having its disclosure and publicity in accordance with art. 39 of Decree No. 10.521/2020.

References

[1] G. T. 21.915, "Digital cellular telecommunications system (Phase 2+) (GSM); Universal Mobile Telecommunications System (UMTS); LTE; 5G; Release description," 3rd Generation Partnership Project (3GPP), Technical Specification (TS) 21.915, 04 2019, version 15.0.0.

[2] G. T. 23.799, "Study on Architecture for Next Generation System," 3rd Generation Partnership Project (3GPP), Technical Specification (TS) 23.799, 04 2017, version 14.2.0.

[3] G. T. 29.949, "Universal Mobile Telecommunications System (UMTS); LTE;Study on technical aspects on roaming end-to-end scenarios with Voice over LTE (VoLTE) IP Multimedia Subsystem (IMS) and other networks," 3rd Generation Partnership Project (3GPP), Technical Specification (TS) 29.949, 04 2022, version 17.0.0.

[4] G. T. 23.501, "System Architecture for the 5G System; Stage 2," 3rd Generation Partnership Project (3GPP), Technical Specification (TS) 23.501, 04 2021, version 17.9.0.

[5] G. T. 23.502, "5G;Procedures for the 5G System (5GS)," 3rd Generation Partnership Project (3GPP), Technical Specification (TS) 23.501, 04 2021, version 17.9.0.

[6] G. T. 23.228, "IP Multimedia Subsystem (IMS)," 3rd Generation Partnership Project (3GPP), Technical Specification (TS) 23.228, 04 2021, version 15.5.0.

[7] X. Xu, J. Hou, C. Hu, J. Yu, H. Guo, and Y. Zhou, "Mobility strategy for vonr in switch boundary scenario," in *2022 International Conference on Information Processing and Network Provisioning (ICIPNP)*, 2022, pp. 39–42.

[8] J. Hou, C. Hu, X. Zhao, H. Guo, J. Yu, and X. Xu, "Coverage and capacity measurements for 5g voice services," in *2023 6th International Conference on Communication Engineering and Technology (ICCET)*, 2023, pp. 72–77.

[9] J. J. Abularach Arnez, M. G. Lima Damasceno, R. K. Gomes Dos Reis, and L. Da Silva Pessoa, "Real time testbeds for 5g nsa and sa mobile architectures to provide volte and vonr services over ip multimedia core network subsystem," in *2022 18th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob)*, 2022, pp. 63–68.

[10] C. B. B. De Souza, J. J. Abularach Arnez, T. Fernandes, C. A. Tavares Alves, and J. O. de Sousa, "Analysis of power consumption in 4g volte and 5g vonr over ims network," in *2022 IEEE 27th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD)*, 2022, pp. 59–64.

[11] X. Li, W. Xie, Y. Zhao, and X. Zhao, "Research on 5g sa network shared voice solution," in *2021 2nd Information Communication Technologies Conference (ICTC)*, 2021, pp. 65–69.

[12] A. F. Chabi, M. F. de Aguiar, J. K. S. Carvalho, V. d. A. Rodrigues, J. V. D. S. Campos, B. M. D. S. Fonseca, and J. O. D. Sousa, "Voice quality experience evaluation: Mos laboratory test and spectrum analysis of failures in volte calls," in *2023 IEEE International Conference on Industry 4.0, Artificial Intelligence, and Communications Technology (IAICT)*, 2023, pp. 201–207.

[13] A. EL RHAYOUR and T. MAZRI, "5g architecture: Deployment scenarios and options," in *2019 International Symposium on Advanced Electrical and Communication Technologies (ISAECT)*, 2019, pp. 1–6.

[14] A. Ghosh, A. Maeder, M. Baker, and D. Chandramouli, "5g evolution: A view on 5g cellular technology beyond 3gpp release 15," *IEEE Access*, vol. 7, pp. 127 639–127 651, 2019.

[15] J. Peisa, P. Persson, S. Parkvall, E. Dahlman, A. Grøvlen, C. Hoymann, and D. Gerstenberger, "5g evolution: 3gpp releases 16 & 17 overview," *Ericsson Technology Review*, vol. 2020, no. 2, pp. 2–13, 2020.

[16] T.-K. Le, U. Salim, and F. Kaltenberger, "An overview of physical layer design for ultra-reliable low-latency communications in 3gpp releases 15, 16, and 17," *IEEE Access*, vol. 9, pp. 433–444, 2021.

[17] K. Nosirov, A. Ataniyazov, M. Rikhsivoev, M. Arabboev, and S. Begmatov, "Analysis of multi-service networks for the provision of multimedia services based on ims," in *2022 International Conference on Information Science and Communications Technologies (ICISCT)*, 2022, pp. 1–4.

[18] Y. Kanoune, C. Yahiaoui, and A. Rachedi, "Toward an approach for securing ims signaling and media planes," in *GLOBECOM 2020 - 2020 IEEE Global Communications Conference*, 2020, pp. 1–6.

[19] J. Zhou, J. Li, Y. B. Xia, B. Cai, and C. Ying, "Sip network discovery by using sip message probing," in *NOMS 2008 - 2008 IEEE Network Operations and Management Symposium*, 2008, pp. 791–794.

[20] M. Hasanzadeh, H. Hamidi, and H. Asghari, "Plaintext transmission over session initiation protocol," in *7'th International Symposium on Telecommunications (IST'2014)*, 2014, pp. 629–634.

[21] O. O. Erunkulu, A. M. Zungeru, C. K. Lebekwe, M. Mosalaosi, and J. M. Chuma, "5g mobile communication applications: A survey and comparison of use cases," *IEEE Access*, vol. 9, pp. 97 251–97 295, 2021.

[22] D. Shukla and S. D. Sawarkar, "A study of wireless network evolution from 4g to 5g: standalone vs non-standalone," in *2022 International Conference on Smart Generation Computing, Communication and Networking (SMART GENCON)*, 2022, pp. 1–6.

[23] H. Guo, J. Hou, X. Xu, C. Hu, M. Wei, and B. Cai, "Research on 5g voice solutions and continuity analysis," in *2022 International Conference on Information Processing and Network Provisioning (ICIPNP)*, 2022, pp. 137–141.

[24] J. Yu, C. Hu, W. Xie, P. Lin, J. Hou, and X. Xu, "Research on coverage and capacity of 5g vonr," in *2022 IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB)*, 2022, pp. 1–5.

[25] A. Elnashar and M. A. El-saidny, *VoLTE/CSFB Call Setup Delay and Handover Analysis*. Wiley, 2018, pp. 158–196.