5G VOICE OVER NEW RADIO (VoNR)

White paper | Version 01.00 | Reiner Stuhlfauth

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CONTENTS

1 INTRODUCTION

The main driver behind the development of 5G networks has always been improved data services such as higher mobile data rates and reduced latency. However, the legacy services of voice and video communications remain key elements for mobile services, and subscribers continue to demand them. According to analysts, the number of voice subscriptions worldwide will double by 2025 [Ref. 21].

This demand for voice services among mobile subscribers will ensure these services remain part of the packages and business models of service providers. However, voice over 5G networks is not just about keeping customers happy; voice also has a role to play in the new data services provided by 5G.

While it may seem simple to just keep the existing voice services that are already in place, some thorny technological challenges are actually required to accomplish this feat. In fact, a single technical solution is not viable because whatever solution is adopted must adapt to the existing network deployment.

Prior to this latest migration of voice over 5G networks (5G voice over New Radio or 5G VoNR), the migration of voice services from 3G and circuit switched mobile networks to the 4G Long Term Evolution (LTE) network was initially slowed by technical challenges. Part of the ability of voice over LTE (VoLTE) to overcome its early technical challenges was the fact that it was based on the IP multimedia subsystem (IMS) architecture. To a certain extent, the adoption of IMS by service providers can be correlated with the rise of VoLTE.

This IMS architecture will play an increasingly important role in 5G VoNR. Like 4G LTE networks, 5G voice calls are implemented as end-to-end voice over IP (VoIP) connections managed by the IMS core. Voice and video communications services in these networks ride on top of the IP data connection. Unlike voice services provided by external applications (i.e. so-called OTT speech services), voice over IMS supports quality of service (QoS) management across the entire 5G system (5GS).

While IMS can provide voice services for any type of access (fixed, cable and 2G/3G) as well as for any 5G deployment model, 5G is not as flexible and must have an IMS network to handle voice services no matter what type of deployment is involved. Just as we could correlate the adoption of IMS with the rise of VoLTE, the introduction of 5G serves as a catalyst to accelerate voice core modernization to IMS from older technologies in networks.

As we mentioned previously, a single technical approach to 5G VoNR is not possible. This white paper will examine all of the possible approaches in detail. In general, however, VoNR has to adapt to the existing deployment modes, i.e. non-standalone (NSA) or standalone (SA).

The NSA deployment mode, known as option 3, involves LTE plus NR with an evolved packet core (EPC). In contrast, the SA deployment involves NR with the 5G core (5GC). This deployment mode is known as option 2.

Once it has been determined whether the RAT is 5G NR or E-UTRA, it is necessary to consider whether co-existing SA networks are involved or a dual connectivity scenario, i.e. E-UTRAN New Radio dual connectivity (EN-DC) or NR-E-UTRA dual connectivity (NE-DC). Of course, it is also important to know whether the RAT even supports voice services.

Most recent 5G deployments have employed option 3, meaning the network providers basically have an existing 4G LTE network and have deployed a 5G network alongside it. In this way, 5G NR serves as a secondary cell and the core technology remains the evolved packet core (EPC).

During operation of option 3, a UE registers to the IMS via the evolved packet system (EPS). When the 5G UE launches (or receives) a voice call, typical VoLTE procedures are followed over the EPS system.

When a service provider chooses option 2, they deploy the 5G network as an SA network without relying on any other network. In this option, the IMS core provides voice as a 5G application service. Voice services on this kind of network are known as voice over new radio (VoNR).

Even this option 2 presents challenges. In these early years of 5G, geographic coverage for 5G will be incomplete. When a mobile device moves out of a 5G NR coverage area, a VoNR voice call in progress will require a handover to use VoLTE in a 4G network. Meticulous network planning is required taking coverage into consideration.

In previous VoLTE systems, circuit switched fallback (CSFB) led to delays which interrupted the call. One procedure that will be discussed in detail in this white paper is known as "EPS fallback for IMS voice". This procedure avoids such dropped calls by directing the UE to fall back to the EPS as soon as any voice call is initiated. Basically, the EPS fallback causes a handover during initial setup instead of during the call. Thus, it avoids impacting the user's in-call experience. With EPS fallback, the UE will camp on the higher prioritized 5G RAT. Since there is no need for full 5GC support yet, EPS can serve as an interim step to speed up the time to market for voice services.

The benefits of 5G VoNR for voice-only calls are obviously the quality and ultra-high definition of the calls. As we pointed out earlier and perhaps more importantly, however, 5G VoNR also has an important role to play in the new data services provided by 5G.

5G VoNR provides a point of integration with applications and content such as announcements, music, conferencing and more. It will also provide enhanced support for real-time communications, including Rich Communication Services (RCS) integration. For example, RCS integration will allow 5G VoNR to enable interactive features such as real-time language translation. Many of the more advanced functions will work only in a 5G NR environment with support from the 5GC infrastructure.

This white paper provides in-depth guidance for navigating 5G VoNR in terms of the network deployment as well as the connectivity options to support voice over NR and enable the relevant VoNR data services. To provide a better understanding of the control plane, a brief summary of the signaling parameters for the network and UE is provided.

At the end of the white paper the question how test and measurement enables the success of voice over NR is tackled. Contemplation is made on lab based testing as well as field based testing with the short descriptions of real setups allowing to test voice over NR.

A general introduction to 5G fundamentals, procedures, technology drivers and system and service aspects can be found in [Ref. 20].

2 VOICE CALL ASPECTS IN 5G NR

Although data services in the context of enhanced mobile broadband (eMBB), ultra-reliable and low latency communications (URLLC) and massive machine type communications (mMTC) are the pivotal drivers behind the 5G evolution, legacy services like voice and video communications still represent important services that operators want to offer to their subscribers. As part of the technology evolution, we have seen a major change from circuit switched 2G networks with an initial focus on telephony to fully packet switched 4G networks focused on internet data communications.

This white paper elaborates the technological details on how a 5G network may support voice services. Unfortunately, a single technical solution will not be offered in the 5G system for voice services including the radio access technology, infrastructure deployment and protocol layers involved. The objective here is to describe the technical evolution required to support voice services and ensure that these services will not be curtailed by the introduction of 5G.

From a high-level perspective, voice over NR needs to adapt to the existing deployment regardless of whether it uses NSA or SA mode and whether the EPC is the core network or the 5GC. The type of voice support in 5G depends on the available radio access technology (RAT) in the form of 5G NR or E-UTRA and whether both are used as coexisting standalone networks or in a dual connectivity scenario (EN-DC or NE-DC). Obviously, which RAT supports voice services is also important. The second question concerning the type of voice service is the availability of a core network (either EPC or 5GC) and again, obviously, which core network supports voice services.

The objective of this white paper is to present the various voice services in 5G in greater detail along with certain evolution paths illustrating how the offered voice services may change with the evolution of the 5G system (5GS), 5G access network (5G-AN) and user equipment (UE) deployment. Lastly, some supplementary services that are supported such as the emergency service, SMS or the automotive emergency service eCall are considered.

From a high-level perspective, voice over NR is voice over IP using the IP multimedia subsystem (IMS) infrastructure. The advantage of using IMS is the ability to set up and ensure a quality of service (QoS) for each application. The task for IMS is to establish, control and maintain a protocol data unit (PDU) session, including all relevant data bearers with corresponding QoS flow for best end-user quality experience. One difference compared to a data PDU session in 5G is that with the non-access stratum (NAS) signaling procedure PDU session establishment request, the UE requests a PDU session for IMS signaling. Like in **voice over Long Term Evolution (VoLTE)**, voice over IMS in 5GS also supports QoS. This is a major difference compared to voice services offered by external applications, e.g. so-called over-the-top (OTT) speech services.

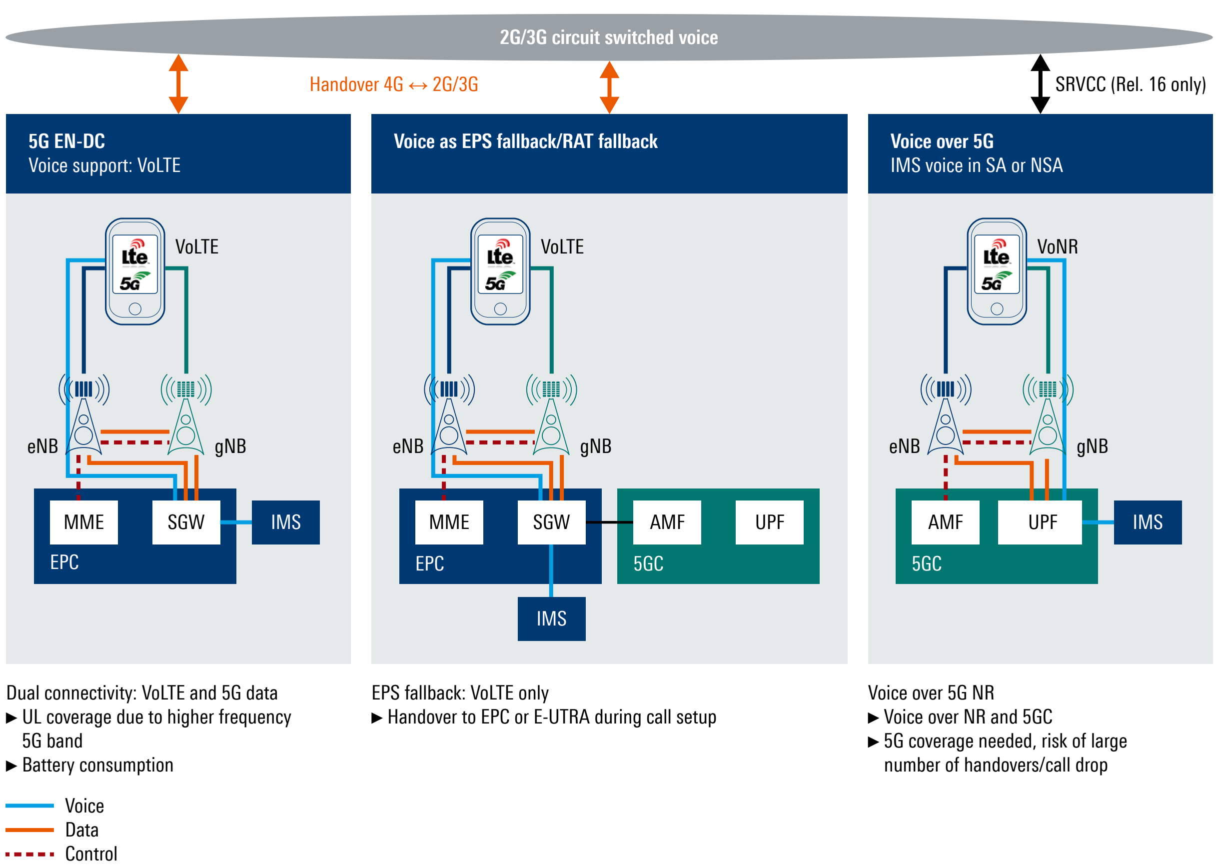
Thus, one question arises concerning how to connect IMS to the next generation network, 5GC. The evolutionary paths describe whether in an NSA connection, voice will be supported by E-UTRA only and if the simultaneous NR data connection can be sustained or will be suspended. This option is referred to as **voice over LTE (VoLTE) in EN-DC** setup.

The evolved packet system (EPS) fallback use case describes the situation where 5GC does not offer voice services. If necessary, the connection will be handed over to an EPS connection (VoLTE). Another fallback mode is **RAT fallback**, assuming the current core network supports voice service but the current RAT, presumably NR, does not. In that case, the connection is transferred from NR to E-UTRA only.

Voice over NR (VoNR) indicates the case where the NR network does support voice services and the 5GC offers a connection to IMS. In general, VoNR is independent of the dual connectivity and thus, it would work with EN-DC. However, the focus is on the NR SA where 5GC connects to IMS supporting voice services. Since LTE is considered here to operate in parallel, inter-system handovers are mandatory to ensure UE mobility and avoid call drops and leverage high-quality key performance indicators (KPI). Note that in 3GPP Release 15, there is no handover defined between 5G and 3G/2G. Thus, no **circuit switched fallback (CSFB)** scenario is possible either. A handover to circuit switched 2G/3G is only possible in two steps via an interim connection to 4G. In 3GPP Release 16, **single radio voice call continuity (SRVCC)** is introduced where a VoNR connection can be transferred to 3G. The objective is to avoid call drops when coverage of 5G services is getting weaker and LTE coverage is not available. See Figure 1 for relevant setups.

Besides the terminal capabilities, support for voice services in 5G NR needs to consider the various network deployment options. Critical questions are, for example, which RAT to use (E-UTRA or NR), which core network is available (EPC or 5GC) and whether the evolved NodeB (eNB) is a next generation evolved NodeB (NG-eNB) or just a legacy eNB. Consequently, we may speak about **EPS fallback**, **RAT fallback**, **voice over NG-eNB** (NGEN-DC) or **standalone VoNR**. Obviously, the frequency band allocation applies to such voice call deployment options, i.e. network operators plan to re-farm legacy frequency bands in the lower frequencies from LTE to 5G. With such enhanced coverage, services like VoNR also become feasible.

Figure 1: Deployment scenarios supporting voice in 5G



Besides the technology evolution from 4G to 5G on both the RAT and the core network, we are witnessing an evolution especially towards introduction of more sophisticated and high-quality voice and video services. One term that accompanies VoNR is the **enhanced voice service (EVS)** with wider audio bandwidth, higher sampling ratio, better quantization and higher resolution. The EVS speech codec was introduced with LTE in several networks already, but 5G voice services rely on this advanced speech coding algorithm more extensively. A concise introduction to EVS with the corresponding speech codec principles is given as well.

Due to the N3IWF interworking, there is even an option to establish a voice call over IMS on a non-3GPP access network (e.g. WLAN) and perform a handover to VoNR. For the sake of brevity, the details of this procedure are omitted here, but they can be found in TS 23.502.

Although a popular derivate of emergency services in the automotive sector known as eCall may operate on LTE as next generation eCall (NG-eCall), there is ongoing research on how to enable future-proof emergency call services over 5G NR.

2.1 Voice services in an NSA dual connectivity setup

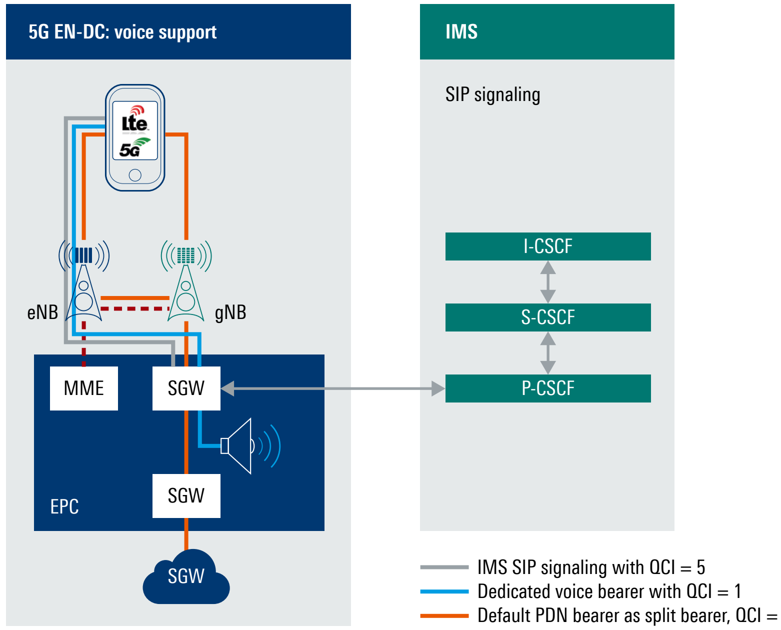
Recent deployments of 5G reveal widespread use of option 3 as one option in the connectivity scenario background in the infrastructure evolution. As a result, EN-DC, where there are two radio links, E-UTRA and 5G are offered. To accelerate the introduction of voice services, the major aspect of this method is that NR does not support voice services at all since this will be covered by LTE. The criterion in EN-DC mode is that NR cannot exist standalone; thus, LTE coverage is the prerequisite. Operators who have deployed VoLTE for 4G can continue to use IMS services over E-UTRAN (partially or fully upgraded to EN-DC). There is no impact on IMS. In fact, the IMS system is not even aware of the E-UTRAN upgrade to EN-DC. All location information exposed to IMS is based on LTE, as before.

All VoLTE principles remain applicable. A PDN connection to the IMS access point name (APN) is used for session initiation protocol (SIP) signaling on the default bearer with QoS class identifier QCI = 5 and for voice media on a dedicated bearer with QCI = 1 [Ref. 1].

The prerequisite for voice services is support for IMS, which is the case in EN-DC since the EPC is connected to IMS already. A possible recommendation includes setup of an IMS packet data network (PDN) connection for session initiation protocol (SIP) signaling messages inheriting the LTE QoS profile QCI = 5 and a parallel PDN connection for the voice content inheriting QCI = 1, as is already recommended for VoLTE. Since the setup supports dual connectivity, a third PDN default bearer with suggested QCI = 9 can now operate as a split bearer to provide additional packet data over E-UTRA and NR radio interfaces. It would be up to the network implementation and UE maturity whether the NR link is suspended or maintained simultaneously to the E-UTRA bearer. This proposal represents an early implementation with support for voice services when deploying 5G since it reuses investments that operators made into their LTE network. Bit rate and latency requirements are easily satisfied over LTE. In a longer-term rollout perspective, EN-DC option 3 may represent an interim stage that extends the existing EPS by a concurrent 5GC deployment and then allows support for VoNR.

The challenge as well as a minor drawback involves providing reliable voice services on early standalone NR deployments. This is because a common scenario uses the middle bands for 5G and lower bands for LTE, which may induce some coverage limitations. Another negative aspect is the higher energy or battery consumption since the UE needs to operate on two radio connections simultaneously. [Ref. 1] suggests RAN features such as RLC unacknowledged mode, transmission time interval (TTI) bundling and robust header compression (RoHC) that should increase the service KPI with optimized quality of experience.

Figure 2: Deployment scenario EN-DC supporting VoLTE and internet split bearer NR and LTE



2.2 Voice services using EPS fallback

2.2.1 Network interworking requirements supporting voice services

Regardless of whether 5G deployment is based on NSA or SA mode, the lesson has been learned from legacy network introductions that initial deployments will not have full coverage. Consequently, 5GC needs to be tightly coupled to EPC, especially to an existing IMS VoLTE supporting infrastructure to provide seamless voice services across the entire network with acceptable quality of experience (QoE) as KPIs. The objective is to register the UE primarily in the 5G network, even if voice services are not supported and a handover to LTE would be required. This method is RAT agnostic and the IMS support for voice services is available via the EPC. A UE camping on NR will then be redirected to EPC as the core and the serving RAT may change from NR to E-UTRA as well.

Note that the fallback procedure where only the RAT is changed from NR to E-UTRA is known as voice services with RAT fallback. This is further described in chapter 2.2.3. To achieve tight coupling between EPC and 5GC, the objective is first to introduce an additional interface between the core network entities and functions. Note that their implementation depends on the deployment strategy of operators and infrastructure vendors. A few of these new connections include the following.

- N6 interface to connect the 5GC user plane function (UPF) to the IMS. TS 23.501 defines N6 generally as the reference point between the UPF and a data network. For voice support, this data network is now represented by the IMS signaling system. A PDU connection can be established with the required QoS flow for voice services. N6 is also the prerequisite for full VoNR support.

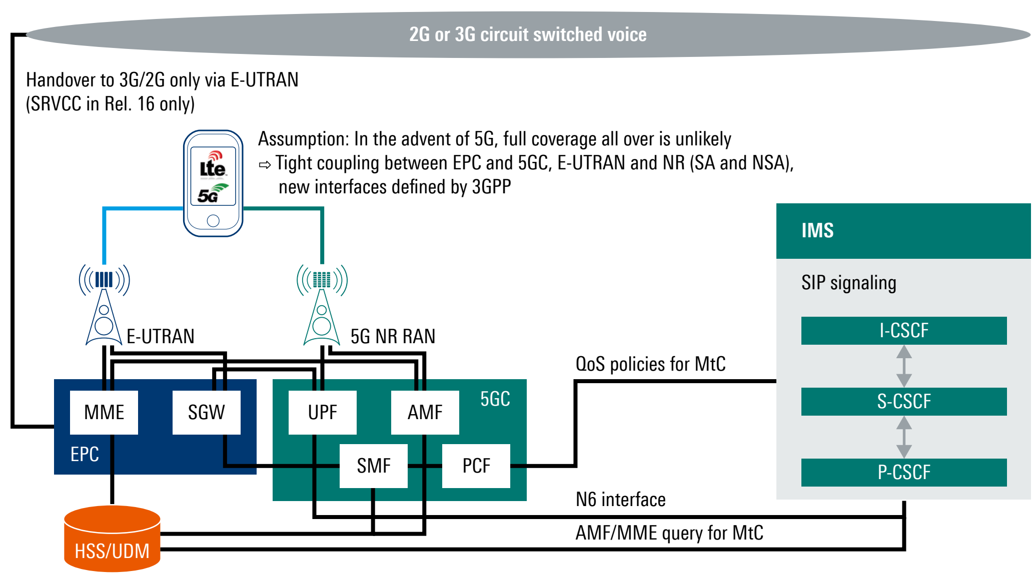
- S5 interface for control and user plane connection between session management function (SMF)/UPF representing the 5GC entities and the serving gateway (SGW) representing the EPC entity. From the EPC point of view, the S5-U interface replaces the public data network gateway (PGW) for voice services as they are now logically established via the UPF.

- ▶ N26 interworking interface between the mobility management entity (MME) and access and mobility management function (AMF) to enable context transfer and network-controlled mobility scenarios like handover between LTE and 5G. N26 represents an optional network deployment. As the main advantage, TS 23.501 indicates that interworking procedures with N26 provide IP address continuity on inter-system mobility to UEs that support 5GC non-access stratum (NAS) and EPC NAS and that operate in single registration mode. Without the N26 interface and assuming a UE in single registration mode, the control coordination between MME and AMF needs to be routed via SMF and PGW.

- ▶ Home subscriber server (HSS) interworking with unified data management (UDM), providing a connection to IMS and supporting the querying of the serving AMF when requested by IMS (see TS 29.563 for further details).

- ▶ Policy control function (PCF) with Rx/N5 PCF: When an indication for a session arrives over the Rx/N5 interface and the UE does not have priority for the signaling QoS flow, the PCF derives the allocation and retention priority (ARP) and 5G QoS identifier (5QI) parameters, plus the associated QoS characteristics as appropriate, of the QoS flow for signaling as per service provider policy (see TS 23.503 for further details).

Figure 3: Reference points between EPC, 5GC and IMS to ensure tight interworking for voice support

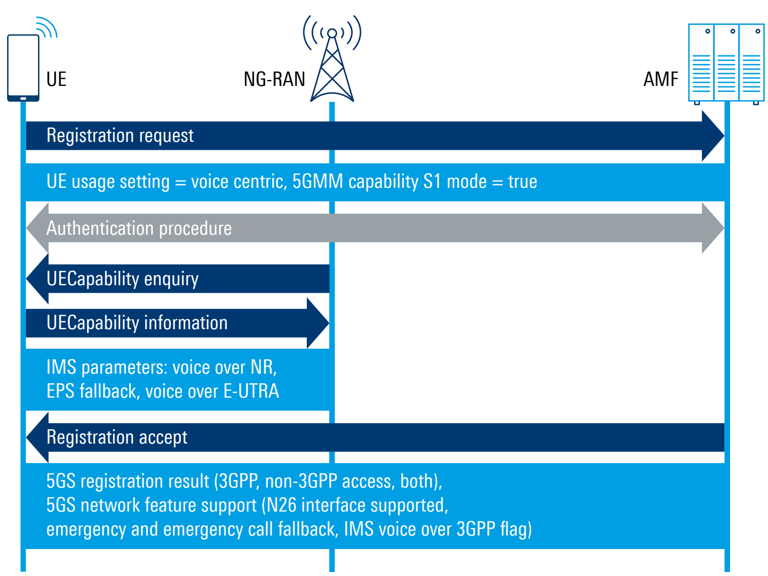


Thanks to these interworking and reference points, one can ensure an IP flow controlled via UPF and SMF independent of whether the UE is camping on LTE or NR. In addition, mobile terminated connections initiated by IMS can be routed properly. Even in a single registration situation, due to the optional N26 interworking it is possible to maintain the IP address allocated to the UE.

2.2.2 Registration procedure – aspects for voice support

The first important procedure in a possible offering of voice services in 5GS is the registration procedure in which the UE and network exchange the intentions and capabilities of both entities. Further details on the registration procedure in the NAS message flow are available in TS 24.501. With the registration request message, the UE reveals its usage setting to the network. The usage setting can be data centric or voice centric. If the UE intends to use voice, the UE usage setting should indicate voice centric mode. Another important flag in this control message is the S1 mode flag contained in the 5G mobility management (5GMM) capability element. With this flag, the UE indicates whether a possible EPS fallback procedure for IMS voice from 5GS to EPC is feasible or not. Via the capability information exchange, the UE discloses its IMS-related parameters. Common IMS parameters the UE may support are, for example, the indication of voice over E-UTRA support, voice over secondary cell group (SCG) bearer support and an indication of voice fallback into EPS. The parameter `voiceOverNR` indicates the UE support for voice over NR. If the UE does not support voice over NR but only EPS fallback, it is recommended to set the parameter flag as `voiceOverNR = False` and `voiceFallbackIndicationEPS-r16 = True`. Note that the UE capability is a procedure between the UE and NG radio access network (NG-RAN) (TS 38.331). The 5GC receives the registration request and needs to provide a proper response depending on the network capabilities or offerings. Obviously, one of them is the support for voice services by the network. With the registration accept message, the network not only confirms the successful transfer into 5GMM_REGISTERED state but also confirms the support for voice call related features. It is worth mentioning in greater detail the information element of the registration accept message 5GS network feature support. This information element (IE) contains flags such as the support for "IMS voice over packet switched (PS) session supported over 3GPP access", "non-3GPP voice support", "emergency call services" or "emergency call fallback support" and whether the N26 network interface does or does not exist. In the following figure, the registration procedure is depicted with a focus on voice-specific control information only. Further details on the NAS registration procedure are available in TS 24.501.

Figure 4: Registration procedure with voice aspects



TS 23.501 defines certain interworking scenarios between 5GS and EPC and provides more information on interfaces such as N26. S1 mode indicates a successful EPS attach and N1 mode indicates a successful 5GC attach. The definition in TS 24.501 is that in N1 mode, the UE has access to the 5G core network via the 5G access network. Single or dual registration indicates simultaneous handling of mobility states. In single registration mode, there is only one active mobility state at any given time. The UE stays in either 5GC NAS mode or EPC NAS mode. Concerning the UE identifiers [Ref. 20], the UE maps the EPC globally unique temporary identify (EPC-GUTI) to 5G-GUTI during mobility between EPC and 5GC. As stated, if the network supports the N26 interface, the UE keeps 5G context such as IP address allocations for re-use when moving from 5GC to EPC. In order to interwork with E-UTRAN connected to EPC, a UE supporting both S1 mode and N1 mode can operate in single-registration mode or dual-registration mode. The first mode (single-registration mode) is mandatory for UEs supporting both S1 mode and N1 mode. Dual-registration mode requires the UE to handle 5GMM and EMM context independently and simultaneously. In this mode, the UE maintains the identifiers 5G-GUTI and

EPC-GUTI independently. The UE can perform 5GC or EPC re-registration/TAU using the corresponding GUTIs.

A UE operating in dual-registration mode may register to N1 mode only, S1 mode only, or to both N1 mode and S1 mode.

During the EPS attach procedure or initial registration procedure, the mode for interworking is selected if the UE supports both S1 mode and N1 mode and the network supports interworking. Depending on the N26 interface support, the UE has different options to operate in single- or dual-registration mode and certain submodes. If both 5GMM and EPS mobility management (EMM) are enabled, a UE operating in single-registration mode should maintain one common registration for 5GMM and EMM. Coordination between 5GMM and EMM is not needed for a UE which is capable of N1 mode and S1 mode and operates in dual-registration mode. TS 24.501 defines the details of the coordination between 5GMM and EMM in single-registration mode depending on whether the N26 interface is supported or not.

2.2.3 5G IMS support

The **IP multimedia subsystem** (IMS) represents connection management for voice services in 5G, like in legacy LTE networks. 3GPP Release 5 introduced IMS to evolve universal mobile telecommunications system (UMTS) networks to deliver IP based multimedia to mobile users. Readers not familiar with basic IMS aspects may consult [Ref. 6] for further information. IMS has become a core component within the 3G, cable TV and 4G networks. Technological refinements were realized in subsequent releases. Nevertheless, IMS is considered to be independent from 5GS.

Initially, IMS was an all-IP system designed to help mobile operators to deliver next generation interactive and interoperable services, cost-effectively, over an architecture providing the flexibility of the internet.

The session initiation protocol (SIP) was selected as the signaling mechanism for IMS, allowing voice, text and multimedia services to traverse all connected networks. The 3GPP works closely with experts in the IETF to ensure maximum reusability of internet standards and prevent fragmentation of IMS standards. For further information on general IMS aspects, see TS 22.228 and TS 23.228.

Since voice services in 5G are not mandatory for the UE and network, the 3GPP agreed to a common implementation and indication policy to ensure proper functioning of voice services when offered. The GSM Association (GSMA) has published a permanent reference document [Ref. 8] defining a profile with a minimum mandatory set of features defined in the 3GPP and GSMA specifications. A wireless device and network must implement these features in order to ensure interoperable, high-quality IMS based communications services for voice, video and messaging over a next generation (NG) radio access connected to 5GC.

A network offering voice services in 5GS needs to support IMS with the following functionality:

- Indication towards the UE if an IMS voice over PS session is supported
- Capability to transport the proxy call session control function (P-CSCF) address(es) to a UE
- Paging policy differentiation for IMS
- IMS emergency service
- Domain selection for UE originating sessions
- Terminating domain selection for IMS voice
- Support for P-CSCF restoration procedure
- Network repository function (NRF) based P-CSCF discovery
- NRF or SCP based HSS discovery

The serving public land mobile network (PLMN) AMF should send an indication towards the UE during the registration procedure over 3GPP access to indicate whether an IMS voice over PS session is supported in 3GPP access and non-3GPP access. The UE usage setting applies to voice-capable UEs in 5GS and indicates whether the UE has a preference for voice services or data services. When a UE selects the usage setting as "voice centric", this includes IMS voice. When a UE selects the usage setting as "data centric", data services include any kind of user data transfer without a voice media component (TS 24.501).

A mobile device offering voice services in 5GS needs to support the IMS capabilities that are required over the Gm and Ut reference points. Reference point Gm supports communications between the UE and IMS related to registration and session control. Reference point Ut facilitates management of subscriber information related to services and settings [Ref. 9]. To ensure proper operation of IMS based services, the 3GPP and GSMA recommend a set of eleven general IMS functions that should be supported. Further details can be found in [Ref. 8].

1. SIP registration

The UE is required to perform a registration to IMS via the SIP protocol and certain aspects of such a registration procedure should be supported and fulfilled:

- Single SIP registration to the known IMS access point name/data network name (APN/DNN) for all IMS services. This is mandatory for all UEs regardless of the home operator or roaming condition.

- Two separate IMS registrations using different APNs/DNNs, each supporting a subset of the IMS services. An application could be an IMS registration to the IMS APN/DNN in concurrent registration to a home operator service (HOS) APN/DNN to combine voice services with Rich Communication Services (RCS). This depends on the RCS VoLTE single registration parameter [Ref. 10] and is applicable if at least one of the RCS messaging services or message session relay protocol (MSRP) based enriched calling services is enabled. If this parameter is set to zero, the UE handles two separate IMS registrations. If it is set to one, the UE uses single registration. If it is set to two, the UE uses single IMS registration if it is registered to the home network; otherwise it handles two IMS registrations.

- P-CSCF discovery prior to initial IMS registration using protocol configuration option settings during PDU session establishment.

- Authentication for SIP registration depending on the related APN/DNN. Two authentication methods are used: IMS authentication and key agreement (IMS-AKA) and SIP digest [Ref. 8].

- IMS user and device identifiers in SIP registration. Depending on the APN/DNN registration and authentication, the UE allows the derivation of public and private IMS identities. Examples are the well-known international mobile subscriber identity (IMSI) or international mobile equipment identity (IMEI) and the IMS private user identity (IMPI) as part of the IP multimedia services identity module (ISIM) application on the universal integrated circuit card (UICC).

- Registration of IMS services. The UE must register multimedia telephony voice services (MMTel voice), short message services over IP (SMSoIP), video services (MMTel conversational video) and MMTEL call composer, always via the well-known IMS APN. Optionally via a second concurrent registration, the UE facilitates home network based complementary services like RCS messaging services and MSRP based enriched calling services.

- SIP registration procedure. The UE and IMS network must follow the SIP registration procedure defined in TS 24.229. To protect privacy, the UE must include a user part in the URI of the contact address such that the user part is globally unique and does not reveal any private information. Note that the UE can execute two separate IMS registration procedures to the default DNN for all IMS services and concurrently to a HOS DNN for RCS-specific services.

- Registration to IMS with service-specific aspects. During the registration procedure, the UE reveals service-related information such as the IMS communications service identifier (ICSI) to indicate IMS multimedia telephony and media feature tags like "audio" or "video" if the UE registers for MMTEL services. Similar information disclosure is defined for services like SMS, call composer or RCS (see [Ref. 8]).

2. Authentication
To ensure secure network access, IMS also requests device and subscriber authentication. The GSMA requirement in [Ref. 8] involves support for two authentication mechanisms (IMS-AKA as defined in TS 33.203 or SIP authentication via the Digest method as defined by the GSMA [Ref. 10]) and provides further details and requirements for these authentication procedures. The latter authentication method includes the mandatory UE and optional network support for HTTP content server authentication. Integrity protection is mandatory for the network and UE, while confidentiality protection for SIP signaling is optional for the network depending on whether radio link layer security is enabled or not.

3. Addressing
Proper addressing of user identities is a prerequisite for successful communications. The UE and IMS core network must support public user identities based on structures defined in TS 23.003 like alphanumeric session initiation protocol uniform resource identifiers (SIP-URIs) and mobile station international subscriber directory numbers (MSISDN) represented as digit telephone URI or SIP URI. For user-friendly operation on a graphical user interface (GUI), TS 24.229 defines the possibility of local numbers used as geo-local numbers, home operator local numbers or other private local numbers. The UE and IMS must support local numbers and the P-called-party-ID-header in the SIP header. Global routable user agent URIs are not required [Ref. 8].

4. Call establishment and termination
Concerning IMS call handling parameters, 5G requires more or less the same policies as in LTE; TS 24.229 defines the exact details. Optionally, the home operator can configure the UE with timers for round trip time estimation (T1), maximum retransmit time for INVITE responses (T2) or maximum message duration within the network (T4) (see TS 24.167). One slight difference is that the UE includes a reason information as cause when terminating a connection via CANCEL or BYE message. If available, the UE should

insert the P-access-network-info [Ref. 8]. To leverage subscriber usability, some connection extension and modification services are required as well. For example, the UE and network should be able to add a video call to a voice session during session establishment via SDP message transfer. If available, the UE should support the services provided by MMTEL call composer and RCS messaging services as defined by the GSMA [Ref. 10].

5. SIP precondition considerations

TS 24.229 specifies a precondition mechanism for MMTEL voice conversational services that should be supported by the UE as requested by [Ref. 8]. The network may disable the use of pre conditions via explicit signaling. For RCS services, SIP preconditions must not be used.

6. Early media and announcements

The UE must support reception of voice and video media associated with one early dialog, e.g. when a SIP 180 message follows the SIP INVITE and the UE must support the P-early-media header field. TS 24.628 provides further details on how the UE renders locally generated communications progress information.

7. Forking

By way of reminder, SIP forking represents a mechanism to split a SIP call into multiple clones for multiple endpoints. This increases usability, e.g. an incoming call could ring multiple endpoints at the same time. With SIP forking, your desk phone can ring at the same time as your softphone or a SIP phone on your mobile.

Network forking is at the discretion of the operator. For interoperability and forward-compatibility reasons, the UE must be ready to receive responses generated due to a forked request and behave according to the procedures specified in TS 24.229. Furthermore, the UE should be able to maintain at least forty parallel early dialogs until receiving the final response on one of them and the UE must support receiving media on one of these early dialogs [Ref. 8].

8. Signaling compression

[Ref. 8] indicates that the UE must not use methods like signaling compression (SIGCOMP) when the initial IMS registration is performed in 5G RAN.

9. SIP timer operation

To enable a connection flow and potentially handle unexpected waiting and expiry times, the UE must handle session expiry timers during the INVITE process as further defined in RFC 4028 [Ref. 15].

10. RCS feature capability discovery

The capability or service discovery mechanism is a process which enhances service usability by allowing a user to understand the subset of RCS services available to access and/or communicate with their contacts at certain points in time [Ref. 10]. If this feature is supported by the UE and the network, a configuration parameter CAPABILITY DISCOVERY MECHANISM can enable this capability exchange procedure. For the dual-registration case mentioned above, the capability exchange can happen on either of the two registrations. In the current version of 5G IMS support, capability discovery is applicable for the following services: MMTEL conversational voice and video, MMTEL call composer, RCS messaging services and MSRP based enriched calling services.

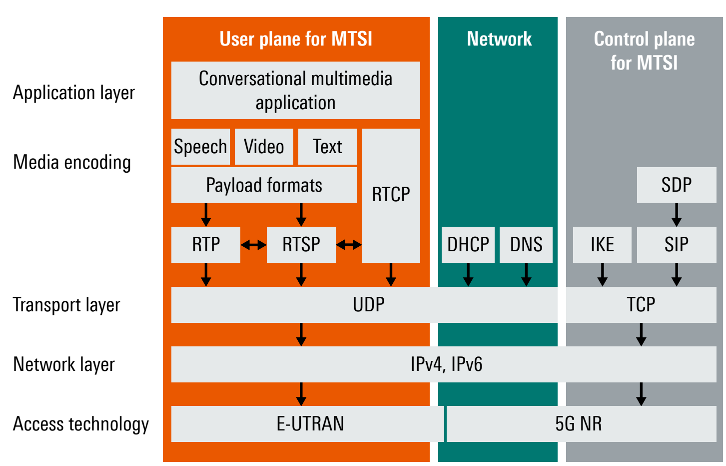
11. User agent

User agent and server headers are used to indicate the release version and product information of the instant messaging (IM) clients and IM servers. The UE should include the user agent header in all SIP request messages and server headers in all SIP response messages. In addition, the user agent header should be included in HTTP requests for XCAP. [Ref. 10] provides further details on the compilation format of these headers.

As in legacy networks, the higher layers describe the voice services and other applications as multimedia telephone services (MTSI) or as MMTEL. They are defined in TS 26.980. Voice or video is the application layer that is transferred via the real-time protocol (RTP) over the user datagram protocol (UDP)/IP protocols [Ref. 13]. In this protocol layer view, the RAT layer can either be E-UTRAN in VoLTE or 5G NR in VoNR. Beside the transport of audiovisual content over RTP, the real-time control protocol (RTCP) adds additional information about the corresponding RTP stream, e.g. calculated jitter values. IMS uses RTP as a radio layer agnostic media transfer protocol. RTP and RTCP are defined in IETF RFC 3550 [Ref. 13]. The main purpose of RTP is to allow the receiver to play received media at the proper pace since IP networks introduce packet delay and loss as well as jitter. For example, assuming two IP packets are sent to the same destination with 10 ms delay between them, nothing ensures that these two packets also arrive at the destination with a 10 ms delay. IP packet no. 2 may arrive right after packet no. 1, or much later or even before it. The RTP time stamps are used to recover the right timing relationship between the IP packets.

Since voice or video can run using a streaming service, the Internet Engineering Task Force (IETF) defined the real-time streaming protocol (RTSP) in RFC 2326 [Ref. 19] as a network control protocol designed for use in entertainment and communications systems to control streaming media servers. The transmission of streaming data itself is not a task of RTSP. Most RTSP servers use RTP in conjunction with the RTP control protocol (RTCP) for media stream delivery. On the control plane, there are two major protocols, i.e. the SIP and session description protocol (SDP). Since some SIP messages may be transferred over an IPsec tunnel, an optional IP key exchange (IKE) may be executed additionally.

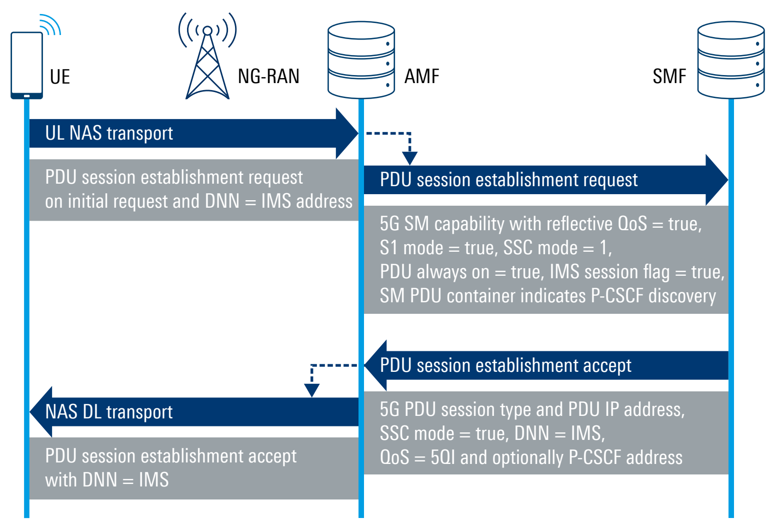
Figure 5: Protocol layer for MTSI



The objective in this chapter is to describe the details of the PDU session that are relevant for IMS connection setup. First, we assume as a prerequisite that the UE is registered and a 5GMM context is established. The PDU session establishment message is conveyed to the AMF via the uplink non-access stratum (UL NAS) transport container message. Here, the parameter message type indicates the NAS message PDU session establishment request as initial request and the DNN is set to the name of the corresponding IMS network. It is the responsibility of the SMF to connect to the IMS, and thus the

PDU session establishment request contains parameters indicating the IMS connection request (see TS 24.501). For example, the SSC mode should be set by the UE to SSC mode 1 request. The PDU session type IE indicates whether the UE prefers an IPv4 or IPv6 address or either one. In the 5GSM capability, the UE should indicate the support for S1 mode and reflective QoS. Using the extended protocol configuration option (PCO), the UE may signal that an IMS session should be established (TS 24.008). If the UE establishes a PDU session for IMS and the UE is configured to discover the P-CSCF address during connectivity establishment, the UE should include an indicator that it is requesting a P-CSCF IP address within the session management (SM) container IE (TS 23.502). In case of successful PDU session establishment, the network responds with a possible setting of the P-CSCF address in the session establishment accept message and the network activates a PDU session with QoS flow 5QI = 5 inheriting the IMS signaling QoS profile. IMS support is obviously a prerequisite for VoNR as discussed in further detail in chapter 2.2.6.

Figure 6: PDU session establishment for IMS voice



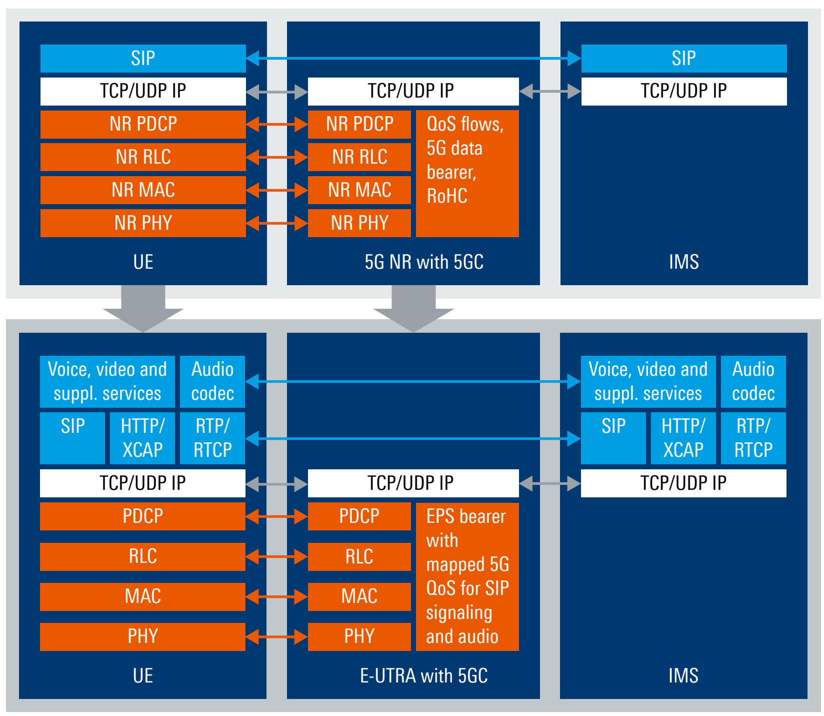
2.2.4 EPS fallback

From a high-level perspective, EPS fallback represents a situation where a voice call is guided from NR to LTE already during the connection setup procedure to keep the connection setup time minimized. Thus, the UE may fully use the offered 5GS services and the operator maintains the expected KPI with this additional mobility trigger to EPC. For example, the advertised 5G QoS flow parameters will be mapped to the corresponding EPC bearer during this handover procedure. The trigger for EPS fallback can be UE based, e.g. when the UE signals limited voice support only for EPS and thus indirectly requests an EPS fallback, or it can be network based. In detail, the network may use two standardized mobility procedures to trigger the EPS fallback: connection release with redirect to E-UTRAN (here, the N26 interface is very beneficial to reduce the call setup time) or the inter-system handover command.

EPS fallback with the updated infrastructure EPC-5GC interconnection facilitates the transition to a VoNR deployment. Assuming an operator has initially deployed support for EPS fallback without supporting voice over NR, then the migration to VoNR involves changing the RAN configuration to not trigger fallback and letting the QoS flow for voice be established on NR connected to 5GC instead. This transition then provides a legacy-compatible and future-proof path to introduce VoNR services from a network perspective only without taking the risk of curtailing the services to existing UEs. The reason for the network commanding the UE to VoLTE can be, e.g. a temporary lack of radio resources in NR for voice and moving the connection for capacity reasons to LTE, or a general non-provisioning of voice services in 5G at all. The latter can apply to an operator with a 5G focus on data services like eMBB or URLLC only. Intentionally, the operator does not yet implement IMS services connected to 5GC. It is also possible for a UE to signal via its capability information that only voice over EPS services are supported. Hence, the UE indirectly requests redirection to EPS.

An EPS fallback scenario from the protocol layer perspective is depicted in Figure 6. First, a UE camps on 5G NR and a 5G connection is established. The 5GC at least provides a SIP control connection to recognize that a voice connection is requested by the UE. Either via redirection or handover procedures, the connection is moved from 5G NR to E-UTRA. The advantage of EPS fallback is that the UE or NodeB (gNB) only needs to support the IMS signaling channel (SIP over NR, low real-time requirements), and does not need to support the IMS voice/video communications channel (RTP or RTCP over NR, high real-time requirements). RTP or RTCP over NR requires lower latency and better 5G NR radio coverage [Ref. 2]. Thus, it can be considered as an intermediate step to the provisioning of VoNR, depending on device and network maturity.

Figure 7: EPS fallback scenario



The migration to VoNR can be accomplished once all required voice capabilities are in place in the network. Devices introduced before this step will still be in the field when voice over NR is introduced. The capabilities of these devices will determine if the devices will use voice over NR or continue to rely on EPS fallback. Hence, the network will support voice over NR including EPS fallback [Ref. 1] for a long period of time.

Upon the attempt to establish the QoS flow for the voice media over NR during call setup, the NG-RAN rejects the QoS flow setup towards the SMF with an indication that mobility is in progress.

The NG-RAN initiates transfer of all PDU sessions from 5GS to EPS using one of the two standardized procedures:
- ► Release with redirect message
- ► Inter-system handover

TS 23.501 and TS 23.502 define general policies of interworking between 5GC and EPC as well as registration aspects. In brief, the UE performs a registration procedure when moving from EPC to 5GC and it either executes a tracking area update or initial attach procedure when moving from 5GC to EPC.

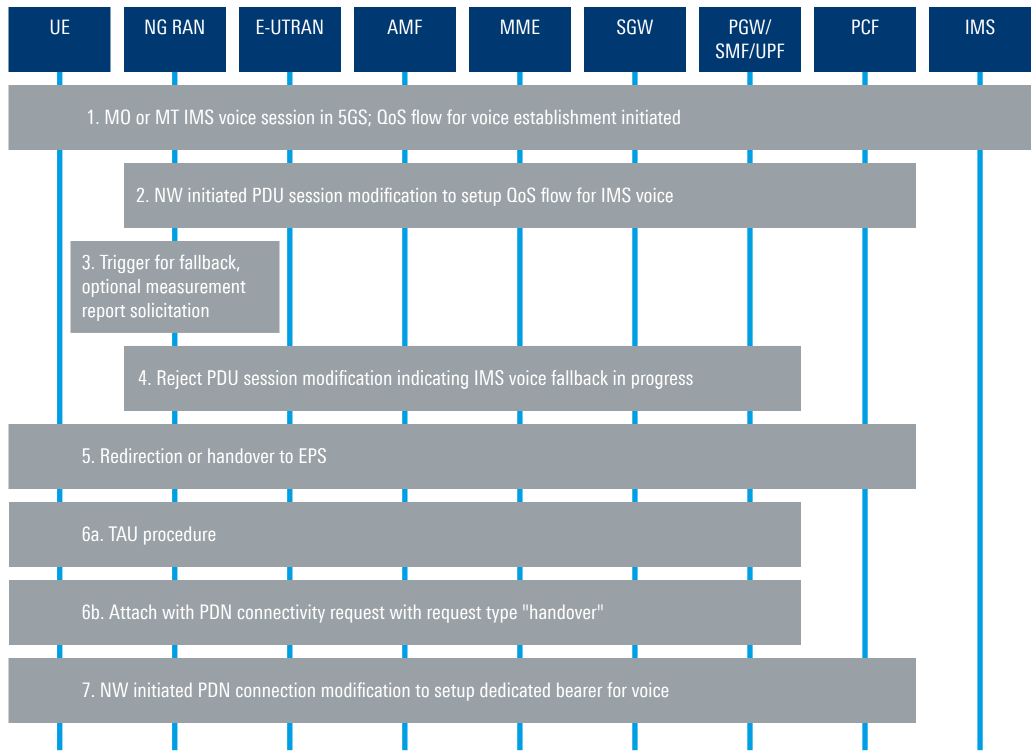
The UE performs a tracking area update procedure if it has at least one PDU session for which session continuity is supported during interworking, i.e. the UE has EPS bearer ID and mapped EPS QoS parameters received.

The UE performs an initial attach procedure if it is registered without PDU session in 5GC or the UE is registered only with PDU session for which session continuity is not supported during interworking to EPC, and either the UE or the EPC does not support attach without PDN connectivity.

Details of the tracking area update (TS 23.501): "When a UE is CM-CONNECTED in 5GC and a handover to EPS occurs, the AMF selects the target MME based on the source AMF Region ID, AMF Set ID and target location information. The AMF forwards the UE context to the selected MME over the N26 Interface. In the UE context, the AMF also includes the UE Usage type, if it is received as part of subscription data. When the handover procedure completes successfully the UE performs a tracking area update. This completes the UE registration in the target EPS."

When the UE is served by the 5GC, the UE has one or more ongoing PDU sessions each including one or more QoS flows. The serving PLMN AMF has sent an indication towards the UE during the registration procedure that IMS voice over PS session is supported, thus inducing an IMS registration. During this registration procedure, the network indicates whether the N26 interface is supported or not.

Figure 8: EPS fallback signaling message flow (TS 23.502)



The signaling flow for EPS fallback as shown in Figure 8 (TS 23.502):

1. The UE camps on NG-RAN and voice session establishment has been initiated, either IMS mobile terminated or originated (see Figure 6).

2. Network initiated PDU session modification via the N2 interface to set up QoS flow with 5QI = 1 for voice reaches the NG-RAN.

3. NG-RAN is configured to support EPS fallback for IMS voice and decides to trigger fallback to EPS, considering the UE capabilities. During the initial context setup (TS 38.413) procedure, the AMF indicates that "redirection for EPS fallback for voice is possible". Moreover, it provides the network configuration (e.g. N26 availability) and radio conditions. The NG-RAN may initiate measurement report solicitation from the UE including E-UTRAN as target.

4. NG-RAN responds by indicating the rejection of the PDU session modification to set up QoS flow for IMS voice received in step 2 by PDU `session modification response` message towards the PGW-C+SMF via AMF with an indication that mobility due to fallback for IMS voice is ongoing.

5. NG-RAN initiates either handover or access network release (AN release) via inter-system redirection to EPS, considering the UE capabilities.

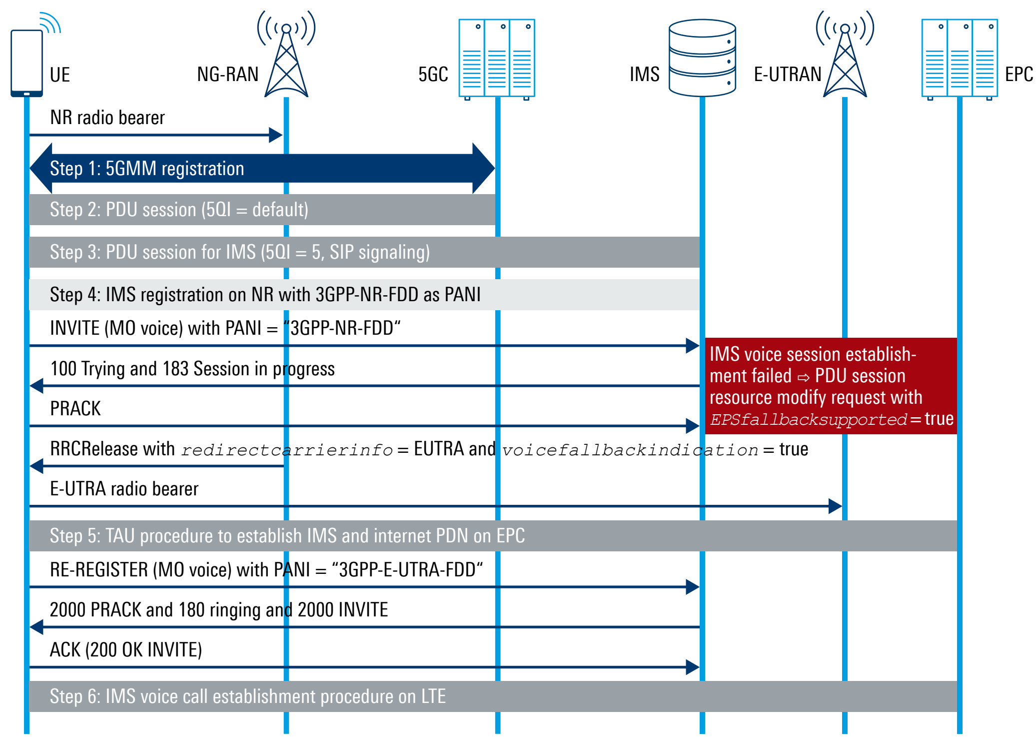
6a. In the case of 5GS to EPS handover and in the case of inter-system redirection to EPS with N26 interface, the UE initiates the tracking area update (TAU) procedure.

6b. In the case of inter-system redirection to EPS without N26 interface, the UE initiates `Attach with PDN connectivity request` with request type "handover".

7. After completion of the mobility procedure to EPS or as part of the 5GS to EPS handover procedure, the SMF/PGW re-initiates the setup of the dedicated bearer(s) for the maintained PCC rule(s) including the dedicated bearer for IMS voice, mapping the 5G QoS to EPC QoS parameters. The PGW-C+SMF reports about successful resource allocation and access network information. The IMS signaling related to IMS voice call establishment continues after step 1 as in legacy VoLTE. At least for the duration of the voice call in EPS, the E-UTRAN is configured to not trigger any handover to 5GS.

A message flow with further IMS signaling information is depicted in Figure 9. In this example, we use a redirection command to E-UTRA and assume a mobile originated call and N26 interface supported by the network:

Figure 9: EPS fallback signaling procedure



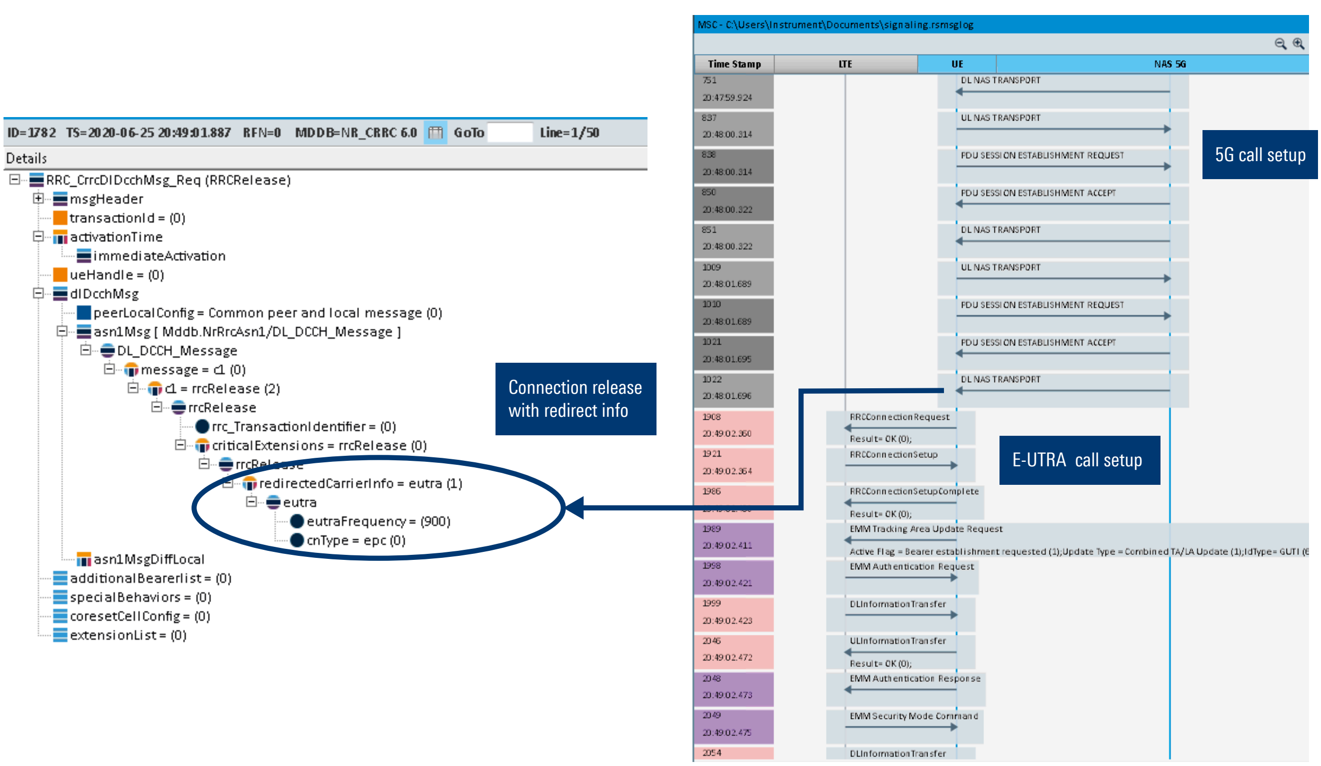
With the step 1 procedure as further explained in Figure 4, the UE registers to 5GMM. The assumption is that the UE settings are voice centric, S1 mode is preferred and the network supports the N26 interface plus voice services. During the registration procedure, the UE and network exchange their capabilities. EPS fallback can be indirectly triggered by the UE. If the UE capability flag `UECapabiltyInformation-NR` sets the indicator `VoiceOverNR` flag as FALSE, it can be understood as an indirect solicitation of EPS fallback and NG-RAN informs the AMF about the `IMSVoiceSupportIndicator` setting to FALSE in the `UERadioCapabiltyCheckResponse` message. In response, the AMF commands the NG-RAN to set the `RedirectionEPSFallbackIndicator` to TRUE in the `IntialContextSetupReq` message. When triggered by higher layers, the UE starts with steps 2 and 3 to establish a 5G NR PDU session for IMS as shown in Figure 6 and a general internet DNN PDU session in parallel.

The IMS registration procedure in step 4 provides some voice-specific details. Like in general IMS sessions, the network assigns an IP address to the UE and informs about the P-CSCF address. The SIP signaling messages REGISTER and SUBSCRIBE contain the primary-access-network-info (PANI) [Ref. 16] as "3GPP-NR-FDD" or "3GPP-NR-TDD" and the SIP definition of a cellular network with parameters such as mobile country code

(MCC), mobile network code (MNC), tracking area code (TAC) and NR cell identity (NCI) (TS 24.229). In the above example, the UE registers via 5G to IMS; thus, the TAC has a length of 6 hexadecimal digits (as length 4 in the LTE case) and NCI is present as well. Via the SDP, the UE requests the establishment of a voice call based on the enhanced voice service (EVS) audio codec. To indicate a pending response, the IMS sends the 183 session in progress message. During the dedicated QoS flow establishment and resource reservation procedures, 5GC decides upon EPS fallback for the voice call because VoNR cannot be established. This decision is either based on previous UE solicitation of EPS fallback or triggered due to missing VoNR support for 5GC. As a consequence, the NR-RAN initiates the radio resource control (RRC) connection release (either via the *RRCRelease* or *HandoverRequest* command) with redirection to E-UTRAN info to fall back to EPS. As in our example, we are assuming there is support for the N26 interface between 5GC and EPC. This allows the procedure for a TAU and the continuation of the DNN and IMS PDU sessions; thus, the UE and P-CSCF IP addresses are preserved. In the TAU message, several parameters are set to specific values: The field containing the old GUTI is set with the "5G-GUTI" value while the EPS bearer status is set with "internet and IMS PDU" as the description and "active" as the status information. With the SIP message RE-REGISTER, the UE sets a new PANI equal to "3GPP-EUTRA-FDD" as the new network access identifier. The final step 6 in this call setup procedure is the establishment of a voice bearer inheriting QCI = 1 for voice.

As examples of real message logs, the following figure contains two extracts from a signaling procedure executing an EPS fallback scenario with the R&S®CMX500 radio communication tester [Ref. 24]. First, the messages on the right indicate the establishment of a PDU session. The extract given here indicates in fact two PDU sessions: one with default 5QI and the second with IMS signaling 5QI details. Via RRC messages (not shown in this extract), the 5G NR network triggers an RRCRelease message with redirection indication to E-UTRA. The latter message is shown as an extract on the left side of this figure.

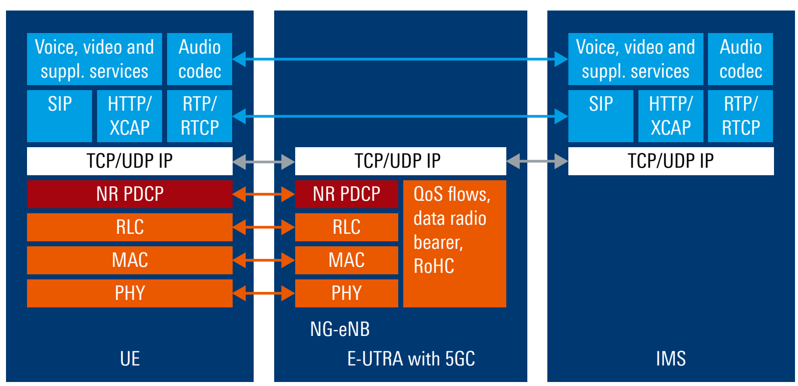
Figure 10: EPS fallback signaling scenario extract from the R&S®CMX500



2.3 Voice services using NG-eNB

Since 5G allows various deployment methods, multiple connectivity options are the consequence. For example, option 4 and option 7 introduce the 5GC as the core network and update the LTE eNB to a **next generation eNodeB (NG-eNB)**. The objective is to offer core network services and application layer bearers with 5G QoS profiles in an early 5G deployment stage. This connectivity option likely includes the provision of voice services, and consequently the 5GC requires a connection to IMS to support such services. One aspect in this deployment scenario is that the UE is camping on the E-UTRA carrier in advance; thus, no handover is needed. The benefit is the shorter call setup time. In the protocol structure, the difference shown in the following figure is the update within the LTE protocol stack such that the packet data convergence protocol (PDCP) layer is upgraded from LTE PDCP to NR PDCP. The advantage is full control of the services – like in the current situation, the voice services by 5GC. This voice scenario does not necessarily require dual connectivity as in option 4 or option 7 of the connectivity scenarios. Thus, it can represent a feasible deployment for upgrading the existing LTE network with connectivity to 5GC in order to provide legacy services like voice over NG-eNB if no VoNR is possible due to lack of coverage. Obviously, the UE should support enhancement with the NR PDCP implementation, so it is not compatible to legacy networks. In such a case, the NG-eNB still needs to provide VoLTE functionality in parallel.

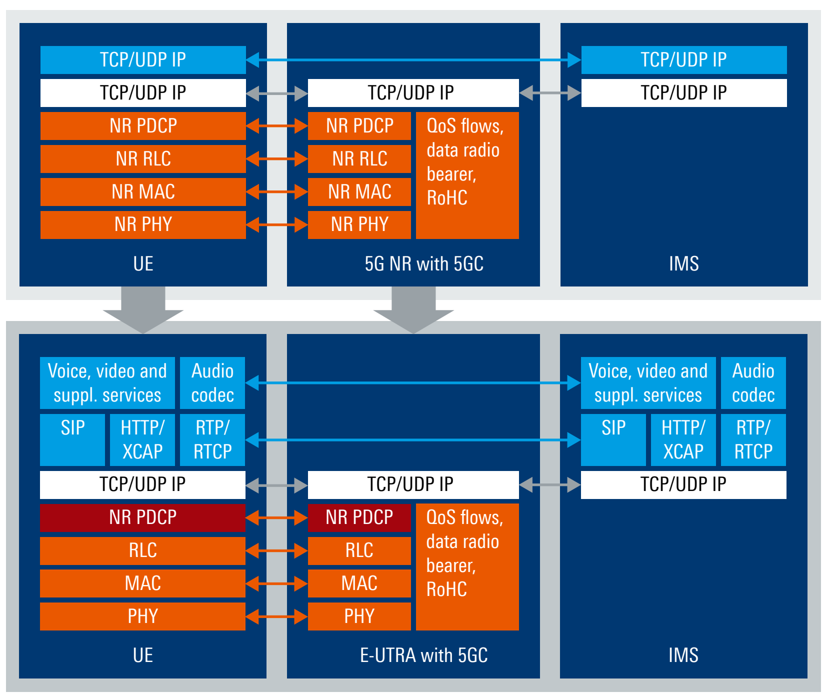
Figure 11: Voice services using NB-eNB



2.4 Voice services with RAT fallback

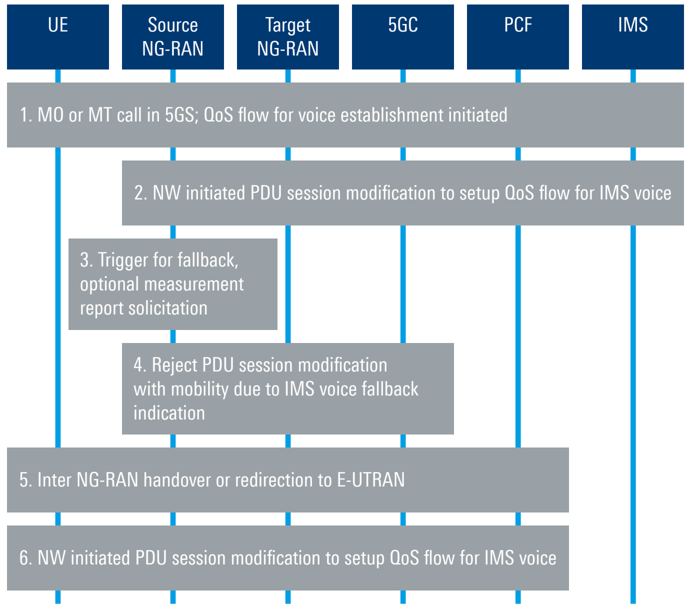
RAT fallback is a similar scenario to EPS fallback. The objective is related to the fact that 5G NR may not provide full voice service coverage. The major difference is that EPS fallback is a kind of double handover. First, it contains a RAT change from NR to LTE and second, a core network handover from 5GC to EPC as shown in Figure 11. The intention of **RAT fallback** is to support the enhanced eNB (NG-eNB) and the provisioning of 5GC as a core similar to the voice services offered over NG-eNB and 5GC, but with the difference that the UE has camped on NR previously. Thus, only the RAT is changed when the UE and network set up a voice connection. The objective is for the 5GC to define the QoS flow parameters for voice services at an early stage, e.g. even during the 5G NR radio bearer setup and maintain them as long as possible, even after the RAT change. TS 23.502 defines this procedure as inter-RAT fallback in 5GC for IMS voice because in a holistic view, the procedure includes any RAT as target. Thus, it may be used for handover from one NR RAT to another NR RAT, assuming operators run services on multiple NR RANs in parallel, or it can involve redirection to a target RAN like legacy E-UTRA, which appears to be the most likely case. Like EPS fallback, the transition is either initiated by a direct handover command or via a redirection procedure. The advantage is that this mode does not necessarily require dual connectivity and 5G NR does not need to provide full voice service coverage including RTP and RTCP; only a basic SIP signaling connection is needed. The drawback is similar to EPS fallback, i.e. a longer call setup time affecting the user QoE.

Figure 12: RAT fallback supporting voice services



The RAT fallback procedure can generally be used to trigger a RAT change (not necessarily E-UTRA since NR to NR RAT changes are also possible). The prerequisite is similar to the EPS fallback scenario; the UE is served by the 5GC and has one or more ongoing PDU sessions each including one or more QoS flows. The serving PLMN AMF indicated during the registration procedure that IMS voice over PS session is supported, triggering an IMS registration. The following figure shows the message flow.

Figure 13: RAT fallback for IMS voice



1. The UE camps on the source NG-RAN in the 5GS and MO or MT IMS voice session establishment has been initiated.

2. Network initiated PDU session modification to set up QoS flow for IMS voice reaches the source NG-RAN via the N2 interface.

3. If the source NG-RAN is configured to support RAT fallback for IMS voice, the source NG-RAN decides to trigger RAT fallback, considering the UE capabilities, network configuration and radio conditions. To ensure a reliable mobility scenario, the source NG-RAN may initiate measurement report solicitation from the UE including the target NG-RAN.

4. The source NG-RAN responds indicating rejection of the PDU session modification to set up QoS flow for IMS voice received in step 2 by PDU session response message towards the SMF via AMF with an indication that mobility due to fallback for IMS voice is ongoing.

5. The source NG-RAN initiates Xn based inter NG-RAN handover or N2 based inter NG-RAN handover or redirection to E-UTRA connected to 5GC.

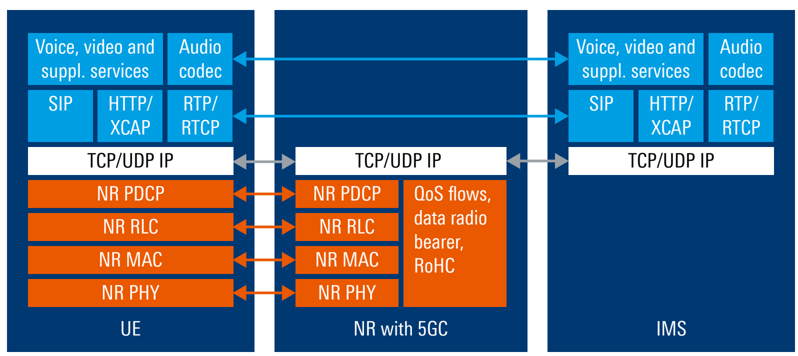
6. After completion of the inter NG-RAN (inter-RAT) handover or redirection to E-UTRA connected to 5GC, the SMF re-initiates the PDU session modification to set up QoS flow for IMS voice. The SMF reports about successful resource allocation and access network information.

The IMS signaling related to IMS voice call establishment continues after step 1 as in legacy VoLTE connections. At least for the duration of the IMS voice call, the target NG-RAN is configured to not trigger inter NG-RAN handover back to the source NG-RAN.

2.5 Voice over NR (VoNR)

Voice over NR represents the voice services provided by the 5G RAN, 5GC and IMS. Besides assumed support for voice within all the involved entities, IMS is integrated into the deployment scenario. The advantage is that IMS manages (like in VoLTE) the PDU session establishment with the relevant QoS flow for optimized voice quality. The prerequisites for VoNR are support for IMS voice over PS by the UE, signaled support for IMS voice and the emergency service support indicator by the network. The assumption is also that the 5GC is available as the core network and most likely the deployment option 2 representing 5G standalone is the underlying infrastructure. There is the possibility of supporting VoNR in option 3, i.e. NSA mode as well, but most likely operators deploying option 3 will go for voice connections via LTE (see chapter 2.2.4). Due to the proliferation of voice services, VoNR can be considered as a prerequisite for successful 5G deployment in standalone operation, e.g. option 2 deployments. The VoNR protocol stack includes the 5G NR stack on the radio link layers. On the application layer, there is full support for IMS and voice services containing the relevant speech codecs, i.e. EVS as demanded by the 3GPP. Although it is not directly related to VoNR support, support for emergency services by 5GC and NR is thus strongly recommended; otherwise, several UEs would likely refrain from camping on NR cells.

Figure 14: Voice over NR (VoNR)



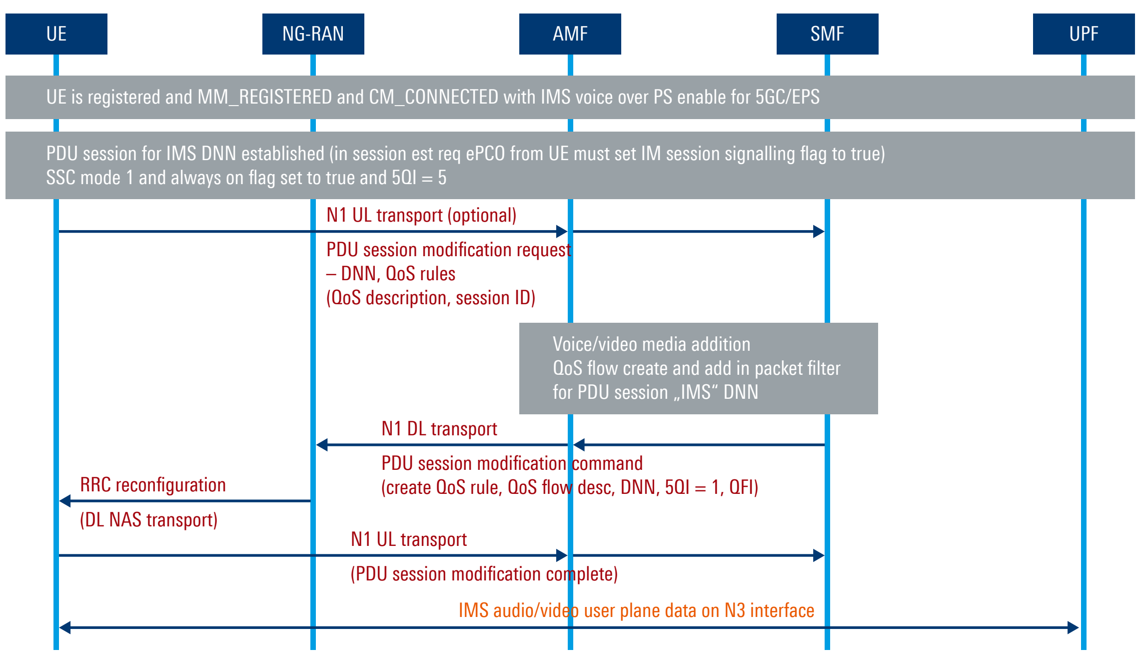
Handling of voice requires that both NR and UE support the QoS flow for voice over the radio access, i.e. QoS flow establishment must be supported by the gNB. The VoNR QoS consideration supports QoS flows for conversational voice and video, for IMS signaling and for non-GBR voice or video for MSRP services. It is worth mentioning that a UE depending on RCS support parameter settings may have two IMS registrations (see chapter 2.2.3). To fulfill the voice gap KPIs and avoid dropped calls, a certain relationship and interconnection between 5GS and EPS are needed to support mobility scenarios, i.e. a traditional inter-system handover from VoNR to VoLTE.

Although not a mandatory requirement but still strongly recommended, in a deployment with support for voice in 5GS, both SMF and UPF are interconnected via the S5 interface and tight interworking between AMF and MME is ensured by the existence of the N26 reference point. Complying with this recommendation increases the chances of providing seamless inter-system mobility with good voice characteristics and short handover interruption times.

Such an inter-system handover initiates transfer of all PDU sessions from 5GS to EPS and all QoS flows in the IMS PDU session/IMS PDN are transferred between AMF and MME, using inter-system handover signaling over N26. The SMF and UPF ensure IP address preservation and QoS mapping between 5QI and traffic flow templates (TFT) for the QoS flows in the IMS PDU session. Handover of EPS to 5GS follows the same procedures. In a real deployment, a phased introduction of handover capabilities is possible, starting with the one-way handover (NR in 5GS to LTE in EPS). The two-way handover or reverse handover from EPS to 5GS may be supported at a later deployment stage. In the case of the one-way handover, the phone stays on the underlying LTE network during the rest of the call, even if it moves back into NR coverage.

The message flow for VoNR follows the connection setup message flow in a VoLTE situation [Ref. 6] except that instead of E-UTRA and EPS, the 5G RAN and 5GS are involved. First, the serving PLMN AMF sends an indication towards the UE during the registration procedure to indicate whether an IMS voice over PS session is supported in the 3GPP access network. A UE with "IMS voice over PS" voice capability over 3GPP access takes this indication into account when performing the core network domain selection. The UE and network establish a PDU session for IMS DNN with QoS flow 5QI = 5 and SSC mode as 1 and the ON flag is always set to TRUE. Within this procedure setup, the UE includes extended protocol configuration options (ePCO) in the PDU session establishment request to the AMF. In this signaling container, the UE includes the P-CSCF IPv4/IPv6 request information element to indicate an IMS DNN target [Ref. 7]. Furthermore, the AMF forwards these ePCO options towards the SMF. The SMF fetches the P-CSCF addresses based on the DNN profile, which maintains IMS-related data and includes the P-CSCF IPv4 or IPv6 address in an N1 message towards the AMF. The SMF does not include the P-CSCF address if the UE does not set the P-CSCF container options in the ePCO field. Optionally, the UE can request a PDU session modification in case it wishes to change QoS rule. On the basis of the selected media or the voice or video codec, the network sends the session modification complete with negotiated QoS parameters that will be confirmed by the UE with the modification complete message. After these QoS and media setting agreements, the UE and the UPF start the user plane data session using the agreed audio or video codec on the N3 interface.

Figure 15: Voice over NR message flow



2.5.1 VoNR radio parameter support recommendation

Support for voice services mainly involves integration and support for IMS connected to 5GC, but nevertheless to ensure the best QoS for voice and video, a recommendation paper has been published [Ref. 8] that also describes certain lower layer functionalities. The network and UE should support these radio layer features. To support voice services with sufficient QoS, these protocol layers should support the following features:

PDCP layer – Robust header compression methods. One of the functionalities provided by the PDCP layer is RoHC as defined in TS 38.323. At a minimum, the UE and network must support the "RTP/UDP/IP" profile (0x0001) to compress RTP packets and the "UDP/IP" profile (0x0002) to compress RTCP packets. The UE and network must support these profiles for both IPv4 and IPv6 address allocations.

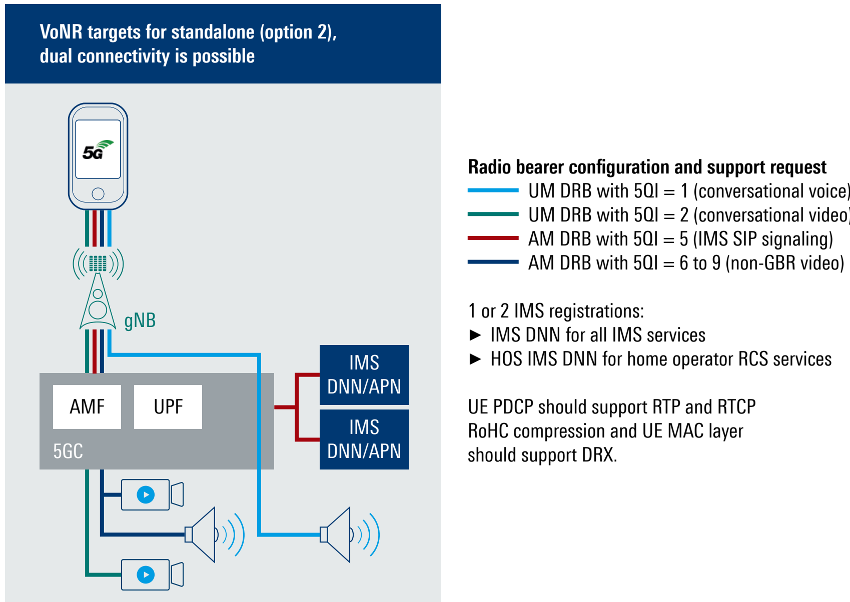
Radio bearers – To support 5G voice and video services, the UE and network establish data and signaling radio bearers with a certain QoS profile. The RLC layer offers transport services in acknowledged mode (AM) and unacknowledged mode (UM). For IMS signaling transfer, the UE and network establish an AM data radio bearer (DRB) with 5QI = 5. An additional AM DRB with 5QI as one of the values 6/7/8/9 is likely to be established concurrently for non-guaranteed bit rate (non-GBR) services. Depending on the service being either voice or video as suggested by the 3GPP, the UE and network set up an UM DRB with 5QI = 1 for voice and/or 5QI = 2 for video. One suggestion to avoid timeouts is that the NG-RAN should set the discard timer (discardTimer) for the IMS carrying DRB to a value of "infinity".

Discontinuous reception (DRX) mode – To maximize the lifetime and efficiently manage UE battery consumption, [Ref. 8] suggests that the UE and network should support MAC layer DRX functionality.

PHY layer settings – There are no direct recommendations concerning VoNR support affecting the physical layer in documents such as the 3GPP specifications or [Ref. 8]. 5G NR does not specify a feature like TTI bundling known from E-UTRA. Since Release 16, it has been possible to schedule via downlink control indicator (DCI) certain repetitions for the physical uplink shared channel (PUSCH), but there is no automatic bundling for the downlink direction. The RRC layer can schedule radio resources in semi-persistent mode (SPS). Since voice and video are characterized by a kind of synchronous data flow, SPS could represent a scheduling mechanism to reduce the signaling overhead in VoNR connections. However, this is more of a recommendation for physical layer scheduling instead of an actual requirement.

One of the characteristics of voice is its relative non-delay tolerance and its requirement for a certain data rate. For this reason, a GBR DRB is recommended for voice services. [Ref. 8] classifies non-GBR bearers as not suitable for IMS based voice services.

Figure 16: Voice over NR radio layer requirements



VoNR IMS signaling and QoS considerations

As a summary of IMS support in VoNR, this chapter briefly discusses signaling flow aspects and QoS considerations. There can be two IMS registrations: one is the default IMS APN/DNN and the second is an optional HOS IMS DNN. By default, the UE registers to the well-known IMS and obtains the single network slice selection assistance information (S-NSSAI), an IPv4 or IPv6 address and discovers the P-CSCF address. The IMS signaling uses 5CQI = 5 and is solely reserved for IMS signaling. The UE should prevent non-IMS applications from using this QoS flow.

Optionally for RCS service support, the UE may register to a home operator (HOS) IMS DNN concurrently. This second QoS flow using the same 5QI may be used for home operator specific HTTP signaling messages with XCAP or HTTP content. Depending on the service, [Ref. 8] suggests 5QI = 1 for voice, 5QI = 2 for video and 5QI = 6 to 9 for non-GBR voice/video. Note that emergency services share the same QoS flow as conversational voice. A detailed description of further IMS signaling parameters and features for voice services can be found in [Ref. 8].

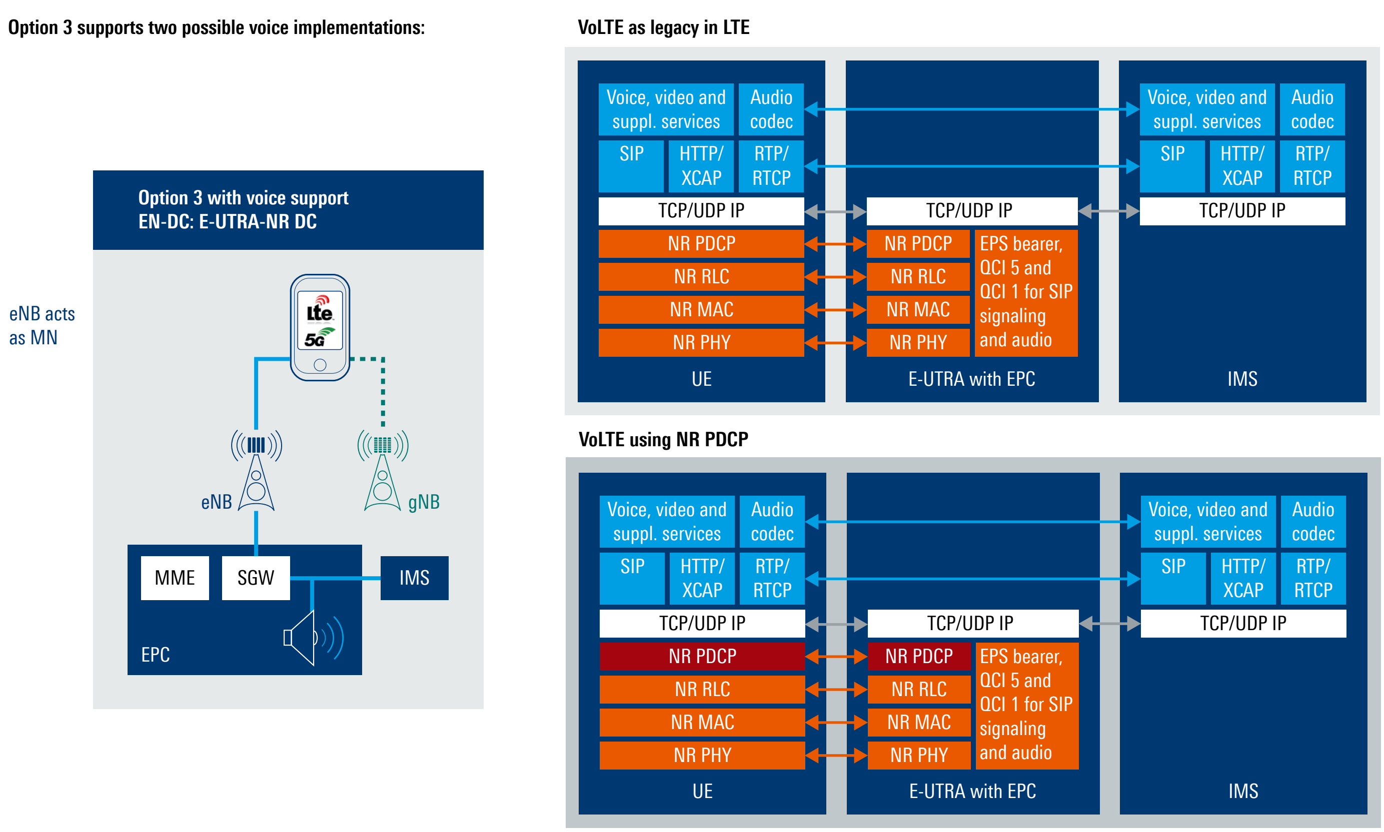
2.6 Network deployment and connectivity options supporting voice

The objective of this chapter is to provide an overview of the network deployment and connectivity options with a focus on how they support the provision of voice services. Previously, several voice scenarios were described with a focus on the protocol and bearer concept and the underlying architectural aspects. Now, these same scenarios are discussed again from the perspective of the underlying deployment options.

Option 3 supporting voice services

Option 3 EN-DC is the NSA deployment in 5G. Thus, the LTE connection is mandatory. With this option 3, the voice services are supported by E-UTRA and the EPC core network. According to TS 37.340, the primary cell group (PCG) (or primary bearer) either supports the LTE PDCP protocol layer or the NR PDCP. Consequently, there are two possible ways to implement voice services in network option 3 mode: legacy VoLTE or enhanced VoLTE using the NR PDCP. The following figure simplifies these implementations of voice services; only the logical flow of voice is depicted, summarizing coded speech as user plane data and SIP signaling. The dual connectivity between LTE and 5G is only depicted symbolically. The advantage of this voice implementation is that it does not require any upgrade for the existing voice supporting infrastructure – except for the minor transition from PDCP to NR PDCP.

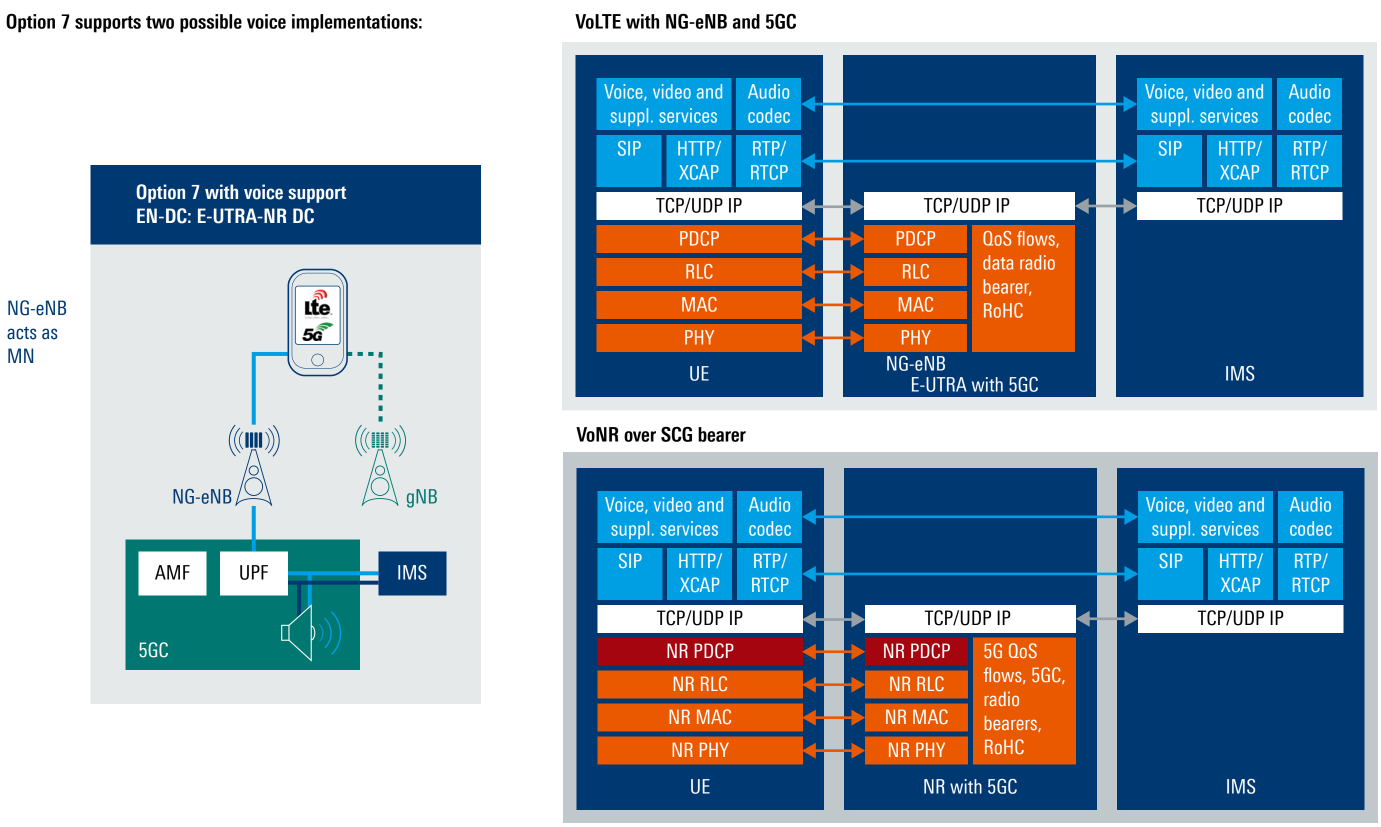
Figure 17: Network option 3 for NSA (EN-DC) supporting voice services



Option 7 supporting voice services

Option 7 can be seen in the background of non-standalone access (NSA) schemes. It represents the NGEN-DC mode including the connection to 5GC and an upgraded eNB to NG-eNB but still with LTE as the primary cell RAT. It provides an LTE PCG bearer and an NR SCG bearer in a dual connectivity scenario. This deployment offers the flexibility to either run voice services as enhanced VoLTE over NG-eNB including 5GC, or additionally support to run VoNR over the secondary cell bearer directly as VoNR and then provide a smooth transition from VoLTE to VoNR.

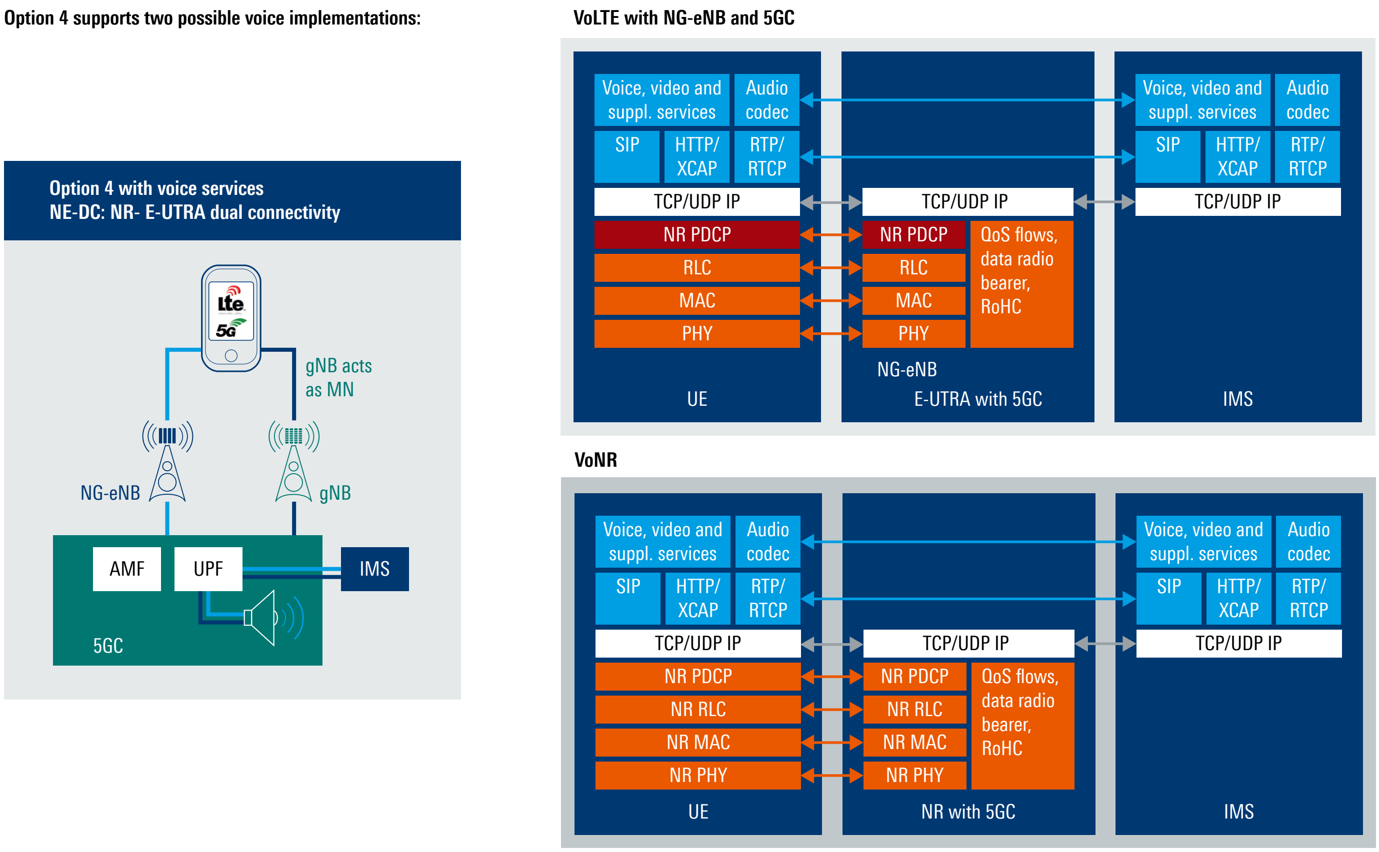
Figure 18: Network option 7 for NSA (NGEN-DC) supporting voice services



Option 4 supporting voice services

Option 4 can also be considered as a kind of non-standalone (NSA) mode. In detail, it represents the NE-DC mode including the connection to 5GC and an upgraded eNB to NG-eNB. Compared to option 7, however, the NR gNB is the PCG. It provides an NR PCG bearer and an LTE SCG bearer in a dual connectivity scenario. Similar to the option 7 connectivity scenario, this deployment offers the flexibility to either run voice services as enhanced VoLTE over NG-eNB including 5GC, or additionally support to run VoNR over the secondary cell bearer directly as VoNR and then provide a smooth transition from VoLTE to VoNR.

Figure 19: Network option 4 for NSA (NE-DC) supporting voice services

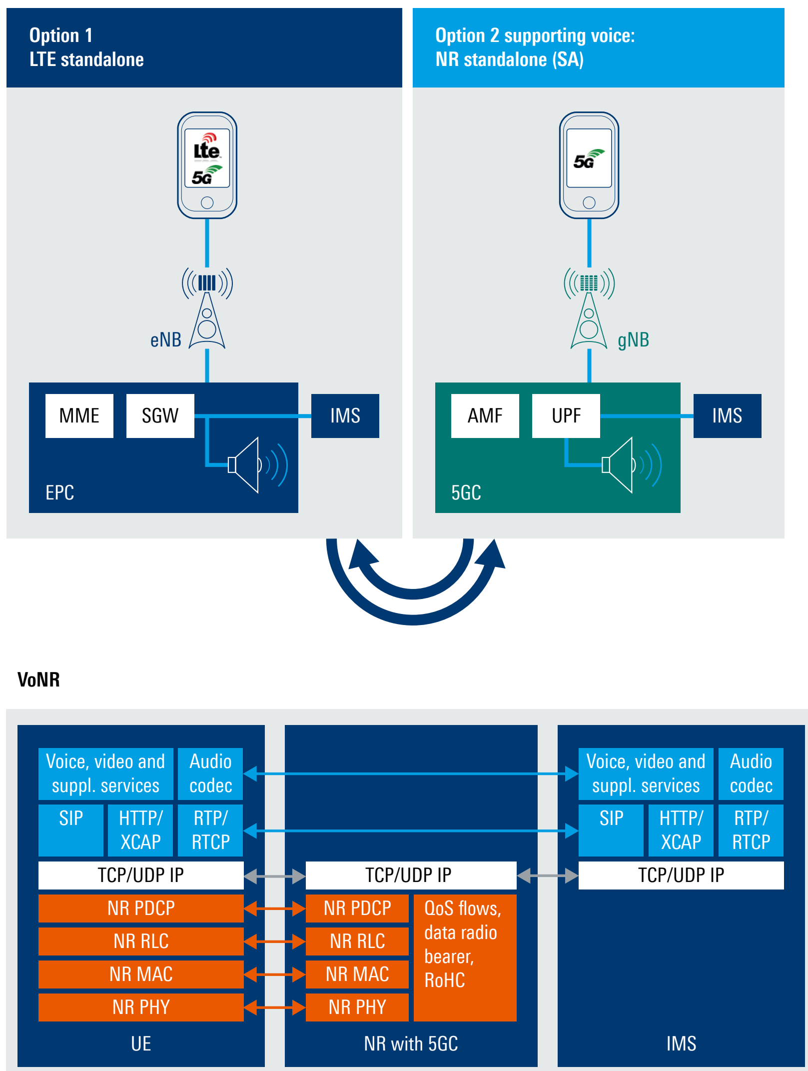


Option 2 standalone (SA) supporting voice services

Option 2 represents the standalone (SA) deployment of 5G NR. If voice services should be supported in the 5G system, it is completely up to the operator to make sure that IMS and the speech codecs are fully supported. The voice services are offered based on the technology and methodologies described as voice over NR (VoNR). Just for completeness and as is also known from legacy technology deployments (e.g. LTE with CSFB), in the option 2 network deployment it is very likely that an LTE carrier provides radio coverage in addition to NR radio coverage. Thus, many of the previously described voice scenarios are possible as well, i.e. EPS fallback providing a handover during connection setup from NR to LTE, or a RAT fallback if the LTE NG-eNB is connected to the 5GC. Further details on these setups can be found in [Ref. 2].

Figure 20: Network option 2 for SA supporting voice services

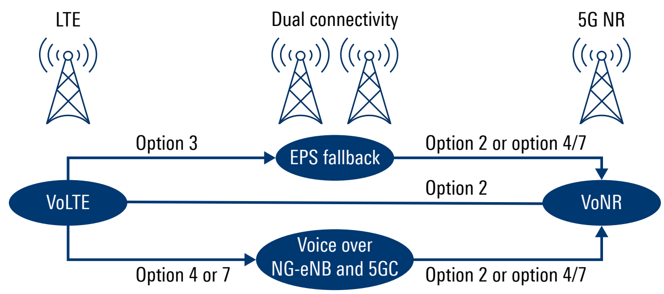
Option 2 supports VoNR with optional EPS fallback or RAT fallback depending on coverage



Strongly recommended: LTE and 5G coexisting in parallel to support inter-system mobility for best voice QoS

Figure 21 attempts to depict the various voice services in 5G related to the network deployment options. Of course, this is a simplified view. Real implementations are naturally more complex and allow mixed modes depending on the UE capability support and network maturity. The RAT fallback mode is not directly depicted here since it can be understood as a similar scenario to voice over NG-eNB with 5GC support. The only difference is the assumption of whether the UE camps before call setup on the E-UTRA carrier or on the NR carrier and a subsequent handover or redirection procedure is needed.

Figure 21: Possible transition scenarios from VoLTE to VoNR in relation to network deployment scenarios [Ref. 2]

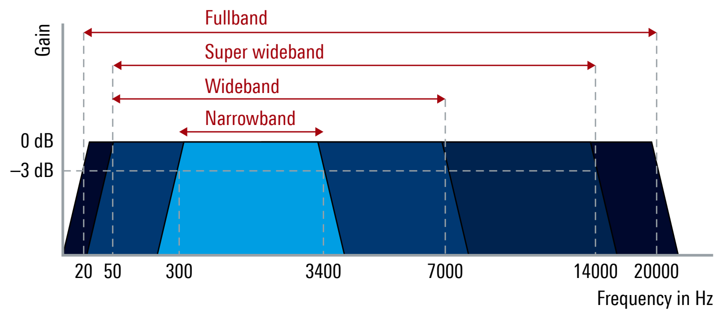


2.7 Speech codec aspects and EVS

It is not our intention to go back into history to the very beginnings of telephone services introduced by Johann Philipp Reiss and Alexander Graham Bell as the fathers of modern communications. Voice transmission over a channel suffers the limitation of data rate versus the requirement to provide audible services. In the early days of 2G (GSM), the limitation to a maximum throughput of 9.6 kbps led to the introduction of speech coding principles. Thus, the audio signal itself is not transferred directly as PCM digitized samples like in corresponding fixed-line telephone services such as ISDN, but instead a "digital voice coder model" of the audio signal is transferred. The basis for this speech codec approach is nevertheless a first step towards audio bandwidth limitation and a digital sample with a certain quantization ratio. The first GSM full-rate speech codec restricted the audio bandwidth to a 300 Hz lower boundary and a 3.4 kHz upper boundary. With a sampling ratio of 8 kHz, the limitation to a maximum throughput of 9.6 kbps could be fulfilled. There have even been notions of using a half-rate speech codec for greater network capacity. Facing competition with fixed-line networks and the voice quality offered there, the trend in wireless communications has obviously moved in the direction of better overall speech quality. This is first achieved through higher audio bandwidth and a higher sampling ratio for lower granularity in the quantization. The bandwidth evolution ranges from narrowband (NB) via wideband (WB) to super wideband (SWB) and ultimately to fullband (FB), covering the audible frequency range of a typical human ear from 20 Hz to 20 kHz.

Figure 22: Evolution of audio bandwidth

- 300 Hz to 3400 Hz: narrowband (NB)
- 50 Hz to 7000 Hz: wideband (WB)
- 50 Hz to 14000 Hz: super wideband (SWB)
- 20 Hz to 20000 Hz: fullband (FB)



In later releases, the concept of the adaptive multirate speech codec (AMR) was introduced to cope with the fluctuating rate due to changing conditions on the radio interface. The speech coder provides multiple speech codec rates and depending on the current radio link quality or channel rate, the most appropriate speech rate is selected. Lower speech codec rates allow more overhead in the channel coding and ensure a more robust voice call if radio conditions deteriorate. The speed can be switched every 20 ms, which is the duration of one speech frame. Tandem free operation (TFO) in the context of AMR describes the agreement that in a bidirectional communications scheme, the same codec is used in either direction. To enable interoperability and future longevity of VoLTE and VoNR, the GSMA has published a requirement document [Ref. 8]. Besides a list of speech codecs that should be supported by the UE, a detailed description of how the SDP should indicate and select the available audio codecs is also provided in this document.

The motivation for introducing **enhanced voice services** (EVS) is to allow a combination of high-end audio such as music and voice [Ref. 3]. In commercial networks, for example, there is a product known as Full-HD-Voice representing an EVS speech codec that is already deployed in several LTE-Advanced networks. Initial speech codecs developed in GSM focused on voice services only while newer codecs focus on high-end multimedia services. To ensure interworking with legacy voice codec technologies, EVS supports the nine codec rates of AMR-WB. This is known as interoperable mode (AMR-WB IO).

The audio encoder takes its input and can produce output at the decoder in the form of a 16-bit uniform pulse code modulated (PCM) signal at sampling frequencies of 8 kHz, 16 kHz, 32 kHz or 48 kHz. The audio may originate from and terminate within the audio part of the UE or from the network side or from the public switched telephone network (PSTN) via a narrowband 13-bit A-law or μ-law (8 kHz) PCM conversion or wideband (16 kHz) 14-bit uniform PCM conversion.

The source codec offers a total of eleven bit rates with support for various audio bandwidths as the EVS primary mode. For legacy interworking, nine different speech codec bit rates (AMR-WB) are supported. In detail, the source codec maps an audio sample (20 ms) as input into a 16-bit uniform PCM format resulting in encoded speech blocks. The EVS codec employs a hybrid coding scheme combining linear predictive (LP) coding techniques based upon algebraic code excited linear prediction (ACELP), predominantly for speech signals, with a transform coding method for generic content. Like legacy codecs, voice activity detection (VAD) may signal discontinuous transmission (DTX) instead of non-existing audio and the receiving entity will play comfort noise generation (CNG) audio signals to feign link maintenance and save bandwidth. The EVS codec is capable of switching between these different coding modes without artefacts (TS 26.445).

Figure 23: EVS modes, bit rates and audio bandwidths

EVS primary mode ← EVS → EVS AMR-WB IO mode

EVS primary mode:

Source codec bit rate (kbit/s)	Audio bandwidth supported	Source controlled operation available
7.2	NB, WB	yes (always on)
8.0	NB, WB	yes
9.6	NB, WB	yes
13.2	NB, WB, SWB	yes
13.2 (channel aware)	NB, WB, SWB	yes
16.4	NB, WB, SWB, FB	yes
24.4	NB, WB, SWB, FB	yes
32	WB, SWB, FB	yes
48	WB, SWB, FB	yes
64	WB, SWB, FB	yes
96	WB, SWB, FB	yes
128	WB, SWB, FB	yes

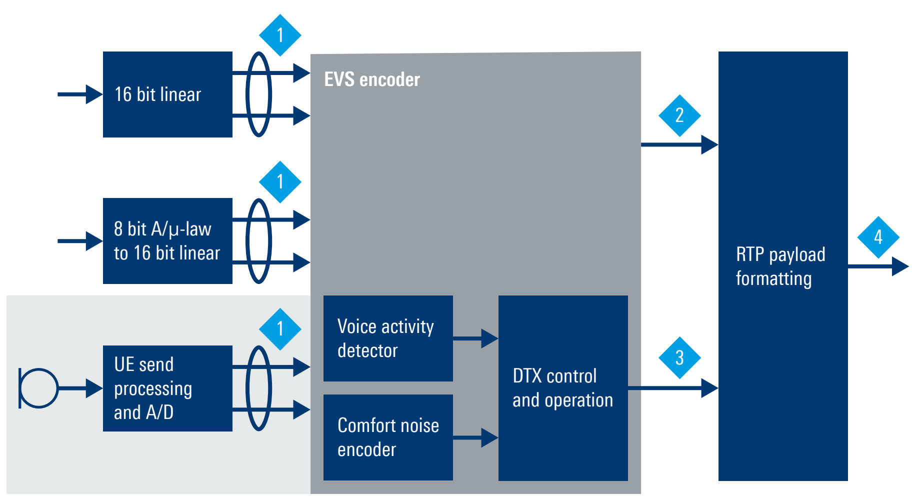
EVS AMR-WB IO mode:

Source codec bit rate (kbit/s)
6.6
8.85
12.65
14.25
15.85
18.25
19.85
23.05
23.85

AMR-WB interoperable mode for legacy codecs compliance

Since our objective is to provide a concise introduction to the speech codec evolution in order to better understand voice aspects in 5G, enhanced voice services (EVS) are illustrated in Figure 24 in an exemplary manner.

Figure 24: Audio processing functions of EVS codec, TX side (TS 26.441)



1 16-bit linear PCM samples and sample rate (8 kHz, 16 kHz, 32 kHz or 48 kHz)

2 Encoded audio frame, 50 frames/s, number of bits/frame depending on the EVS codec mode

3 Encoded silence descriptor frames (variable frame rate)

4 RTP payload packets

The enhanced voice service speech coder consists of the multirate audio coder optimized for operation with mixed content signals (voice and music), a source-controlled rate scheme, a voice or sound activity detector and a comfort noise generation system together with an error concealment mechanism to combat the effects of transmission errors and lost speech packets (TS 26.441). Since speech packets are presumably transferred over a packet switched network, jitter buffer management ensures time-aligned output of the audio signal without excessive delays.

The focus of this chapter has been on codecs for voice. Other modern and popular cellular communications systems incorporate video communications. This requires support for and definition of video codecs. In TS 26.114, the 3GPP stipulated that a network and UE supporting video over NR (ViNR) services must support ITU-T Recommendation H.264 as a video codec. There exist various video codecs and due to their evolution, the GSMA has published a list of requirements. To ensure interoperability, these video codecs should be supported by the UE [Ref. 8]:

- ITU-T recommendation H.264: constrained baseline profile (CBP)
- ITU-T recommendation H.264: advanced video coding (AVC) or constrained high profile (CHP)
- ITU-T recommendation H.265: high efficiency video coding (HEVC) main profile

2.8 Supplementary speech services, emergency calls and SMS

2.8.1 Supplementary speech services

Along with organizations such as the GSMA and Open Mobile Alliance (OMA), TS 24.173 defines and promotes certain supplementary services for multimedia telephone calls (MMTEL). Although they are not directly related to 5G, [Ref. 8] recommends supporting these services in the interest of forward-looking service support and longevity of use cases. Besides direct IMS configuration parameters, the UE should also support a wide range of supplementary voice services. Among these voice services are well-known candidates such as calling party presentation, waiting indication, barring of incoming or outgoing calls, barring of international calls, ad hoc multi-party conferences, etc. See [Ref. 8] for the full list of supplementary services that are requested to be supported by the UE.

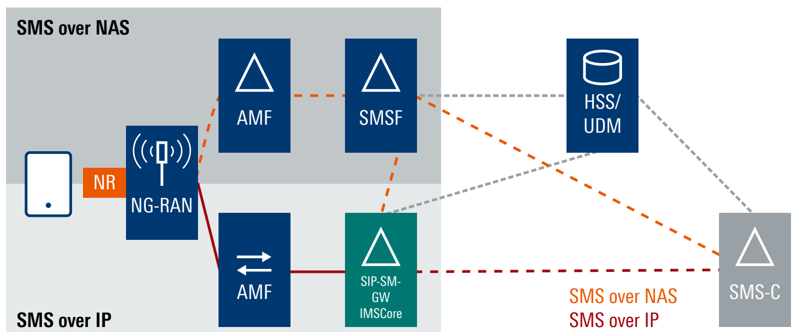
Supplementary MMTEL services include protocols like the XML configuration access protocol (XCAP) [Ref. 14], which is an application layer protocol allowing a client to read, write and modify application configuration data stored on a server. Multi-party conferences can be set up on the fly via a three-way session creation process. The IMS core network must support a certain list of conference attributes such as conference info, maximum user amount, user display, media support as voice and/or video and a status indication as connected or disconnected. As is familiar from legacy networks, 5G supplementary speech services should also support mechanisms for message and call waiting indications, originating or terminating ID restrictions and communications diversion. Triggered by security concerns such as spamming and stalking or just for avoidance of high costs, 5G IMS supplementary services also support a wide range of communications barring mechanisms.

2.8.2 SMS in 5G

The short message service (SMS) concept introduced in the early days of 2G remains an important use case in 5G. There are two methods of transporting SMS messages over the 5G access (similar to LTE). The first method is **SMS over IP** (SMSoIP) using IMS as a management and coordination network to ensure proper data transfer. The second method is **SMS over 5G NAS** (SMSoNAS), i.e. an approach to encapsulate the SMS data container into a 5G control message. In SMSoNAS, originated and terminated SMS messages are transported between the UE and AMF via NAS messages. According to [Ref. 8], both SMS transfer methods are mandatory for a UE claiming to be SMS-capable, while the network may select which options are offered. For the sake of completeness, we should mention that a short message can be transferred via RCS messaging services as well, but this is not the focus of this section. A short message service function (SMSF) has been defined in 5GS for handling these originating and terminating SMS using the legacy transport protocols MAP [Ref. 11] or Diameter [Ref. 12] for SMS exchange between the UE and SMS service center (SMS-SC). In SMSoIP, an SMS service gateway for IP based SMS (IP-SM-GW) must be present for originating and terminating SMS. This IP-SM-GW may also perform MT domain selection to other accesses (4G, 3G, 2G) while SMS transport between the UE and IP-SM-GW is via IP.

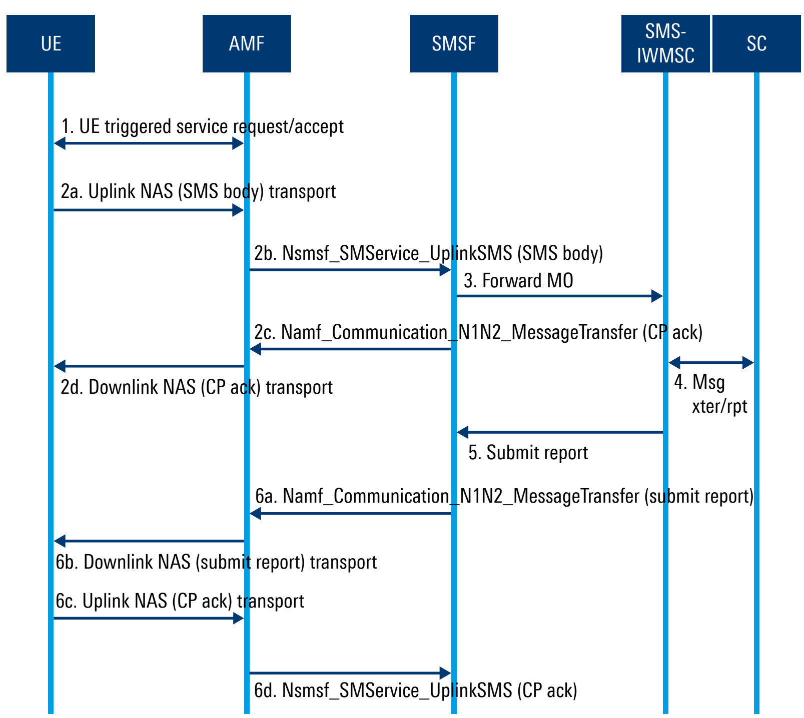
Both SMS over NAS and SMS over IP must be supported by a 5GS UE supporting voice, whereas each operator has the freedom to decide whether to support SMS over NAS, SMS over IP or both. These SMS solutions can be combined and can also be used in case EPS fallback is used for voice [Ref. 1]. During the registration procedure in 5GS, the UE includes an "SMS supported" indication in the registration request indicating the UE's capability for SMS over NAS transport. TS 23.502 provides further details on that registration procedure as well as the distinct SMS connectivity scenarios involving mobile originated or terminated SMS messages when the UE is in either the CM_IDLE or CM_CONNECTED state.

Figure 25: SMS in 5G [Ref. 1]



By way of example, the message flow for a mobile originating SMS over NAS in the CM_IDLE state is illustrated in Figure 26. The main function applied to the 5G system is the short message service function (SMSF). This represents the 5G function that provides the ability to deal with SMS and interconnect to the legacy SMS interworking MSC (SMSIWMSC). The SMSIWMSC ensures delivery of the SMS to the endpoint regardless of the RAT of the destination UE.

Figure 26: SMS transfer in 5G, message flow (TS 23.502)



2.8.3 Emergency services in 5G

Due to the proliferation of wireless communications technologies worldwide, cellular technologies are the number one access technology for emergency calls today according to first responder statistics. 5GS may offer emergency services directly or via fallback to E-UTRA. Support for emergency services is indicated via system information broadcast. Emergency services in 5G provide the possibility to set up an emergency call via IMS based emergency sessions, transferring emergency information such as the UE location and voice over an IP data network. Within the 5G system several possibilities exist, ranging from full support for emergency services within the 5G system through handover to legacy networks. Emergency services in 5GS behave like a VoNR connection, while during the IMS and RRC signaling flow, the RRC and SIP control messages indicate emergency as the use case. The PDN bearers, IMS registration and IMS connection setup behave according to the details described below. There is also the possibility that 5GS does not directly support emergency services. However, 5GS offers the possibility to hand over or redirect an emergency session to EPC. This procedure is defined as the emergency fallback procedure. Two derivates for 5G voice services exist, EPC and RAT fallback, and the same also applies to emergency services. With 3GPP Release 16, voice call handover to UMTS is also possible and is known as SRVCC. For emergency services, it is possible for the 5G RAN to trigger a SRVCC handover to UTRAN. Last but not least, depending on the current circumstances, the UE may also set up an emergency session via non-3GPP radio access, i.e. via WLAN.

Concerning the registration status details and service offering, one may differentiate between a UE with normal 5GMM context after the registration procedure and a UE with limited registration. For example, the latter case could be an emergency call permitted for a UE without previous USIM registration to the network. This NAS agnostic permission is broadcast via SIB1 in a 5G NR RAN. A UE that is 5GMM registered obtains permission to start emergency services per RAT and per registration area during the NAS registration process. TS 23.501 describes further details for these circumstances and also whether the UE needs to be fully registered, i.e. the GMM context is established or whether the UE is allowed to set up an emergency call in emergency registration mode, i.e. possible USIM free network access. The latter mode requires a legal indication by the national regulator whether a valid network subscription is a prerequisite or not. Depending on local regulations and the operator's policy, the network may allow or reject a registration request for emergency services from UEs that are identified to be in a limited service state. If the 5GS supports emergency services, the support is indicated to the UE via the registration accept message and this permission is valid per registration area and per RAT. This indication also includes the possibility of an emergency fallback. If the 5GS supports emergency service fallback, it indicates the support to the UE via the registration accept message and this indicator flag is a complement to the emergency service support flag. This indication means that the 5GS does not directly support emergency services and if needed, they will be handed over to legacy technologies. Thus, it prevents the UE from camping on NR. TS 23.501 defines the details of when the network indicates support for emergency services, i.e. the network supports emergency calls directly or the network supports fallback or SRVCC to the legacy networks E-UTRAN or UMTS. Support for emergency services is also signaled within the network from 5GC to the 5G RAN as it influences the possible setup of dual connectivity connections and the decisions about which RAT will be the primary cell RAT. A UE camping on a cell in a limited service state and not fully registered with valid 5GMM context may execute an emergency registration procedure to obtain information about whether the network supports emergency services (TS 23.501).

On the access stratum or RAT, two signaling aspects are worth mentioning in the context of emergency service signaling. At first glance, the procedures may appear similar to legacy technologies but there are some minor differences. The RAN signals support for emergency services in SIB1 with a flag, `ims-EmergencySupport`. Unlike legacy technologies, however, this flag indicates support for emergency services to UEs in limited service only, e.g. when a UE is not 5GMM registered or even without USIM. A UE that has a valid 5GMM context receives emergency service support during the registration procedure with important details as mentioned. This permission is valid per RAT and per registration area. In the uplink direction, the process is business as usual, i.e. the UE indicates with an RRC establishment cause set to "emergency" when it requests an RRC connection in relation to an emergency session. One can see the priority of the emergency situation since the UE signals an emergency situation with the first full and plainly visible UL message.

5G includes the concept of standalone, non-public networks (SNPN). TS 38.300 states that such SNPNs do not support emergency services.

2.8.3.1 Barring methods avoiding network congestion using access category and access identity

In the DL direction, the network has the option to restrict access to the network via sophisticated barring mechanisms known as uniform access control (UAC). Under high network load conditions, the network may protect itself against overloading by using the unified access control functionality for 3GPP access to limit access attempts by UEs. Some of the barring mechanisms are RAN-specific, such as random access channel (RACH) backoff, RRC connection reject, RRC connection release and UE based access barring mechanisms. Other mechanisms are NAS-specific in terms of where the definition of access categories and access identities happens; this is defined as UAC. Obviously, there is an interaction between the UAC on a higher layer and the barring info signaling on the AS layer. Depending on the network configuration, the network may determine whether certain access attempts should be allowed or blocked based on categorized criteria. Such criteria are access categories and access identities. The NG-RAN may broadcast barring control information associated with these access categories and access identities.

Such mechanisms allow congestion control even in emergencies, e.g. in a catastrophic situation, first responders typically apply plans in order to prioritize and cluster emergency messages. Another common solution could involve restriction of cell access to network operator business only for maintenance work or restriction of access to a certain kind of user or device group. 5GS defines access categories and access identities. When the UE needs to initiate an access attempt, the UE should determine one or more access identities from the set of standardized access identities and one access category from the set of standardized access categories. One important aspect here is that both the access categories and access identities are valid per access attempt; thus, they are not to be understood as static identifiers. To complete this procedure and allow certain operator-specific policies as well, there are operator-defined access categories to be associated with a given access attempt. TS 24.501 provides further details on these standardized access identities and categories along with what access events will trigger an access check before the attempt. Access identities could be priority settings such as a UE belonging to a mission-critical access group of devices, or a UE that has multimedia priority service (MPS) or belongs to one of the access classes 11 to 14. As access categories, TS 24.501 defines situations such as MT or MO voice or video calls, IMS signaling, access attempt for delay tolerant traffic, etc. A UE requesting emergency services uses access category 2 or access category 8 if there is a resume procedure for an emergency call. In the downlink direction, SIB1 indicates restriction parameters via the IE *uac-BarringInfo*. To allow higher flexibility, barring information can be configured to be valid for common access attempts via the IE *uac-BarringForCommon*, to be valid per PLMN via the IE *uac-BarringPerPLMN* or valid per access category and access identity via the IE *uac-BarringInfoSetList*. 5G NR introduces a more elaborate barring mechanism where a certain access category is combined with barring information. Furthermore, it is possible to provide access policies to a certain access identity within an access category. TS 38.331 defines the details of such barring information.

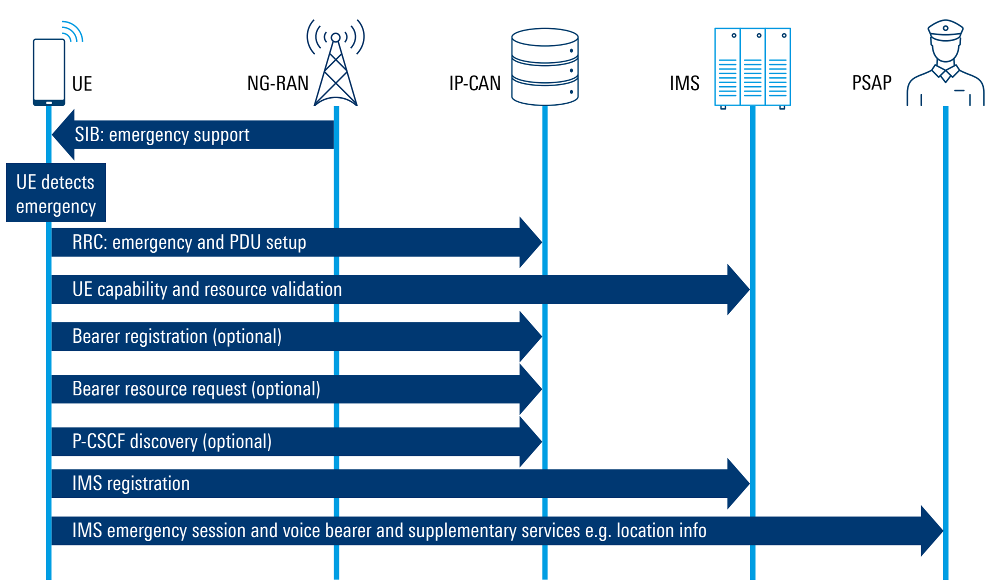
The network can configure multiple barring sets of this kind and combine them with the access category for which this information becomes valid via an index parameter. Furthermore, the parameter `uac-BarringForAccessIdentity` allows greater barring granularity since it supports barring policy definition per access category and per access identity. The barring method itself describes a `uac-BarringFactor` as a probability factor that the access attempt would be allowed during that access barring check. If such an access attempt is barred, the UE waits a `uac-BarringTime` (range from 4 seconds to 512 seconds) until a new access attempt is started. Since emergency service support depends on the RAT itself, there is a possible restriction in mobility procedures like inter-RAT handover or dual connectivity in case an emergency call is ongoing.

Besides emergency services and uniform access control, TS 22.153 specifies the service requirements for multimedia priority services (MPS). MPS allows priority access to 5GS to service users such as government-authorized personnel or emergency management officials.

2.8.3.2 Emergency services in 5GS

5GS may support emergency services directly, which requires 5GC to be connected to IMS since the connection will be an IMS emergency call and the 5G RAN supports emergency bearer services. If 5GS offers emergency services, it will indicate the permission to UEs in limited registration via the `ims-EmergencySupport` flag in SIB1 and via the registration accept message, valid per RAT and registration area, to UEs that are properly 5GMM registered. 5GS emergency service support behaves similar to VoNR; IMS is the control backend coordinating the SIP message flow and providing a PDU connection with the required QoS. RRC protocol messages indicate an emergency situation to establish an early PDU connection to an IP-CAN or data network. IP is the transfer protocol for emergency-related information like voice and optional assistance information like the UE location, etc. A high-level signaling procedure for an IMS emergency session is illustrated in the following figure.

Figure 27: IMS emergency services in 5GS – high-level message flow



As a prerequisite, we assume the proper emergency support indication from the network, either via SIB broadcast for UEs in a limited registration state or via registration accept to UEs in a fully 5GMM registered state. It is the responsibility of the UE to recognize and detect the emergency situation based on the dialed number, i.e. via dialing the known emergency numbers 112, 999, 911 or via explicit GUI selection. Next, the UE starts an SRB and DRB connection. The difference compared to a standard PDU connection is that here, there is RRC signaling of an emergency to obtain higher priority and optionally, some security procedures like UE authentication and ciphering enabling are skipped to reduce the call setup time. Unlikely but as an optional step, a UE that recognizes that it has insufficient resources or capabilities to establish an emergency call should terminate ongoing communications and suspend the radio connection. The objective is to set up a PDU connection to a so-called IP-CAN, i.e. an IP based access network. The IP-CAN should support emergency bearers; otherwise, TS 24.229 defines alternative behavior for the UE in this unlikely situation. Most commonly, this emergency bearer is a 5G PDU bearer connection with default settings. Optionally, the UE may need to register, i.e. obtain an IP address and a QoS flow. Secondly (also optional), the UE may negotiate the resources with the IP-CAN. The latter case is typically the QoS flow, but in 5GS, emergency services use a default QoS flow. The IP-CAN should be aware of the emergency call QoS and reserve as well as ensure the required bearer resources. Like in an IMS connection, the first signaling procedure is the P-CSCF discovery. Either the UE obtains the IP address of the P-CSCF via the 5GS bearer setup (most likely in emergency situations) or the UE has to start the P-CSCF query as in the standard IMS connection setup.

If the UE has sufficient credentials to authenticate with the IMS network, it should initiate an IMS emergency registration by providing its allocated IP address to the P-CSCF. The IMS registration request should include an emergency indication. TS 24.229 describes the details when the UE needs to perform an IMS emergency registration or not; both possibilities exist. The P-CSCF establishes a SIP connection to S-CSCF like in a standard IMS message flow. Note that for emergency services, the S-CSCF is also called the E-CSCF as the emergency service function. It is up to the implementation whether there is a difference between S-CSCF and E-CSCF, or they are a common entity and the use case distinguishes between the roles. The last step is that the E-CSCF establishes an IP voice connection to a public safety answering point (PSAP). It is up to local regulations to decide who behaves as a public answering point for emergency sessions. Most common are local police stations or ambulances/firefighters, but also specific help desk functions such as an emergency service help desk with a facility running their own SNPN are possible. Thus, as the final step, the UE should initiate IMS emergency session establishment using the IMS session establishment procedures containing an emergency service indication and optionally any registered public user identifier in case the UE has performed a previous emergency registration. Note that this describes a high-level message flow for IMS emergency call setup. Some of the message signaling steps are optional.

Further signaling details for an IMS emergency connection are discussed in the following section. There is the option for an emergency registration procedure that is further described in TS 24.501. A UE triggering such an emergency registration indicates within the registration request message the "emergency" purpose in the registration type IE. The AMF may then skip a UE identity request and authentication procedure, depending on local regulations. When contemplating an emergency connection, the registration procedure, especially the network-oriented registration accept message, provides details on what kind of emergency service is supported by the network. With the 5GS network feature support information element contained in the registration accept message container, the network informs the UE about support for specific features, such as IMS voice over PS session, location services (5G-LCS), emergency services or emergency services fallback. When initiating an emergency call, the UE upper layers take into account the IMS voice over PS session indicator, the emergency service support indicator and the emergency service fallback indicator for access domain selection. First, the IMS voice over PS session over 3GPP access indicator flag signals whether IMS voice services are supported in 5GS directly or not. Second, with the emergency service flags EMC and EMF, the network may describe details of emergency service support within 5GS. The emergency service support indicator for 3GPP access (EMC) indicates the network status as one of four options:

- 5GS does not support emergency services.
- Emergency services are possible when NR is connected to 5GCN.
- Emergency services are possible when E-UTRA is connected to 5GCN.
- Emergency services are possible when E-UTRA and NR are connected to 5GCN.

The emergency services fallback indicator for 3GPP access (EMF) indicates the network status as one of four options:
- 5GS does not support emergency services fallback.
- Emergency services fallback is possible when NR is connected to 5GCN.
- Emergency services fallback is possible when E-UTRA is connected to 5GCN.
- Emergency services fallback is possible when E-UTRA and NR are connected to 5GCN.

5GS divides support for emergency services into four different behaviors, similar to IMS emergency service support in EPC (TS 23.401). Thus, emergency services are offered to UEs in valid registration only, to UEs with valid IMSI authentication only, to UEs that provide their IMSI identity, or to all UEs (even anonymous access).

Within the 5GS entities, provision of emergency services requires storage of configuration data within the various functions. The first access entity is the AMF. It needs to contain emergency configuration data such as the slice selector identity S-NSSAI and the address of the emergency DNN or IP-CAN in Figure 27 above which is used to derive an SMF. The latter can also be statically configured. Optionally, the AMF may also store statically configured UPF information. Typically, the emergency service support permission parameters and emergency service configuration parameters (e.g. PSAP info and optionally the address of a location resource function LRF if the network needs to provide the UE location) in the AMF are handled according to local regulations. One common scenario is that emergency services are offered within the entire PLMN. In such a case, every AMF and at least one SMF should contain the emergency service configuration data. There are no specific architecture and protocol stack requirements for emergency service provision.

There is no direct mechanism to control QoS in an emergency service since the requirements range from unauthorized UE access through UEs with subscription to only emergency services. Therefore, the initial QoS parameters used for establishing emergency services are configured in the V-SMF (local network) in the SMF emergency configuration data. The QoS flows of a PDU session associated with the emergency DNN are dedicated to the IMS emergency session only.

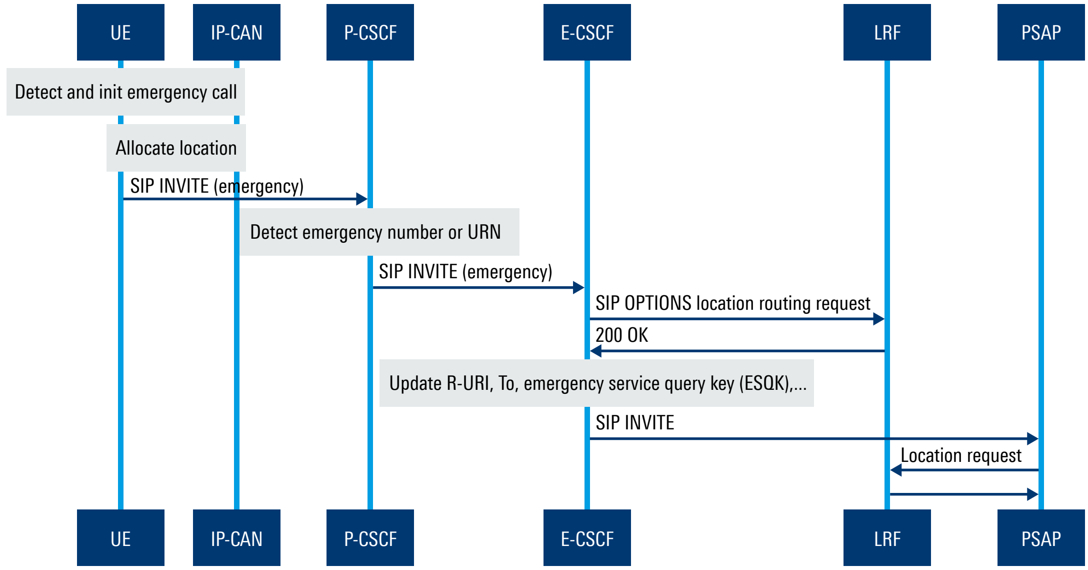
In 5GS, the flow and initiation of an IMS emergency session follow the same principles and concept previously defined in LTE. TS 24.229 defines details such as different connection criteria when the UE is aware of being in its home network, meaning it may skip certain security-related credentials or use default bearers and address configurations. As a radio technology agnostic management system, IMS provides supplementary services enhancing the information flow in combination with emergency services. It is possible for the RAN (as the AS) to recognize the emergency situation within an ongoing connection and trigger generation of emergency signaling towards the IMS. As requested by local authorities, location information such as GNSS positioning may be included in the SIP control messages.

Following the high-level message flow in Figure 27, a more detailed signaling message flow is shown in Figure 27. Due to the complexity, we omit the establishment of a 5G PDU connection and emphasize the IMS signaling aspects with a focus on emergency services only. As the first step, it is the responsibility of the UE to recognize the dialed number (e.g. 112, 119, 911 known as E911, 999) as an emergency number. Some operators even recognize a kind of "panic" number such as 9999 or 911111 as an emergency. Consequently, the UE sets the top-level services "SOS" within the universal resource name (URN) signaled to the IMS. The P-CSCF is the IMS entity responsible for recognizing emergency calls and prioritizing them over normal calls. To check whether an initial request is part of an emergency call, the P-CSCF compares the request URI to the emergency dial string (e.g. 112, 911), the **emergency universal resource name** (URN) and known PSAP SIP or TEL URIs [Ref. 4]. Beforehand, the UE may execute an initial emergency registration via the REGISTER message to the IMS. The emergency registration follows the general registration procedure in IMS as defined in TS 24.229 with these specific settings: In the contact header field of the SIP URI parameter, the UE includes the term "sos". In the "to" and "from" fields within the REGISTER message, the UE includes the public user identity (either the default value, a temporary value or a value obtained in a previous normal registration). To start emergency session setup via the INVITE message, the UE sets the URN parameter to high-level service type "sos" with optionally detailed service URNs, e.g. "urn.service.sos.ambulance" if the UE is aware of a medical emergency. TS 24.229 provides more details on UE behavior regarding emergency connection setup without previous registration. For example, the UE uses an anonymous ID in the INVITE message, sets the URN to emergency as described in the registration procedure and also includes its own IP address obtained from the IP-CAN. If available, the UE may include geolocation information in the INVITE message. A similar behavior is defined in cases where the UE performs an emergency registration before the connection setup. The only difference is the placing of the public user ID used during the emergency registration in the INVITE message. There is also the possibility to start an emergency connection setup within a non-emergency registration. The difference here is that the UE includes its identity such as a telephone number instead of a public identity. Further details on timer settings, abnormal emergency connection release or network-initiated deregistration, etc. are provided in TS 24.229.

An example of an emergency reject would look as follows: If the P-CSCF recognizes an emergency number or urn:service:sos, it responds back with *380 Alternative Service* and an XML body which contains the <ims-3gpp> element with the <alternative-service>.

A successful IMS emergency flow is shown in Figure 28. First, the UE identifies the dialed number as an emergency and sets urn:service:sos as the emergency identity signaled to the P-CSCF [Ref. 17]. The P-CSCF handles the registration requests with an emergency public user identifier, detects and prioritizes the emergency session and selects an emergency CSCF (E-CSCF) in the same network to handle the emergency session request. The emergency CSCF (E-CSCF) receives an emergency session establishment request from a P-CSCF and optionally requests the location resource function (LRF) to retrieve the UE location information. It is the responsibility of the E-CSCF to route emergency session establishment requests to an appropriate destination such as a PSAP like a local police station or an ambulance, including anonymous session establishment requests.

Figure 28: IMS emergency call sequence



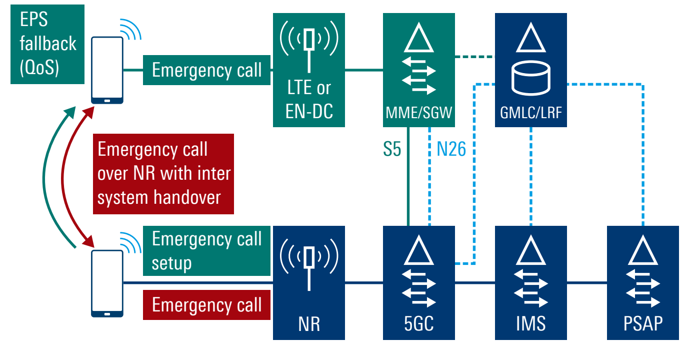
2.8.3.3 Emergency services fallback (ES-FB)

EPS emergency services fallback is an early handover of an emergency connection to E-UTRAN. This solution is new in 5GS, i.e. there is no equivalent in 4G. Similar to the fallback procedures for normal voice and depending on the core network and RAT support, the fallback can either be a RAT fallback so only the RAT changes from NR to E-UTRA, or it can be a system fallback where the fallback goes from 5GC to EPC. During the registration accept procedure, the network indicates the support for emergency services fallback to the UE. The UE indicates the service request "emergency" towards the AMF if support for emergency services has been indicated by the AMF in the registration accept message to the UE. Upon receiving the service request for emergency, the AMF interacts with gNB to perform EPS fallback. In this solution, there is no need for NR and 5GC to support emergency features other than what is needed for the service request for emergency handling. However, voice over NR (possibly including EPS fallback) has to be supported on NR and 5GC; otherwise, the UE would not even camp on NR.

If the 5GC has indicated emergency services fallback support for the routing area and RAT where the UE is currently camping and if the UE supports emergency services fallback, the UE should initiate the signaling message flow shown in Figure 29. The architectural concept of EPS emergency fallback is depicted in this same figure:

Figure 29: Emergency services fallback to EPS architecture

[Ref. 1]



The architectural background and circumstances decide which scenario is applied. In other words, it is first necessary to check which core network exists (5GC or EPC) and whether emergency services are supported, and additionally which radio access technology supports emergency services. The objective is to support various deployment scenarios for emergency services. The first situation is that the UE camps on 5G NR and the NR RAT does not support emergency services. This will trigger a RAT fallback as described in chapter 2.4, but only for emergency services instead of standard voice; thus, the IMS signaling is according to emergency services. The second situation can be a deployment including 5GC, but according to our assumption, 5GC does not support emergency services and a fallback to EPS is initiated as described in chapter 2.2.4.

Upon the QoS flow establishment request for emergency services, the network triggers either the EPS fallback procedure shown in Figure 8 or the RAT fallback procedure shown in Figure 13.

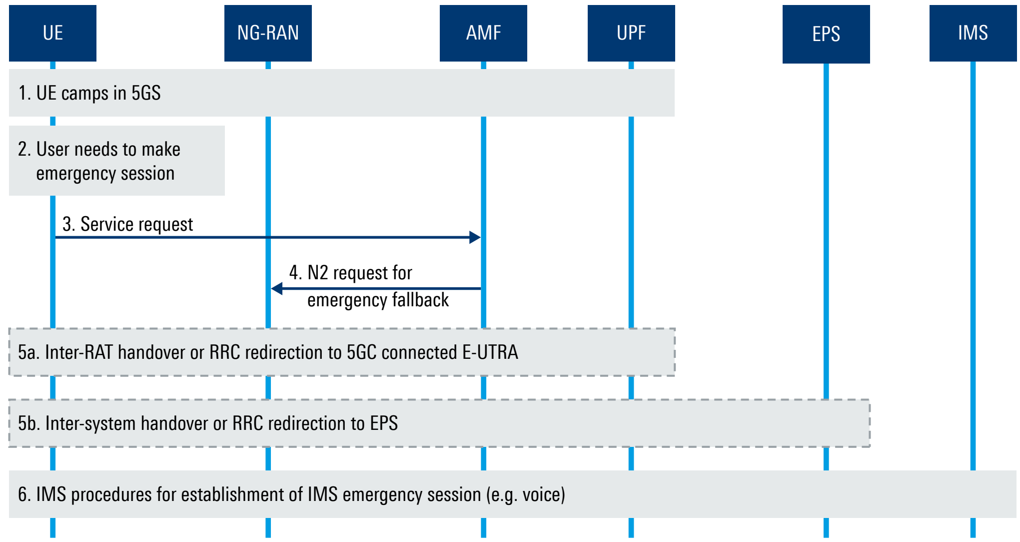
The emergency services fallback procedure follows the signaling flow shown in Figure 15. The assumption is based on prior signaling of emergency services fallback support to the UE to allow it to camp on the supporting RAT (either E-UTRA or NR). It is the responsibility of the UE to recognize the emergency situation (as described previously) based on the dialed number. With the service request message to the AMF, the UE signals the request for emergency services fallback. 5GC triggers the emergency fallback by executing an NG-AP procedure in which it indicates to NG-RAN that this is a fallback for emergency services. Depending on the core network availability and its support for emergency services, the AMF indicates the target core network to the RAN node. This distinguishes whether the handover is inter-RAT fallback or inter-system fallback. The AMF may forward the security context for UEs that are already successfully authenticated and registered to the corresponding RAN. Based on the target core network being either 5GC or EPC, the NG-RAN initiates one of the following procedures (TS 23.502):

- Handover or redirection to E-UTRAN cell connected to 5GC if the UE is currently camping on NR.
- Handover or redirection to E-UTRAN connected to EPS. NG-RAN uses the security context provided by the AMF to secure the redirection procedure.

If the redirection procedure is used, the network signals the target core network type (EPC or 5GC) in order to trigger the appropriate NAS procedures (S1 or N1 mode).

The final step in the signaling message flow after handover or redirection to the target cell is that the UE establishes a PDU session for IMS emergency services (see Figure 29).

Figure 30: Emergency services fallback to EPS – message flow



2.8.4 Automotive eCall in 5G

In May 2010, the UN General Assembly proclaimed the period from 2011 to 2020 as the decade of action for road safety. The European Union's contribution to this effort was to design **eCall, an automatic emergency call system.** There are several European standards by the ETSI summarized under the term eCall. Just to name one of them, CEN EN 16072 defines the Pan-European eCall operating requirements [Ref. 4].

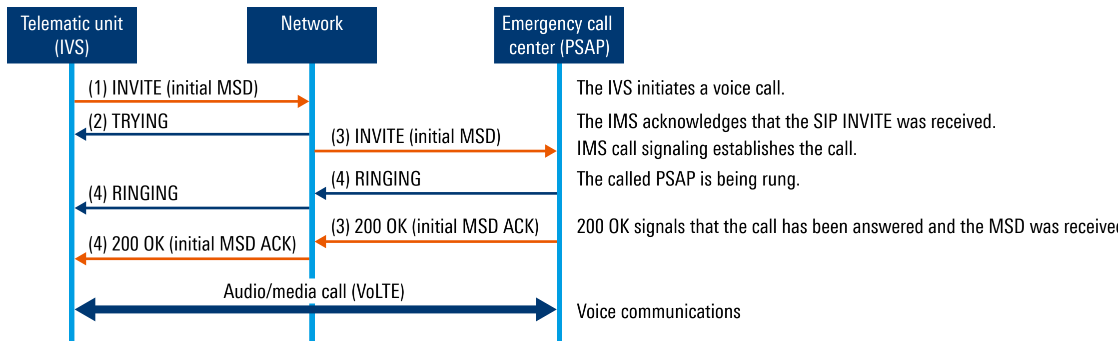
Since eCall is based on GSM radio technology and the lifecycle of a new car is typically greater than ten years, 3GPP specified eCall communications over UMTS in later releases. To ensure a future-proof technology over a much longer period, eCall evolves with 3GPP Release 14 into the **next generation eCall** (NGeCall) [Ref. 5]. The general working principle stays untouched but as a major difference, the radio access technology used to convey the emergency minimum set of data (MSD) is LTE instead of GSM. Thus, the voice call moves from circuit switched to packet switched and from single voice call to IP data.

NGeCall requires voice services offered by LTE (VoLTE) connected to IMS. With the IMS system, the minimum set of data (MSD) is sent in a SIP invite message during call setup. As 5G enters the communications world with its new radio system, 5GS must support the eCall type of emergency services to ensure the longevity of the eCall automotive emergency communications system. The SIB1 contains a network indicator flag *eCallOverIMS-Support* to indicate that the network supports eCall over IMS. Note that this flag is defined since 3GPP Release 14 and would also be included in the system information provided by E-UTRAN.

In the current standard, the existence of a USIM in the UE is mandatory; anonymous access is not allowed. The same applies for eCall over a non-3GPP radio access network. There is the possibility of a device supporting eCall-only mode, e.g. a vehicle based emergency telematic control unit (TCU) modem. Such a UE configured for eCall-only mode should remain in the RM-DEREGISTERED state, should camp on a network cell when available but should refrain from any registration management, connection management or other signaling with the network (TS 23.501). The UE may instigate registration management and connection management procedures in order to establish, maintain and release an eCall over IMS session.

Dispatching of the eCall connection on either 5G NR RAT or E-UTRA RAT depends on the support of both radio access technologies, the support of EPC and 5GC, and the interconnection among them. Depending on these circumstances and the eCall over IMS support flag, an eCall emergency session can be routed via 5G NR and 5GC to the IMS or there can be a fallback to E-UTRA with routing via either 5GC or EPC to IMS. There is no difference between the general message flow of an LTE based NGeCall or a 5G NR based NGeCall. Assuming the prerequisites are fulfilled (5G NR supporting IMS), Figure 31 shows a general IMS SIP message flow for such an emergency call.

Figure 31: SIP message flow for NGeCall



The details of the message flow between an emergency call triggering telematic control unit and the emergency call center (e.g. PSAP) illustrate the RAT-agnostic behavior of the SIP message content. One optional SIP feature as a difference can be the signaled URN; here, the UE can set the parameter "urn:service:sos.ecall.automatic" if this is an automatically generated eCall or "urn:service:sos.ecall.manual" if this is a manually triggered eCall. Once the emergency session is established and the minimum set of data (MSD) is exchanged, the PSAP operator has the option to establish a voice channel that is answered by the telematic control unit automatically. NGeCall extends this feature so the PSAP can request transmission of the MSD once again without interruption of the voice communications channel. In a major difference between eCall, as defined in the first setup based on GSM, and NGeCall, the MSD is no longer sent as inband circuit switched modem data but is included in the SIP message directly. The 140 bytes of information, including the position information for the caller UE, is transferred via SIP [Ref. 18]. The following screenshot, taken from the R&S®CMW500 wideband radio communication tester [Ref. 25], provides more signaling message details for the SIP INVITE message establishing an NGeCall emergency connection.

Figure 32: SIP INVITE message containing details for NGeCall setup

```
INVITE urn:service:sos.ecall.manual SIP/2.0
From: <tel:1220>;tag=2883044717
To: <urn:service:sos.ecall.manual>
CSeq: 735561065 INVITE
Call-ID: 2883044713_3440660140@fc01:abab:cdcd:efe2::1
Via: SIP/2.0/TCP [fc01:abab:cdcd:efe2::1]:40589;branch=z9hG4bK1697007878
Max-Forwards: 70
Contact: <sip:425a0f9f-61c1-4c6b-aaf2-ee62552e17e0@[fc01:abab:cdcd:efe2::1]:40589;user=phone>;
+sip.instance="<urn:gsma:imei:000000000-000000-0>";+g.3gpp.icsi-ref="urn%3Aurn-7%3A3gpp-service.ims.icsi.mmtel";audio;+g.3gpp.nw-init-ussi;
+g.3gpp.mid-call;+g.3gpp.srvcc-alerting;+g.3gpp.ps2cs-srvcc-orig-pre-alerting
Route: <sip:[fc01:cafe::1]:5102;lr>
P-Access-Network-Info: 3GPP-E-UTRAN-FDD; utran-cell-id-3gpp=0010100010000100
Security-Verify: ipsec-3gpp;alg=hmac-sha-1-96;q=0.900;prot=esp;mod=trans;ealg=aes-cbc;spi-c=3872527343;spi-s=2777027566;port-c=5103;port-s=5102
Proxy-Require: sec-agree; Require: sec-agree; P-Preferred-Identity: <tel:1220>
Allow: INVITE,ACK,CANCEL,BYE,UPDATE,PRACK,MESSAGE,REFER,NOTIFY,INFO,OPTIONS
Content-Type: multipart/mixed;boundary=boundary1
Accept: application/sdp,application/EmergencyCallData.control+xml
Recv-Info: EmergencyCallData.eCall.MSD
P-Preferred-Service: urn:urn-7:3gpp-service.ims.icsi.mmtel
Accept-Contact: *;+g.3gpp.icsi-ref="urn%3Aurn-7%3A3gpp-service.ims.icsi.mmtel";audio
Supported: timer,100rel,replaces,precondition,from-change,histinfo,tdialog
P-Early-Media: supported
Call-Info: <cid:user1@test.3gpp.com>;purpose=EmergencyCallData.eCall.MSD
Content-Length: 1151
01234567890123456789012345678901234567890123456789 0...
Session-Expires: 1800;refresher=uac
Content-Type: application/sdp  --boundary 1  …session parameters … -boundary 1
Content-Type: application/EmergencyCallData.eCall.MSD
Content-ID: <user1@test.3gpp.com>
Content-Disposition: by-reference;handling=optional
```

- INVITE with uniform resource name (URN) ← INVITE urn:service:sos.ecall.manual SIP/2.0
- Involved participants in the call "from/to" ← From / To
- NG-eCall over E-UTRAN ← P-Access-Network-Info
- Message body part and body ID ← Call-Info
- MSD content … Session description ← Content-Type: application/sdp …

2.8.5 Emergency services over non-3GPP access

Since 5G in general supports radio access via non-3GPP networks, the support for emergency services is signaled to the UE during non-3GPP registration via the 5GC. There is a priority policy within 3GPP specifying that the UE should try to use 3GPP RAT for an emergency first. A UE may only attempt to use emergency services over untrusted non-3GPP access if it is unable to use emergency services over 3GPP access. TS 23.167 defines further details for the criteria to support non-3GPP emergency services. Trusted and untrusted non-3GPP access to 5GC for emergency sessions is supported.

The UE may establish an emergency session over non-3GPP access to 5GC only when 3GPP access for emergency calling is not possible or available, e.g. no coverage. The emergency service support for non-3GPP access indicator (EMCN3) within the registration accept message tells the UEs whether emergency calls over non-3GPP access technologies such as WLAN are possible.

The procedure is similar to the described procedure for emergency calling over 5G NR or E-UTRA. First, the UE needs to identify and recognize the dialed number as an emergency number. For the specific case where the UE has selected to make an emergency call and the radio access network is non-3GPP access to 5GC, TS 23.167 defines some action items the UE has to perform:

- The UE should establish an emergency PDU session over non-3GPP and should perform an IMS emergency registration before sending an IMS emergency session request.
- The UE should include any available location information in the IMS emergency session request.
- For the media supported during IMS emergency sessions, standardized media codecs and formats should be applied.

A UE should not establish an emergency PDU session over non-3GPP access if the UE has initiated and successfully established an emergency session via 3GPP RAT.

In a high-level protocol procedure, the UE should signal IMS emergency as the establishment cause over the non-3GPP RAT and the IMS should reject any connection request without such an establishment cause from the UE. Further details are provided in TS 23.167 and TS 23.502.

2.9 Signaling aspects for voice support in 5G

The objective of this brief chapter is to provide an overview of the signaling parameters on the network and UE sides in AS and NAS that are relevant in relation to voice support. The network signals the support for voice and emergency calls via system information broadcast and via NAS signaling during the registration procedure. This split between AS and NAS signaling has the advantage that services like voice or emergency can be indicated in a UE-specific manner, valid per radio access technology and per registration area. The objective is to react flexibly to various UE types and reduce the signaling impact.

System information broadcast parameters relevant for voice aspects

The system information block SIB1, being part of the initial BWP, occurs at the highest repetition rate and signals the emergency call support parameters *ims-EmergencySupport*, *eCallOver-IMS-Support* and *UAC-BarringInformation*. The support for emergency and cell barring information is indicated to the UE at the earliest possible moment. Since the network may offer emergency calling to UEs in a limited registration state, the SIB broadcast is the way forward to provide such information to the UE. Cell barring is needed at that stage to allow network congestion control. In addition, SIB1 contains UAC access category assistance information enabling the UE to determine whether it belongs to access category 1, representing delay tolerant traffic and optionally deferring the UE radio access attempts. The barring policies and the corresponding information parameters within the system information are explained in chapter 2.8.3.1 and in TS 38.331. While LTE SIB2 allows transmission of barring information related to voice calls, 5G NR uses a slightly different barring concept. On the radio interface access, attempts can be barred with information parameters valid for common access, valid per PLMN or valid per access category or access identity. To allow higher flexibility, some access policies are decoupled from the AS layer and shifted to the NAS layer. Thus, support indication such as for voice services is provided during the UE registration.

UE capability indicator

Obviously, the UE needs to indicate its capability to the network during the attach procedure, which further impacts the UE and network behavior concerning service and domain selection. In general, UE capability transfers represent a very complex aspect in 5G. For example, some of the UE features are clustered within feature groups and there are certain dependency requirements across the different features. Due to the complexity, this chapter only presents the UE capabilities relevant for voice. The parameters UE usage setting as voice or data centric, the availability of IMS support and the UE operating in single- or dual-registration influence the behavior of the UE for domain selection. In the present situation, we understand the signaled condition "the UE supports IMS voice over 3GPP access" if one of the following is fulfilled (TS 24.501):

1. The UE supports IMS voice over NR connected to 5GCN.
2. The UE supports IMS voice over E-UTRA connected to 5GCN.
3. The UE supports IMS voice in EPS.

Among the many UE capability parameters defined in TS 38.306 and signaled via the RRC message UECapabilityInformation, the IMS parameters field is one of the most important in relation to UE voice service support.

- *voiceOverEUTRA-5GC* indicates whether the UE supports IMS voice over E-UTRA via 5GC. This support also includes IMS voice over E-UTRA connected to EPC, i.e. VoLTE.
- *voiceOverSCG-BearerEUTRA-5GC* indicates whether the UE supports IMS voice over SCG bearer of NE-DC. This is a future-oriented parameter. In the current release, IMS voice over split bearer is not supported (neither NR-DC nor NE-DC).
- *voiceFallbackIndicationEPS* indicates the support for EPS fallback. If this field is included, the UE should support IMS voice over NR and IMS voice over E-UTRA via EPC.
- *voiceOverNR* indicates whether the UE supports IMS voice over NR. It is mandatory for an IMS voice capable UE in NR, and otherwise optional. This parameter represents a backward-compatible capability. VoNR support includes support for VoLTE as long the UE supports E-UTRA.

Although not directly an AS-related UE capability, for proper VoNR support TS 38.306 requires the UE PDCP capabilities to support RoHC profiles 0x0000, 0x0001 and 0x0002 to perform proper compression of PDCP SDUs containing voice corresponding to the correct voice codec. As stated, one conditionally mandatory UE capability feature is support for IMS emergency calls in case the UE supports voice services in NR.

RRC signaling control messages for voice

While this chapter cannot delve into the RRC signaling details in 5G NR, we wish to provide a concise presentation of the signaling messages that are relevant for voice. In this context, the first and most important RRC message is the RRCSetupRequest message containing the information element establishment cause. In the current release, the UE can signal the following reasons why a connection is needed to the network: emergency, high priority access, MPS or MCS priority access, mobile terminated access and mobile originated signaling, data transfer, SMS or voice.

Similar reasons can be signaled by the *RRCResume* message in a failure case when the connection should be resumed. The EPS fallback procedure explained in chapter 2.2.4 requires the release of the NR radio link via the *RRCRelease* message and the signaling of its cause. To trigger a redirection to E-UTRA, the 5G RAN signals the *voiceFallbackIndication* as the release cause. As an alternative to connection release and redirection to E-UTRA, the 5G RAN can directly send the RRC *MobilityFromNRCommand* with the *voiceFallbackIndication*.

NAS relevant network features

For greater flexibility, 5GS provides an indication of the voice service support not only in the AS layer but also in the NAS during the registration procedure. The objective is to provide higher granularity in feature support indication and in access restrictions. At least from an abstract point of view, the support for voice services can be realized on a per UE basis. The access restriction described previously is valid per access attempt, but the UAC mechanisms are intended to avoid network congestion while the feature signaling is intended to indicate the supported services. Using the 5GS network feature support information element, the network indicates support for certain features to the UE. It is contained in the registration accept message and the IE structure is given as follows (TS 24.501):

Figure 33: 5GS network feature support for voice aspects

5GS network feature support IEI								octet 1
Length of 5GS network feature support contents								octet 2
MPSI	IWK N26	EMF		EMC		IMS-VoPS-N3GPP	IMS-VoPS-N3GPP	octet 3
5G-UO P CIoT	5G-HC-CP CIoT	N3 data	5G-IPHC-CP-CIoT	Restrict EC		MSCI	EMCN3	octet 4
0 spare	0 spare	0 spare	0 spare	0 spare	5G-EHC-CP CIoT	ATS-IND	5G-LCS	octet 5

Due to space and complexity constraints, only network features that are relevant to voice and emergency services are mentioned here:

- MPSI indicates whether the network supports multimedia priority services (MPS) or not. The content influences whether the UE may use access identity = 1 or not.
- IWKN26 is not a direct voice-related indicator, but it indicates whether the network supports interworking without the N26 interface between EPC and 5GC. It has an effect on network selection and camping of the UE and how signaling message parameters should be set during call establishment.
- EMF is the emergency services fallback indicator to indicate emergency fallback support.
- EMC is the emergency support indicator.
- IMS-VoPS-3GPP is a very important flag to indicate support for voice over IMS services in the 5G network. Note that this also includes support for EPS or RAT fallback voice support, but not necessarily full VoNR support.
- IMS-VoPS-N3GPP indicates that the network supports voice over non-3GPP.
- MCSI is the indicator bit for whether a UE can use access identity 2 representing mission critical services.

Information on additional signaled parameters within network feature support can be found in TS 24.501.

3 VoNR – HOW TEST AND MEASUREMENT ENABLES ITS SUCCESS

Test and measurement helps ensure and verify the proper functioning and implementation of voice services, thereby improving the user quality of experience (QoE).

Voice over 5G operates in a similar way to voice over LTE. The general test setup does not differ that much, but various fields of testing should be contemplated. Regarding a timeline perspective, testing 5G voice services starts with the implementation and functional behavior analyses. Can a call be established and is the voice signal audible? Enhanced analysis determines the audio quality under well-known and reproducible lab conditions. In addition to device-oriented voice or video call testing, mobile network testing and deployed service benchmarking in a live network improve the experienced user quality.

3.1 Lab based testing of VoNR

Lab based test setups enable reproducible, repeatable measurements under predefined conditions.

Voice quality test setups include mobile radio testing capability supporting signaling and functional testing, enhanced protocol procedures including interoperability, multi-connectivity and mobility scenarios. To determine the proper audio quality, the test setup may include audio quality test equipment. An audio analyzer is connected to the mobile radio tester using digital or analog interfaces. For stress tests, the test setup activates fading on the radio interface and optionally emulates network impairments like IP-packet disordering, delay or discarded packets. The objective is to emulate different network conditions for verifying UE performance in a controlled environment.

Optionally, voice communications test setups should also support legacy RATs like 2G/3G and non-cellular technologies like Bluetooth® and Wi-Fi. 3GPP specifications also incorporate the possibility of transferring audio over non-3GPP radio technologies.

A voice over 5G test setup must be able to emulate the IMS network and its signaling protocols SIP, SDP and user plane data provisioning.

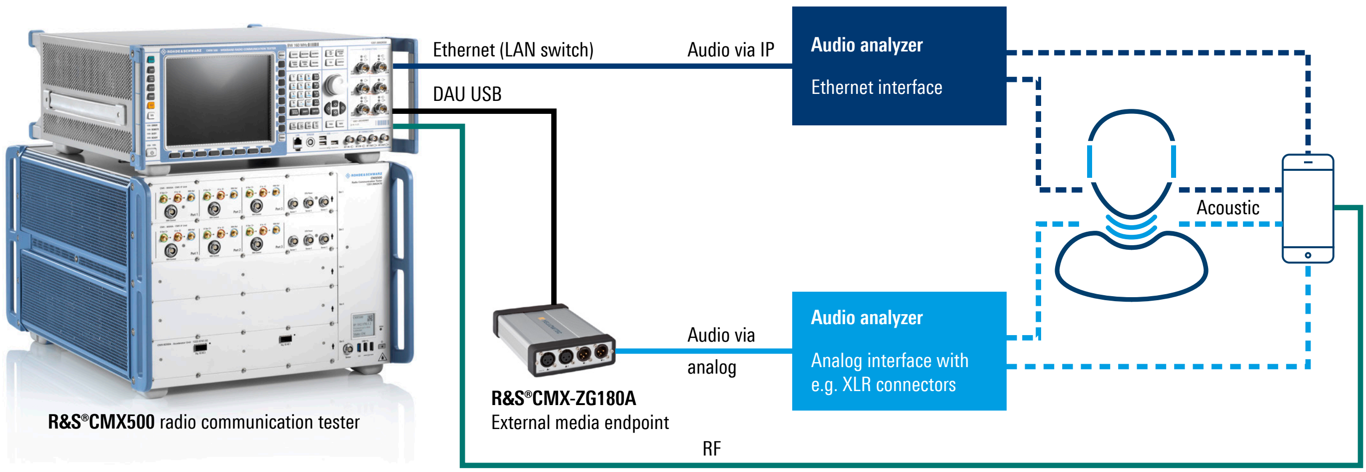
VoNR testing aspects include the VoLTE, EPS or RAT fallback and VoNR scenarios mentioned in the previous chapters. From a speech codecs perspective, a test system for voice over 5G must support the legacy AMR-NB and AMR-WB speech codes in addition to the EVS codec.

VoNR testing is the culmination of the evolution of various audio testing procedures, tackling the audio quality of a speech call transferred over a wireless radio connection. Useful methods of testing telephone band speech signals were first standardized by the International Telecommunication Union (ITU-T). The ITU-T recommendation P.800 defines the absolute category rating test method using a five-grade quality scale from 1 (bad) to 5 (excellent) as used in listening experiments. This scale also refers to the mean opinion score (MOS) value. In brief, the algorithms working principle consists of the recordings of many spoken sentences in different languages and from different speakers. The recordings were subject to coding-decoding processes of various speech codecs and impaired by typical network distortion. A statistical relevant and sufficient number of listeners qualified these samples subjectively. Testing is performed without a comparison to an undistorted reference. This copes with a typical phone call, where the listener cannot compare the voice with the original voice of the other party. However, it should be noted that listening tests in line with P.800 can be regarded as a comparison between a test signal and a reference "in the mind" of the listener. This is because listeners are very familiar with the natural sound of a human voice. The task of the international expert groups for an improved speech quality model was a perceptual evaluation of speech quality (PESQ) model [Ref. 28]. The first fully described objective speech quality predictor in ITU was ITU P.862 PESQ. The standard was approved twenty years ago and reflects the telephony of the time. It focuses mainly on fixed-line PSTN and the first mobile networks put in place back then. In practice, the standard is limited to traditional narrowband telephony.

Because of the complex test requirements of mobile network services and IP based services, the perceptual objective listening quality analysis (POLQA) technology update has been developed and standardized in ITU-T recommendation P.863. POLQA offers measurements for higher audio bandwidths and is also certified for acoustic measurements. The totally revised psychoacoustic and cognitive model of POLQA allows a true quality prediction in case of variable delay and time scaling, non-optimal presentation levels, filtering and spectral shaping effects. POLQA is not only a full replacement for PESQ, it is a significant enhancement to end-to-end voice quality testing. An objective method was developed which can predict the subjective rating with sufficient correlation by comparing the impaired signal to the original signal as a reference. POLQA is continuously upgraded and revised to reflect latest coding and transmission technologies. The current P.863 version is v3, approved by the ITU in 2018. Further info on POLQA can be found in the IEEE document [Ref. 29].

A test setup for 5G voice and video applications is depicted in Figure 34, showing the R&S®CMX500 radio communication tester [Ref. 24] together with the R&S®CMW500 wideband radio communication tester [Ref. 25] supporting LTE and 5G NR for either standalone or non-standalone connectivity testing. The setup can be extended as shown by an audio analyzer. To permit audio tests in line with the ITU-T P.58 standard that specifies audio tests using a head and torso simulator (HATS), the setup shown in Figure 34 is extended by a dummy head with an artificial ear and mouth. For electrical measurements, the DUT is connected to the audio analyzer input via the speaker output and the microphone output is connected to the audio analyzer output. The R&S®CMX500 supports an internal IMS server allowing a virtual UE emulation and audio loopback mode for fast and easy functional VoNR testing. Two interfaces allow the connection of an external audio tester. One option is to output the digital RTP audio signal via Ethernet to an external digital audio analyzer (IP forward mode). [Ref. 22] describes the setup implementation using an external audio tester. The second option shown in Figure 34 uses the R&S®CMX-ZG180A external media endpoint for connecting an external audio tester via an analog interface, for example the R&S®UPV audio analyzer. The R&S®CMW500 wideband radio communication tester [Ref. 25] makes it possible to test RAT from 2G to 4G and non-3GPP technologies like CDMA2000®, Bluetooth® or Wi-Fi.

Figure 34: Voice over 5G test setup



The R&S®CMX500 data application unit (DAU) has a built-in IMS server allowing the verification of IMS-related functions like registration and voice/video handling procedures. Functional tests start with activating a 5G cell either as standalone or non-standalone in combination with LTE, connecting the UE to the RAN and registering the IMS. The setup allows either mobile terminated or mobile originated calls. As a first basic functional test, the R&S®CMX500 can be configured to audio loopback mode. In this mode, the built-in IMS server emulates a virtual UE as communications partner and all uplink audio is looped back to the downlink with a few seconds delay. The user can speak into the DUT microphone and listen to the echo at the DUT loudspeaker. This helps quickly verify functions such as SIP registration and call setup procedures, representing a functional test of the DUT IMS client, microphone and speaker as well as RAT-specific communications. Besides IMS server functionality, the data application testing solution based on the R&S®CMX500 DAU provides pre-configured servers for testing DNS, FTP, HTTP and video with either IPv4 or IPv6 connections using protocols like UDP or TCP. [Ref. 24] provides more detailed information. The built-in IMS server allows the configuration of IMS related security parameters, e.g. IPsec encryption and integrity protection settings.

Additional connection routing options in the R&S®CMsquares GUI include "IP forward" audio routing via a digital interface connected to an external audio tester, and "DAU USB" audio routing to an external media endpoint, e.g. the R&S®CMX-ZG180A. With the IP forward configuration, IMS SIP/SDP signaling is still performed by a built-in IMS server and the audio/video data encapsulated into RTP packets is routed to the Ethernet connection to be analyzed by external audio test equipment. The connection supports all voice codecs, ranging from AMR-NB and AMR-WB to EVS. [Ref. 22] provides further details of a real-world setup describing connection and cabling details as well as operational GUI steps.

The "DAU USB" option makes it possible to connect an external media endpoint like the R&S®CMX-ZG180A. This media endpoint offers USB, digital in/out and analog in/out connections and provides the interface to analog audio test equipment like the R&S®UPV audio analyzer [Ref. 28] via an XLR connector.

The R&S®CMsquares graphical user interface combines signaling and non-signaling tests for all applications. The configuration ranges from pre-defined test scenarios without the need of further programming to fully customizable setups. The GUI allows configuration of several network parameters and incorporates RF measurement views, protocol analysis and end-to-end data verification [Ref. 24].

An easy-to-use feature for verifying the VoNR settings is the R&S®CMsquares GUI window "Bearer&flow monitor" that allows a fast and comprehensive overview of the activated data bearers and their QoS flows. It is possible to add a video call during an established VoNR call by clicking on the GUI icon. The QoS flows should be extended by another QoS flow carrying the video data.

For protocol decoding and debugging, the R&S®MARS message analyzer allows detailed analysis of the 5G protocol stack. Here, relevant c-plane messages such as UE capability transfer or the PDU session establishment procedure can be analyzed. SIP signaling messages can also be viewed.

The tool provides a simple function to extract a connection's ciphering keys and to decode SIP and SDP control messages. SIP messages are transferred via 5G PDU sessions that are typically encrypted, thus a protocol analyzer like Wireshark may not be able to decode those messages instantaneously. With the Rohde&Schwarz ciphering extract function, it is possible to use Wireshark [Ref. 26] on the R&S®CMX500 platform. The Wireshark network protocol analyzer makes it possible to analyze RTP streams and investigate issues like timing, packet loss and packet reordering that may deteriorate the speech quality.

3.2 Field based testing of VoNR

Field and drive tests are necessary to monitor the quality of voice/video applications and fulfill the KPI requirements of real-world networks. Passive measurement equipment like a scanner is extended by devices that can actively set up a connection and perform QoE analyses. In addition, network operators may want to compare their network quality in a benchmarking process against other networks or monitor the entire network via multiple samples and statistical analyses to obtain a summarized view.

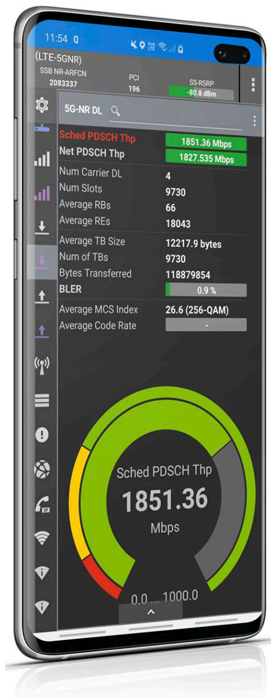
The objective is to analyze the voice call quality and the call retainability, including KPIs such as blocked calls, low MOS values and dropped connections. Network operators are also interested in call setup time, audio transmission time, handover and radio conditions as they influence the QoS as well.

Similar to lab based testing, users want to analyze RAT and IMS/SIP control messages as well as connection parameters such as call setup, handover scenarios and QoS parameters like throughput, MOS or latency. The document [Ref. 27] provides further details on voice quality testing in real-world networks.

A distinction should be made in field testing between the achieved audio quality and the conversation quality. The first application analyzes and contemplates the audio quality observed at the UE endpoint corresponding to a general implementation of the network parameters and the achievable KPI. Uncompensated delay jitter may lead to decoder actions causing perceptible distortions in audio quality. Network operators implementing voice services in their packet switched networks have to find the right balance between audio quality and conversation quality (audio delay). For this reason, pure MOS measurements must be supplemented by audio delay measurements to get the complete "conversation quality" picture.

A test setup for voice quality testing in the field is depicted in Figure 35, showing QualiPoc Android, the smartphone based tool for troubleshooting voice and data service quality and RF optimization [Ref. 23].

Figure 35: Field based voice over 5G test setup



T&M will play a pivotal role in making the market introduction of voice services in commercial 5G networks a success. Certain standardization bodies, industry alliances and network operators will integrate voice over 5G testing into their test plans to ensure proper operation.

4 SUMMARY

Voice services are not just a legacy burden that rides on the back of 5G and prevents it from realizing its full potential. Voice in 5G networks should play an active part in delivering a host of key data services well into the future.

Of course, mobile subscribers will continue to demand voice as part of their services. But because of the integral role voice will play in the emerging generation of data services, voice services will occupy an important position in the packages offered by service providers.

While standalone (SA) 5G deployments are increasing, these deployments are often launched alongside non-standalone (NSA) networks, indicating that there remains some hesitancy among operators to fully commit to SA 5G networks. This will continue to produce complications in terms of the deployment of voice services over these 5G networks. However, some key circumstances are already in place that will ease the deployment of voice over 5G.

VoLTE is a critical enabler of 5G VoNR

Today, LTE is still the most widely used mobile radio technology, connecting more than half of all mobile users across the globe [Ref. 21]. Circuit switched fallback (CSFB) has provided an initial solution for most service providers to prioritize 4G services using LTE, while continuing the provision of voice services by enabling handover to 3G circuit switched voice for this particular application only. This was considered an interim step before VoLTE became more mature. However, service providers are increasingly adopting voice over LTE (VoLTE) in their networks, using the IP multimedia subsystem (IMS) as the management and orchestration core. This use of IMS is providing key support for voice over 5G.

While VoLTE continues to attract investment and be deployed for voice services, investment in 5G is accelerating. This growth in 5G deployments will lead to major changes for many voice service providers going forward. This is because service providers will no longer have the option to run LTE with the ability to support voice either with or without IMS as the core. 5G VoNR is only feasible through migration to an IMS based core network.

IMS adoption is growing

Voice over 5G uses the same IMS based architecture as VoLTE. IMS enables convergence of and access to real-time services (voice, video), streaming, messaging, data and web based technologies for the wireless user. The IMS system provides an easy-to-maintain and highly scalable IP multimedia communications network. IMS is access independent and provides a peer-to-peer addressing architecture for IP based voice sessions, end-to-end quality of service (QoS), charging, authentication and security (TS 22.228).

Preparing the VoLTE network for 5G

It is neither technically nor economically feasible to launch a 5G network capable of supporting voice with full nationwide coverage from day one. Leveraging existing networks has always been part of the plan for the 5G rollout. The IMS based architecture of VoLTE provides a good starting point for 5G. It reuses the existing infrastructure and methodologies while allowing future-proof introduction of new technologies.

To a large extent, this evolution stems from the fact that optimization of a network and its constituent parts must be carried out in coordination rather than in isolation. Otherwise, this process risks being ineffective. Coordinated optimization of all aspects ranging from EPC to IMS is needed in order to ensure a positive customer experience.

The evolution of IMS in VoNR

In the initial Release 15 (Rel-15) of 5G, there was an attempt to minimize the impact on IMS in order to facilitate the deployment process. In fact, from the perspective of IMS, Rel-15 looked essentially like a 4G EPC. The IMS used for VoLTE lays the groundwork for 5G VoNR. By Release 16 (Rel-16), however, IMS becomes part of 5GC and its service based architecture (SBA).

Options for deploying voice over 5G

This white paper has gone into extraordinary detail on all the factors and options in deploying voice over 5G networks. However, in general terms, it is possible to break down these deployment scenarios into option 3 and option 2.

Option 3 is probably the most widely used deployment scenario since it involves using existing 4G VoLTE networks (and in some cases 3G networks). In this case, the actual 5G connection is only used for data.

Option 2 can only be used where a 5G core is already deployed. In this deployment option, voice services are provided in two ways. The first method is EPS fallback, i.e. a mobile phone is forced to fall back from 5G to LTE when the call is first set up. Voice and data traffic is carried over the LTE network during the entire call. The second method uses VoNR, i.e. voice is handled entirely by 5G, enabling simultaneous voice and high-speed 5G data services.

No matter which deployment option is used, they both rely on the IMS architecture as the basis for providing voice and video communications over a 5G network. Even in deployment options 4, 5 and 7, the same voice solutions found in option 2 still apply. All the architectural approaches that use the 5G core will look like option 2.

Emergency services

In option 3, emergency service calls will continue to be handled using VoLTE. In option 2, it becomes possible to handle these emergency calls with either VoNR or EPS fallback. There is also a third approach, dubbed the emergency call fallback, in which the fallback to LTE occurs before the IMS call setup.

In this emergency call fallback, the UE operates using 5G NR. When the user initiates the call, the UE detects it and recognizes that the emergency service is not supported by the radio/core combination being used. In this case, the UE sends a special request to the access and mobility management function (AMF). The AMF then forwards this request to the gNB, signaling it to turn the request over to EPS and LTE. Not until the UE falls back to LTE is the emergency call initiated. This all means that the infrastructure for IMS emergency calls from LTE can be implemented with option 2 deployments.

Conclusion

Option 3 deployments have enabled voice services to continue by using either an IMS/VoLTE network or circuit switched fallback (CSFB). With option 2, voice services for 5G UE require an IMS based network that supports VoLTE. This also means that a VoLTE solution is a fundamental requirement for the introduction of a 5G core. Test and measurement helps to enable the success of the market introduction of voice and video services in commercial 5G devices and networks.

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Note: All links have been checked and were functional when this document was created. However, we cannot rule out subsequent changes to the links in the reference list.

6 SPECIFICATIONS

TS 22.153	Multimedia priority service
TS 22.228	Service requirements for the internet protocol (IP) multimedia core network subsystem (IMS), stage 1
TS 23.228	IMS architecture, stage 2
TS 23.167	IMS emergency call aspects
TS 23.401	General packet radio service (GPRS) enhancements for evolved universal terrestrial radio access network (E-UTRAN) access
TS 24.008	Mobile radio interface layer 3 specification, core network protocols, stage 3
TS 24.167	3GPP IMS management object (MO), stage 3
TS 24.173	IMS multimedia telephony communication service and supplementary services, stage 3
TS 24.229	IP multimedia call control protocol based on SIP and SDP, stage 3
TS 24.628	Common basic communication procedures using IP multimedia (IM) core network (CN) subsystem, protocol specification
TS 26.114	IP multimedia subsystem (IMS), multimedia telephony, media handling and interaction
TS 26.441	EVS general overview
TS 26.445	EVS speech coder details
TS 26.980	Multimedia telephony over IP multimedia subsystem (IMS), media handling aspects of multi-stream multiparty conferencing for multimedia telephony service for IMS (MTSI)
TS 29.563	5G system, home subscriber server (HSS) services for interworking with unified data management (UDM), stage 3
TS 33.203	3G security, access security for IP based services
TS 23.503	Policy and charging control framework for the 5G system (5GS), stage 2

7 ABBREVIATIONS

Term	Explanation
5GC	5G core
5GS	5G system
5QI	5G QoS indicator
AMF	Access and mobility management function
AMR	Adaptive multirate
AMR-WB	AMR wideband
AS	Access stratum
CSFB	Circuit switched fallback
DAU	Data application unit
DNN	Data network name
DRB	Data radio bearer
DRVCC	Dual radio voice call continuity
EPC	Evolved packet core (LTE core)
ePDG	Evolved packet data gateway
EPS	Evolved packet system
E-UTRAN	Evolved UMTS terrestrial radio network
EVS	Enhanced voice services
GBR	Guaranteed bit rate
GSM	Global system for mobile communications
GSMA	GSM association – www.gsacom.com
GUI	Graphical user interface
HOS	Home operator services
IETF	Internet Engineering Task Force
IMS	IP multimedia subsystem
IP-CAN	IP connectivity access network
IVS	In-vehicle system
KPI	Key performance indicator
LRF	Location resource function
LTE	Long term evolution
MAC	Medium access control
MCS	Mission critical services
MM	Mobility management
MME	Mobility management entity
MOS	Mean opinion score
MPS	Multimedia priority services
MSRP	Message session relay protocol
MTSI	Multimedia telephony services for IMS
NAS	Non-access stratum
NSA	Non-standalone
OMA	Open Mobile Alliance
OTT	Over-the-top
PANI	P-access-network-info SIP header
PCC	Policy and charging control
PCF	Policy control function
PCO	Protocol configuration option
P-CSCF	Proxy call session control function
PDCP	Packet data convergence protocol
PDN	Packet data network
PDU	Packet data unit
PESQ	Perceptual evaluation of speech quality
PSAP	Public safety answering point (emergency)

Term	Explanation
POLQA	Perceptual objective listening quality assessment
QoE	Quality of experience
QoS	Quality of service
RAN	Radio access network
RAT	Radio access technology
RCS	Rich Communications Services
RLC	Radio link control
RRC	Radio resource control
RTCP	RTP control protocol
RTP	Real-time protocol
SA	Standalone
SDAP	Service data adaptation protocol
SDP	Session description protocol
SIP	Session initiation protocol
SM	Session management
SMF	Session management function
SNPN	Standalone non-public network
SPS	Semi-persistent scheduling
SRB	Signaling radio bearer
SRVCC	Single radio voice call continuity
UAC	Unified access control
UE	User equipment
UPF	User plane function
URN	Universal resource name
VoLTE	Voice over LTE
VoNR	Voice over new radio
ViNR	Video over new radio
XCAP	XML configuration access protocol

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PD 3609.6370.52 | Version 01.00 | May 2021 (ch) | White paper
5G Voice over New Radio (VoNR)
Data without tolerance limits is not binding | Subject to change

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