Delivering Exceptional VoLTE Service Quality

The VoLTE Advantage

Delivering quality voice services in an LTE environment is a major goal of operators around the world. Voice has always been a fundamental service of mobile communications and will continue to be so in the future—yet the service needs to adapt to social changes and the ways people communicate today. This is where voice over LTE (VoLTE) comes in—to deliver a mobile voice service that embraces the latest technologies available and meets the growing demands of mobile users.

User Advantages

VoLTE is what we might term voice plus— it builds on what has been a core service since communications began and sets the foundation for what voice will be in the future. VoLTE brings:

- Faster connection times — the ability to create instant voice connections
- HD voice — superior voice quality
- Rich communication services (RCS) — integrated with other services such as messaging

Faster connection times and vastly improved voice quality will deliver major benefits to the user. The integration with other services is what will transport voice from a vanilla service to a service that supports the way we want to communicate: with video capability support, integrated with instant messaging, and with social media connections.

Voice, through VoLTE, will become a fully integrated service that the mobile user will flexibly use like any other major mobile app.

Operator Advantages

In addition to the user benefits, an operator also benefits from delivering VoLTE. VoLTE enables:

- More efficient use of scarce RAN resources
- Integrated, IP-based services
- IP multimedia subsystem (IMS) functionality to grow differentiated services
- A foundation for higher value services
- Reduced operational costs

Being able to converge all IP LTE services around IMS gives operators the flexibility they need to deliver and evolve their mobile services. IMS provides the platform and architectural framework to deliver all IP multimedia services, allowing authentication, charging, policy management, and service control.

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Standards

LTE was originally defined as a project of the 3rd Generation Partnership Project (3GPP) Release 8. LTE standards have continued to evolve in subsequent 3GPP releases, covering both radio and core network evolution, although Release 8 (R8) focused primarily on the access part of the evolved packet system (EPS).

Although many people believe LTE was defined as data only, many of the components supporting an LTE voice service were key considerations in designing LTE. Voice in LTE is essentially a media stream, albeit a very important one, that can be communicated. In R8 as well as defining always-on IP connectivity requirements for LTE, the work developed a radio and core network evolution optimized for the transfer of packets. In fact, in Release 7, work was done around IMS signaling and VoIP encoding as well as emergency call requirements which were adapted and defined in Release 9 along with location support. Release 10, in addition to focusing on LTE-A, introduced some enhanced capabilities for voice call continuity. Release 11 includes the addition of network-provided location information to the IMS charging functions and enhancements to SRVCC (refer to section 7 for details on SRVCC) for priority handovers.

In addition, the GSMA has been involved in the definition and standards work around delivering VoLTE. In particular, the GSMA IR.92 – IMS Profile for Voice and SMS – documents "a minimum mandatory set of features which are defined in 3GPP specifications that a wireless device and network are required to implement in order to guarantee an interoperable, high-quality IMS-based telephony service over LTE radio access." Also, the GSMA IR.94 focused on the IMS profile for conversational video services. These GSMA proposals are the preferred industry choice for mass-market voice and video calling over LTE.

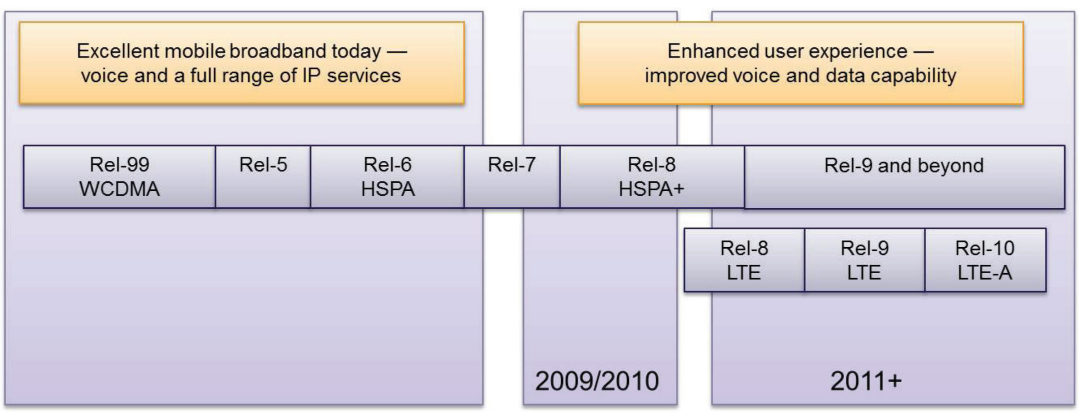

Figure 1. Evolving standards

VoLTE Introduction to Live Networks

With over 260 LTE networks live today and another 87 expected this year (GSA, 2014) it will not be long until LTE becomes the dominant technology in most countries. In terms of HD voice services, the GSA confirms that 109 operators have commercially launched HD voice services in 73 countries (GSA, June 2014). HD voice can, of course, be offered over multiple technologies, one of which is LTE. Of 109 operators, 8 have launched HD VoLTE services. Yet, VoLTE technology is still maturing. The GSA lists more than 30 operators who have committed to VoLTE deployments or trials.

Teleanalysis offers some insight into VoLTE commitments and deployments. They state that 40 operators are currently committed to, trialing, or deploying VoLTE. 23 operators are in the process of deploying VoLTE, whereas seven operators are trialing VoLTE.

VoLTE Technology

Before we look at the challenges of VoLTE and what is needed to address the various pain points, let's turn our attention to some of the technologies needed to deliver VoLTE. The diagram below provides a high-level network architecture of a mobile network, showing many of the components that we will discuss.

There are three fundamental components that make up an LTE evolved packet system (EPS):

- eUTRAN — describes the RAN air interface, evolved from UMTS
- EPC — the evolved packet core, covering the core architecture
- IMS — the control framework for delivering IMS

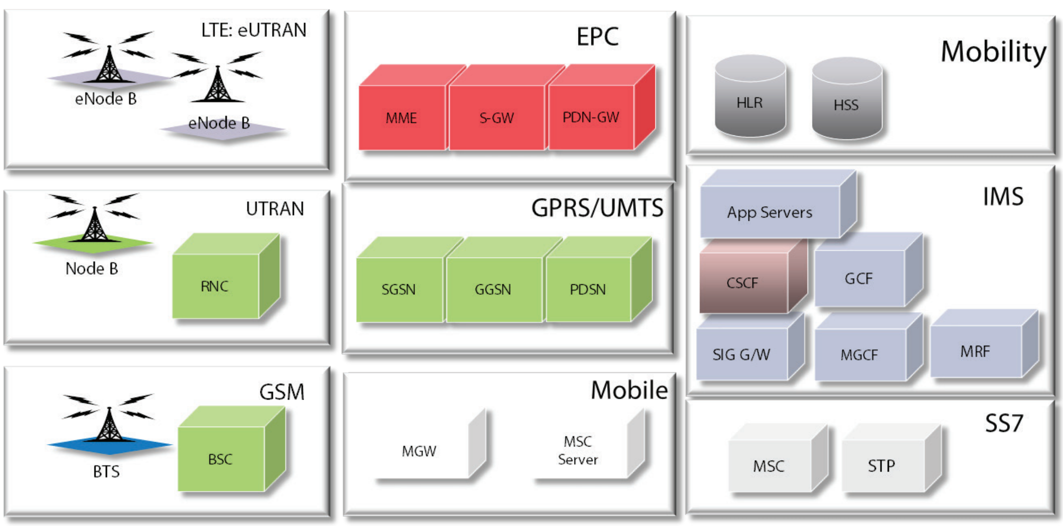

Figure 2. Mobile architecture

Bearers

Bearers are a key concept in LTE for delivering IP-based multimedia services. A bearer is essentially an IP data session with a defined QoS. All traffic mapped to the same bearer receives the same packet forwarding treatment. The defined QoS is crucial here, given the importance of this to voice quality (more on this in Section 6). Think of a bearer as a pipeline connecting two or more points through which data traffic can flow.

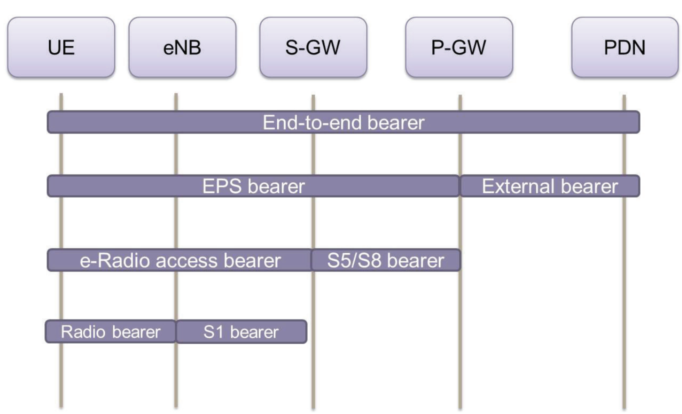

Figure 3. Subbearer architecture

Figure 3 shows that in order to establish an end-to-end bearer, several subbearers must also be established. For example, a radio bearer between the user equipment (UE) and eNodeB (eNB) must be established as part of the creation of the EPS bearer. The EPS bearer is a virtual connection.

An EPS bearer can either be default or dedicated. Each EPS bearer has a defined set of QoS characteristics including:

- QCI — QoS class identifier, determines bearer-level packet forwarding treatment
- Priority — determines if a bearer establishment or modification request can be accepted depending on resource limitations
- GBR or non-BGBR — guaranteed bit rate or not

Default Bearer

When an LTE UE attaches to the network for the first time, it is assigned a default bearer which remains active as long as the UE is attached. Each default bearer has a separate IP address and a QCI assigned (5 to 9). This provides a non-guaranteed bit rate. Note that signaling will have its own bearer (separate from the user plane) with a QCI of 5 (and a priority of 1).

Table1. QCI values in LTE

QCI	Bearer Type	Priority	Packet Delay	Packet Loss	Example
1	GBR	2	100 ms	10-2	VoLTE call
2		4	150 ms	10-3	Video call
3		3	50 ms	10-3	Realtime gaming
4		5	300 ms	10-6	Video streaming
5	Non-GBR	1	100 ms	10-6	IMS signaling
6		6	300 ms	10-6	E-mail, FTP, …
7		7	100 ms	10-3	Voice, video (live streaming)
8		8	300 ms	10-6	E-mail, FTP, …
9		9	300 ms	10-6	E-mail, FTP, …

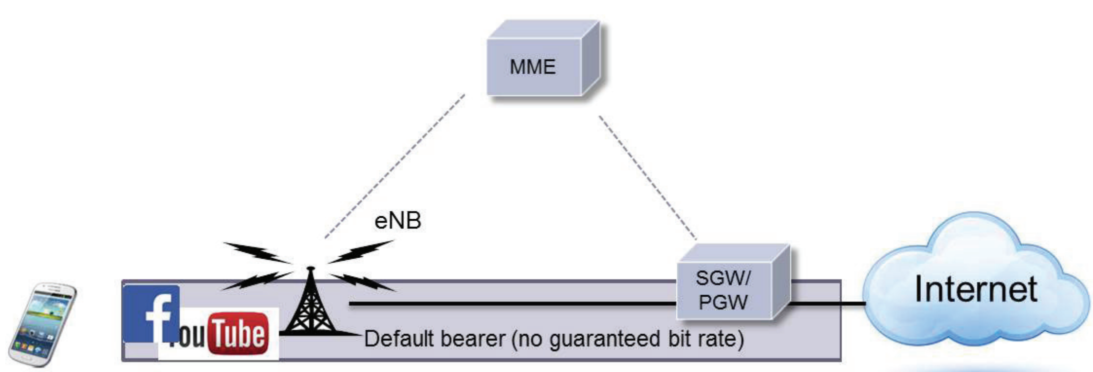

Figure 4. The default bearer in the network

Dedicated Bearer

Dedicated bearers provide dedicated tunnels. They do not require a separate IP address and as such are linked to the default bearer. For services like VoLTE, dedicated bearers can provide the level of quality needed for a high-fidelity voice service. A dedicated bearer for conversational voice would be set up with QCI = 1 for a guaranteed bit rate (and a priority of 2).

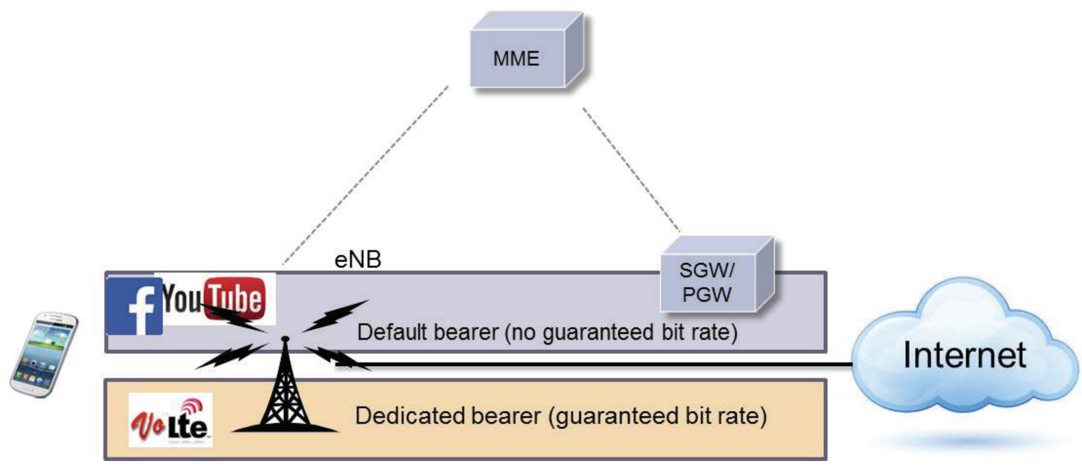

Figure 5. The dedicated bearer in the network

Radio Bearer

In the hierachy of establishing and managing bearers for end-to-end communication, the radio bearer between the UE and eNB is a crucial component since RF optimization can support specific QCIs. For each radio bearer, signaling radio bearer (SRB), or data radio bearer (DRB), the radio resource control (RRC) establishes the configuration of the various protocol stack layers. When delivering a VoLTE service, there are particular air interface capabilities that can be used:

Robust header compression, (RoHC)

- RoHC takes an IP packet header and strips out the information that has already been established between the UE and eNB. For example, once the destination IP address has been established there is no need to keep sending it because the connection is point-to-point. With VoLTE, which has a relatively small payload, the effect can be significant. If we were using IPv6, then the header would reduce from 60 bytes to 3 bytes.

Unacknowledged Mode (UM) RLC

- Unacknowledged mode allows the eNB to monitor error rates without retransmitting packets. Typically, in VoLTE environments where the bearers are real-time, voice retransmissions can be delayed to the point where they are no longer useful to the call in progress.

Semi-persistent scheduling (SPS)

- With SPS the eNB can assign a predefined block of radio resources for VoLTE users and the UE is not required to continue to request resources, saving control-plane overhead.

Transmission time interval (TTI) bundling

- A TTI is a subframe in LTE. TTI bundling allows multiple hybrid automatic repeat request (HARQ) transmissions to be sent within the timeframe. This helps avoid delays and reduces control plane overhead at the MAC layer.

IP Multimedia Subsystem (IMS)

IMS began as a 3GPP standard in Release 5 of the core network evolution and was refined in Releases 6 and 7. Beyond these releases, IMS has been further enhanced for LTE support and policy control. IMS defines a control framework architecture for delivering IP services. Defined by 3GPP specifications, IMS uses IETF protocols, in particular session initiation protocol (SIP) for establishing and managing sessions and the Diameter protocol for authentication, policy, and charging.

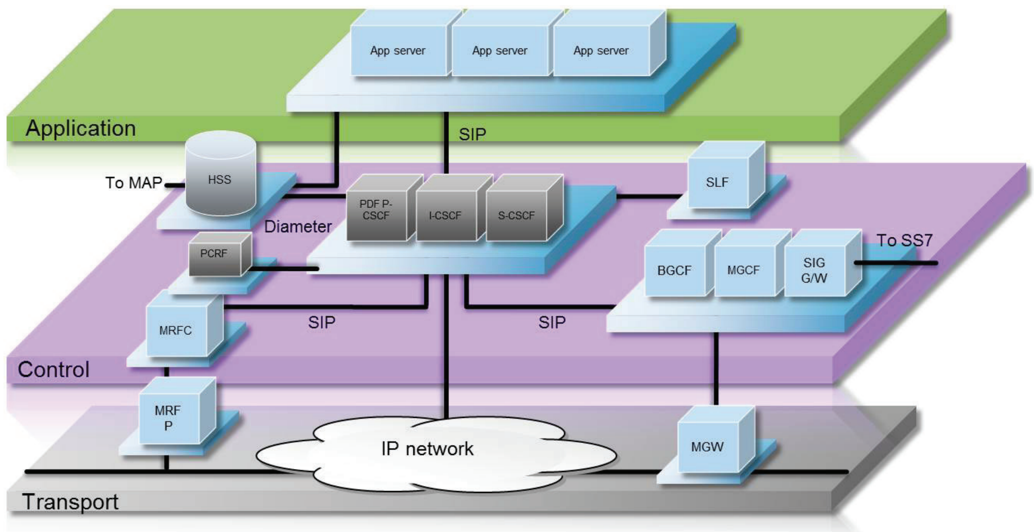

Figure 6. IMS in detail

IMS forms the foundation for delivering VoLTE and is a crucial architectural framework. We shall now look at some of the key components of IMS. Note that IMS is focused on the control plane of IP services. No media (user plane) flows through IMS.

Home Subscriber Server (HSS)

The HSS is the central repository for subscriber information. It is an evolved version of the GSM home location register (HLR). It holds the subscriber data to manage, among other things, VoLTE calls including:

- Location information
- Security information (used in authentication and authorization)
- Profile information defining subscribed services
- Which serving call session control function is allocated

Call Session Control Function (CSCF)

The CSCF nodes are fundamental elements in IMS. These nodes are proxies and process SIP signaling packets. There are three separate functions:

The proxy CSCF (P-CSCF) is a SIP proxy and is the first point of contact into IMS. It sits as the interface into IMS, protecting the framework and interfacing to the IMS terminal. All SIP signaling from a VoLTE UE will be sent to the P-CSCF. The P-CSCF is essentially responsible for:

- SIP compression
- IPsec security association
- Interaction with the PCRF
- Control of network address translation (NAT)
- Emergency session detection

The serving CSCF (S-CSCF) interfaces through the Diameter protocol to, for example, the HSS. It handles:

- SIP registrations and policy control
- Challenging the UE
- Downloading subscriber authentication data from the HSS
- Using the service profile to decide which AS is contacted
- Translating the MSISDN to SIP URI
- Routing requests via the P-CSCF

The interrogating-CSCF (I-CSCF) forwards SIP requests while hiding the internal network. The I-CSCF focuses on:

- Getting the name of the next node from the HSS
- Assigning an S-CSCF
- Routing incoming requests to that C-CSCF (or AS)

Policy and Charging Rule Function (PCRF)

The PCRF decides on policy and charging control based on session and media-related information from the P-CSCF. The PCRF plays a key role in authorizing VoLTE bearer establishment and modifications.

Media Gateway Control Function (MGCF)

The MGCF controls the media gateway (MGW) and the signaling gateway (SGW). H.248 is the protocol typically used with the media gateway.

An example call setup using IMS is shown below (source: IEEE). There can be a highly complex set of interactions involved in establishing a call.

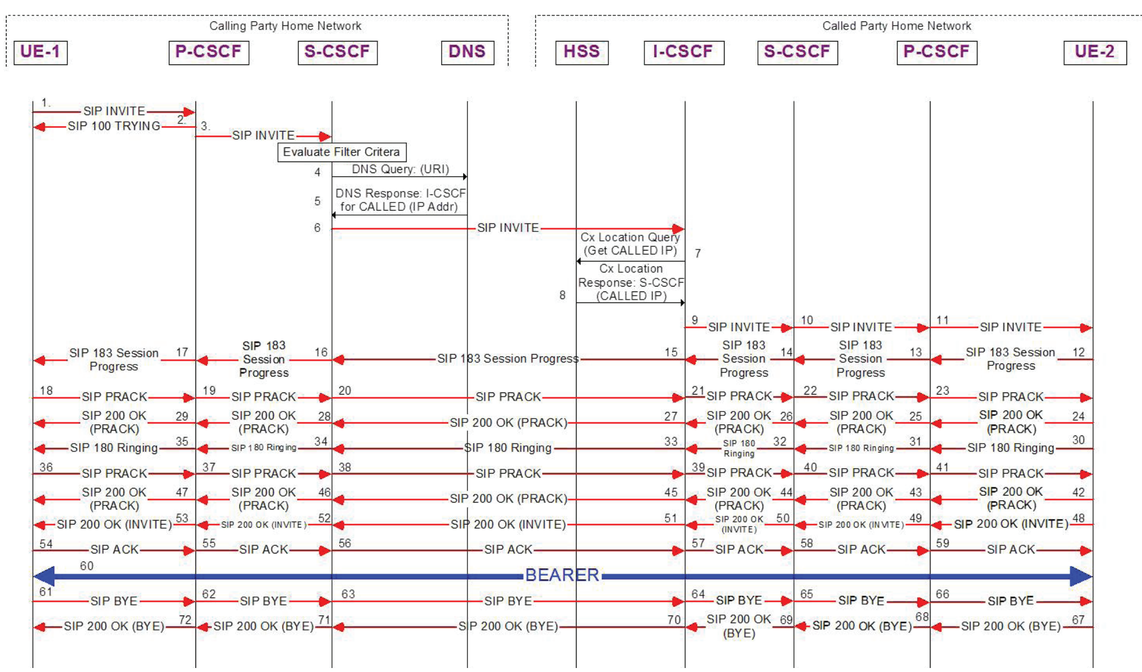

Figure 7. Typical IMS call setup

In summary, IMS provides the control (call setup, management, teardown) environment for VoLTE.

The elements and technology to successfully deliver VoLTE end-to-end requires a coordinated set of actions across a large number of network components. Any of these steps not performing exactly as needed can have a significantly detrimental effect on the VoLTE service. Later in this paper we look at ways of addressing these challenges and the solutions needed.

Voice Quality

A key selling feature of VoLTE to subscribers is an enhanced audio experience via the delivery of HD voice, enabled by wideband AMR technology that doubles the voice bandwidth to almost 7000 Hz. To understand any service being delivered, one must be able to measure the service quality. VoLTE is no exception. To support a real-time application with stringent demands on the network, measuring voice quality is paramount.

MOS and R-Factor

The mean opinion score (MOS) has been used for many years to assess voice quality. Historically a subjective measure, MOS when applied to VoIP services is an objective measure based on the underlying IP network. Figure 8 shows the factors involved and how they can affect voice quality as well as the parameter ranges to determine good or poor voice quality. Constituents such as packet loss, jitter, and delay (latency) will cause impairments to the perceived voice quality. The table below shows how a variation in the value of these constituents can affect voice quality. By measuring these, we can calculate (using ITU G.107.1) a scalar rating of transmission performance known as R-factor MOS.

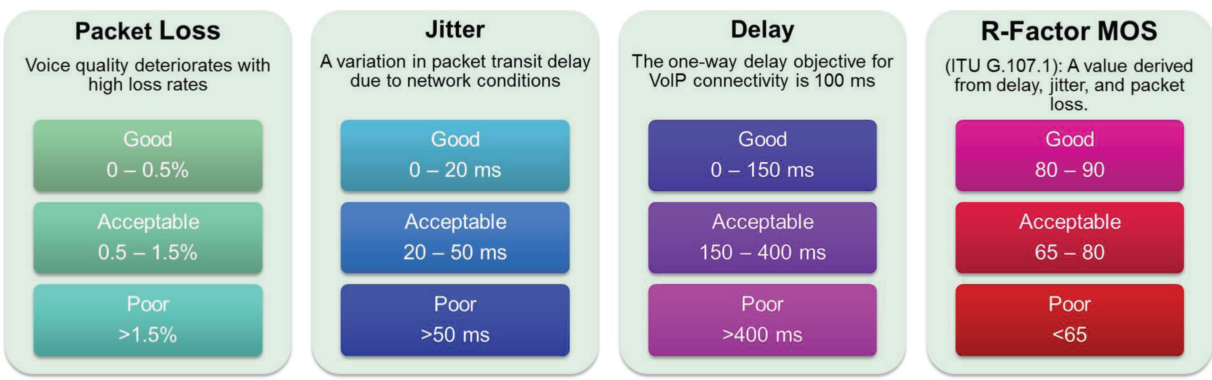

Figure 8. Factors affecting R-factor MOS

Traditional MOS is calculated on a scale of 1 to 5 where 5 is best and 1 is worst.

MOS	Quality	Impairment
5	Excellent	Imperceptible
4	Good	Perceptible, not annoying
3	Fair	Slightly annoying
2	Poor	Annoying
1	Bad	Very annoying

R-factor MOS is an evolution of MOS and is intended to provide a more granular measure of voce quality. R-factor ranges from 0 to 100.

User Satisfaction	R Factor Value Range
Very Satisfied	90–100
Satisfied	80–89
Some Users Dissatisfied	70–79
Many Users Dissatisfied	60–69
Nearly All Users Dissatisfied	50–59

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Note that both MOS and R-factor are measuring the underlying RTP streams for voice: the network's effect on voice quality. Neither is analyzing the media traffic contained within the RTP packets.

Perceptual Evolution of Speech Quality (PESQ) and Perceptual Objective Listening Quality Assessment (POLQA)

Rather than assessing the transport network, PESQ uses actual voice samples as test signals in order to characterize listening voice quality. POLQA is the successor to PESQ, and is extended towards handling higher bandwidth audio as delivered through VoLTE. With POLQA, a reference waveform is injected into the network and then analyzed on reception to determine any degradation. It processes the speech signal received and compares it to the original signal. POLQA typically provides a 1 to 5 scale similar to the PESQ scale.

Voice quality can be measured and determined by a number of different methods. MOS and R-Factor are passive measurements based on network parameters whereas PESQ and POLQA are active measurements based on the actual media.

MOS	Passive	Transport
R-Factor	Passive	Transport
PESQ	Active	Voice samples
POLQA	Active	Voice samples

What Happens Outside LTE Coverage

We will now discuss how voice can be delivered when the user roams outside the LTE network or VoLTE is not supported.

Circuit-Switched Fallback (CSFB)

Prior to VoLTE being deployed, a mechanism was required to allow LTE-enabled handsets to connect to all IP data services while also being able to make and receive voice calls (which uses circuit switching rather than data-packet switching). With CSFB, when the user's device is operating in LTE mode and a voice call comes in, the LTE network will page the device. The device responds with a special service request message to the network, and the network signals the device to move (fall back) to 2G/3G to accept the incoming call. For an outgoing call, the user device makes a CSFB request to the network (MME). The MME informs the eNB of the request and the eNB then redirects the device to interact with the circuit-switched network (MSC). A downside is that the user is now using data rates at 3G levels rather than LTE when voice is in progress.

The following diagram illustrates the key elements and interfaces between them required to implement CSFB.

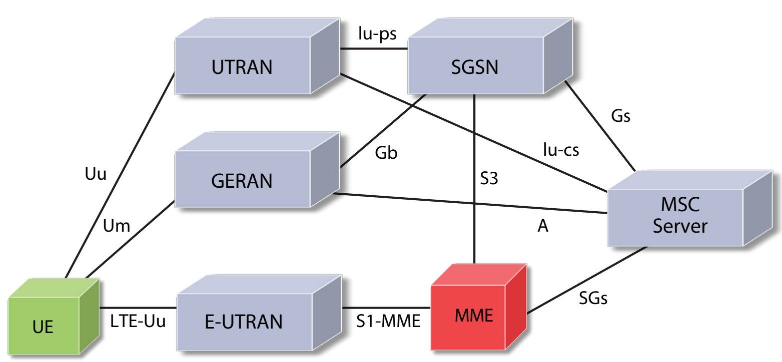

Figure 9. CSFB elements and interfaces (source: 3GPP TS 23.272 V10.14.0)

Single Radio Voice Call Continuity (SRVCC)

When VoLTE users move out of LTE coverage, they need to be able to continue to make and receive voice calls. SRVCC seamlessly maintains voice calls when a mobile user moves from LTE to a non-LTE coverage area. Given that LTE networks and VoLTE services may be deployed gradually, SRVCC is crucial for delivering ubiquitous voice services.

The seamless handover is a crucial part of SRVCC. A VoLTE call must be able to be transferred from the LTE packet-switched network to the legacy circuit-switched voice network while the call is in progress. SRVCC also satisfies the critical demands of emergency calls.

When a user is moving out of the LTE coverage area with a VoLTE call in progress, the user device notifies the LTE network (MME). The MME determines that the voice call needs to be moved to the legacy-circuit domain. It notifies the MSC server of the need to switch the voice call from the packet to the circuit domain and initiates a handover of the LTE voice bearer to the circuit network. The MSC server establishes a bearer path for the UE in the legacy network and notifies the IMS core that the mobile's call leg is moving from the packet to the circuit domain. The IMS core then performs necessary interworking functions.

When a mobile device arrives on-channel in the legacy network, it switches its internal voice processing from VoLTE to legacy-circuit voice, and the call continues.

3GPP Release 10 extends SRVCC to enhanced SRVCC (eSRVCC) which builds on the soft handover capability and introduces new functionality within IMS such as the access transfer control function (ATCF) and the access transfer gateway (ATGW).

The following diagram illustrates the key network elements and interfaces required to deliver SRVCC.

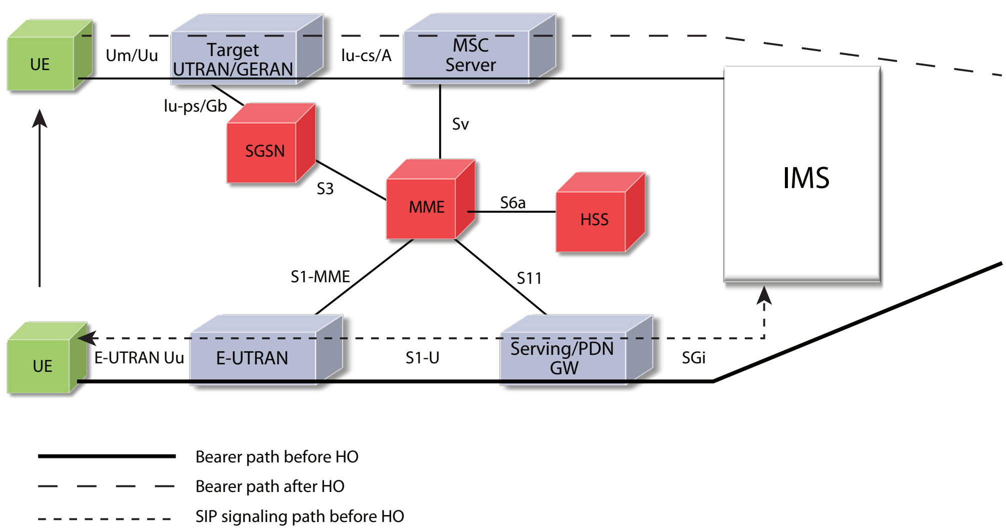

Figure 10. SRVCC elements and interfaces (3GPP TS 23.216 V10.6.0)

Both CSFB and SRVCC are highly complex, spanning multiple networks involving multiple elements to interact.

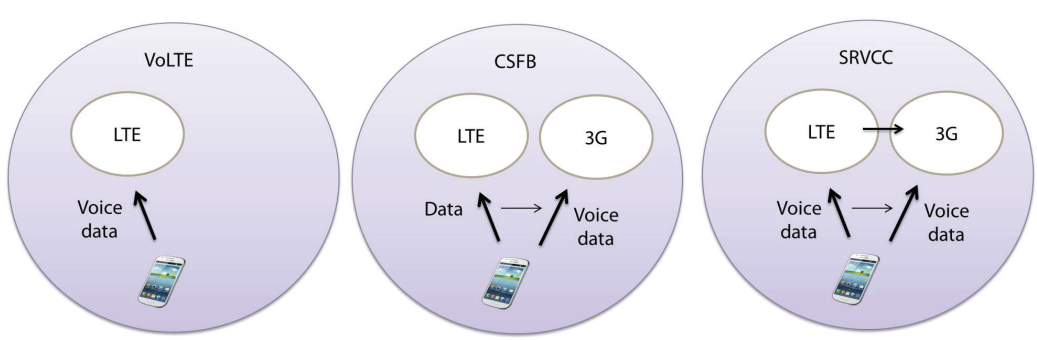

Figure 11. The span of VoLTE, CSFB, and SRVCC

VoLTE Challenges and Solutions

VoLTE brings many benefits to both the user and the operator. However, it is not without its challenges, from the complexity of a call set up with the relevant QoS to ensuring the radio network can deliver the necessary resources. The user expectation is that VoLTE will be a superior voice service and the operator will need to ensure the service meets the customer needs and forms the foundation for integrated IP multimedia applications.

Below are some of the challenges to consider when testing, deploying, and managing VoLTE:

- Pre-deployment lab testing — rigorous testing in the lab before the user experiences the service is vital, especially with a service as important as voice. Interoperability testing, managing the scale, and analyzing voice quality are important topics to consider.
- RF considerations — the RAN is fundamental to delivering high-quality voice. The operator not only may be deploying LTE but may also be considering or deploying MIMO and LTE-A. Being able to characterize the RF component of the network will prove vital in the testing and maintenance phases.
- Measuring voice quality end-to-end — service quality is only as good as its weakest link and quality in a VoLTE network must be negotiated at each hop. Not only should an operator be able to measure the voice quality, they should also be able to resolve the issues causing any service disturbance. This must be considered from the user device right to the network core. The complexity of the control plane as well as the user plane needs consideration as evidenced by the number of network elements involved in a VoLTE call in addition to the heterogeneous array of network element vendors.

In summary, understanding the RF, RAN, and core elements end-to-end is fundamental in optimizing VoLTE for the user.

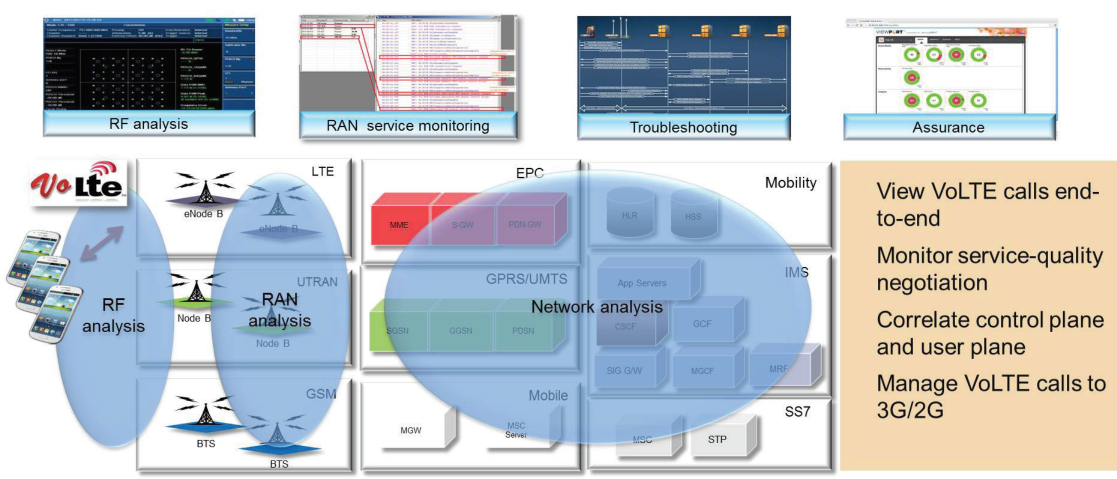

Figure 12. Managing VoLTE end-to-end

Pre-Deployment Lab Testing

There are two related components to pre-deployment lab testing that need considering:

- Generating traffic and emulating 1000s of end users, loading sites, and recreating the real world in the lab
- Capturing, indexing, storing, and analyzing VoLTE calls as well as other LTE and non-LTE traffic

In addition, interoperability testing between the various elements that are required to be combined to deliver VoLTE needs planning. Given the complexity of the IMS environment and the many nodes that must be considered from multiple manufacturers, it is important to have a clear testing methodology before deployment.

Another key consideration is the correlation of the user plane (the media) and the control plane (the signaling). Determining voice quality involves understanding the complex interactions between the user plane and the control plane in order to not only measure voice quality, but also to determine the root cause of any service-affecting issues.

ETSI, NGMN, and the Small Cell Forum have conducted many plugfests to emulate the environments of LTE and VoLTE deployments and test interoperability between elements.

RF Considerations

The RF properties of any LTE network require testing prior to deployment to ensure optimal cell-site operation. In addition, once the cell site is operational, maintenance and troubleshooting is needed to manage and optimize the radio infrastructure. Earlier, we made clear the importance of RF characteristics to VoLTE given the requirements on the RAN from a real-time, high-quality, low-latency service such as VoLTE.

Constellation shows modulation quality on data channels.

The acceptable modulation quality (EVM) of data channels per resource block are user configurable by the assignment of EVM limits to each data channel (QPSK, 16 QAM, 64 QAM).

VoLTE is a data service and will be impacted by potential modulation issues on the data channels.

VoLTE traffic will be assigned to resource blocks—the JDSU CellAdvisor Base Station Analyzer shows resource block activity.

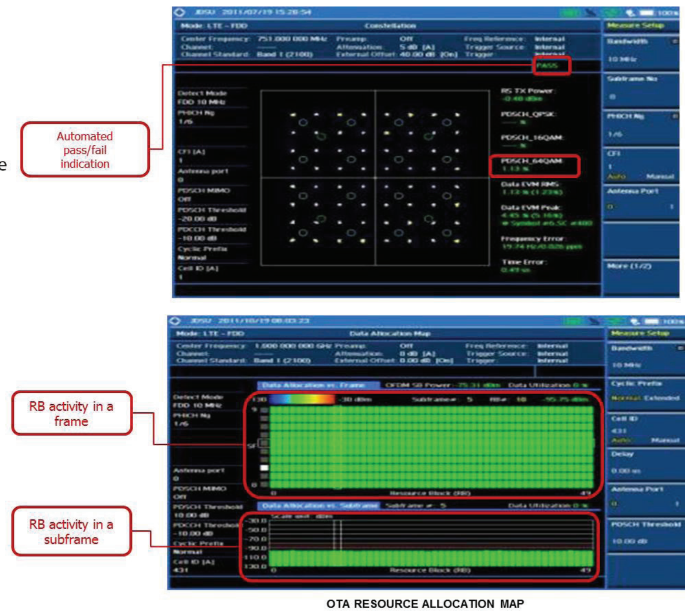

Figure 13. LTE RF signal analysis of VoLTE: demodulation and resource block analysis

The diagram above shows an example of RF analysis. Being able to analyze the modulated signals of the data channels at a granular level as well as the resource block activity is vital to ensuring RAN efficiency.

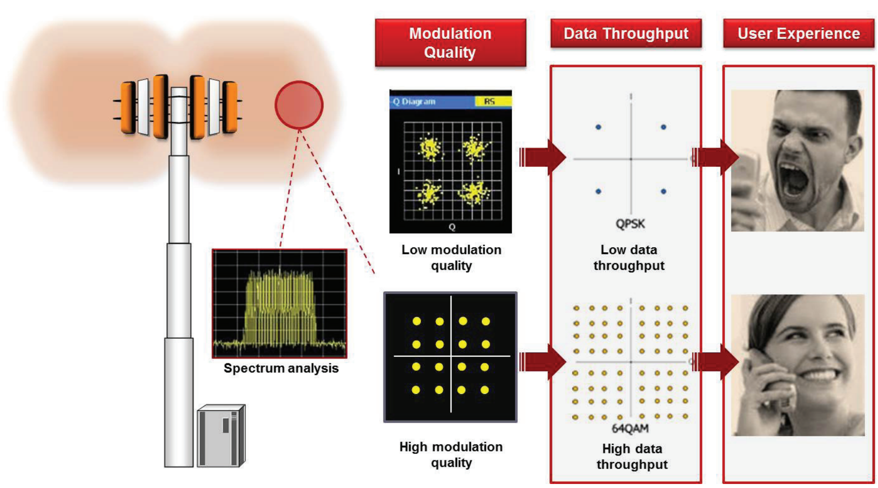

Figure 14. LTE signal analysis; LTE modulation quality indicates the modulation scheme and data throughput assigned to each user

Reference signals are used by mobile terminals as signal quality indicators, such that if the modulation quality of the reference signal is poor, then the mobile sends a low signal indicator (channel quality indicator) to the cell site, which in turn assigns a low modulation scheme (data throughput) to the user.

Conversely, the better the modulation quality of the reference signal, the better a channel quality indicator is communicated and the cell site assigns the highest modulation scheme to the user, achieving maximum data throughput.

Measuring Voice Quality End-to-End

We discussed various voice quality metrics to consider for a VoLTE service. Now, we look at measuring, analyzing, and trouble-shooting the VoLTE service.

Measuring from the User Device

First, we want to be able to check that the VoLTE service has been setup with the bearers negotiated correctly.

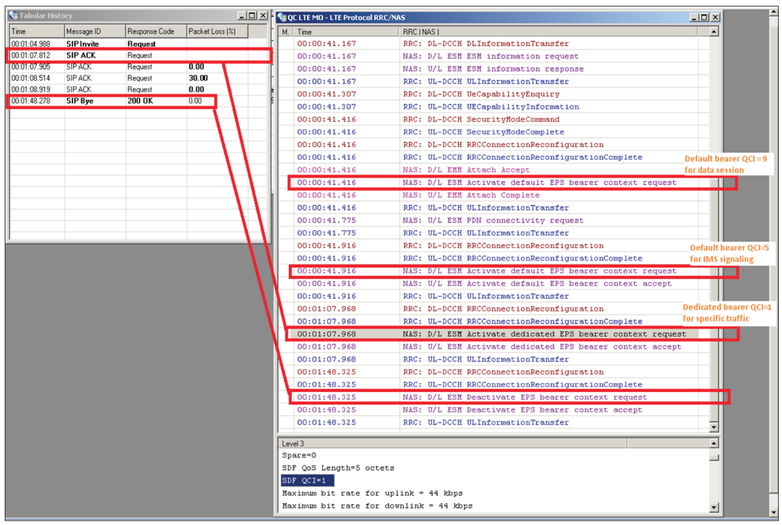

Figure 15. SIP negotiation sequence

In Figure 15, the default bearer is first established with a QCI of 9 for a data session. The IMS signaling is given a QCI of 5. A dedicated bearer is then established with a QCI of 1 (GBR for VoLTE).

We can also perform handset-to-handset testing to measure voice quality.

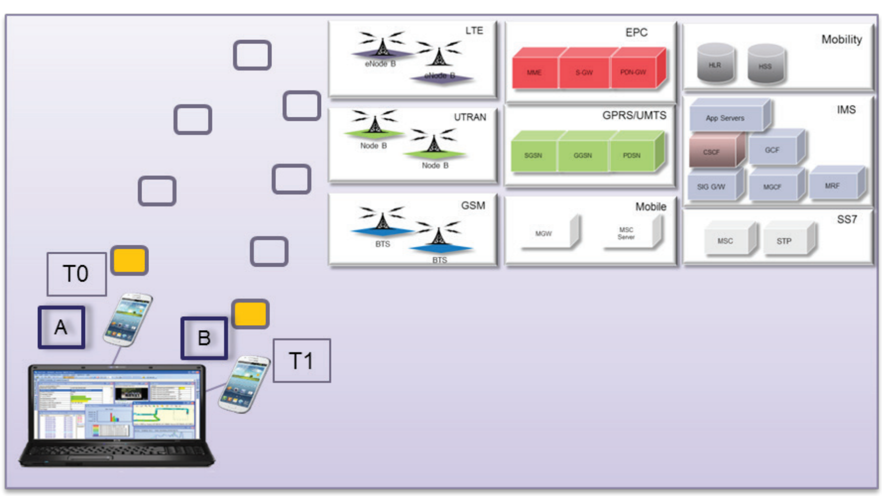

Figure 16. VoLTE call negotiations

In the scenario in Figure 16, a VoLTE call has been established between handset A and handset B. We can now make measurements such as one-way delay, delay variation (jitter), and packet loss that go towards an R-factor measurement. An accurate time in milliseconds from T0 to T1 can be measured using the RTP packet timestamp. The time interval accuracy is crucial here and throughout the call.

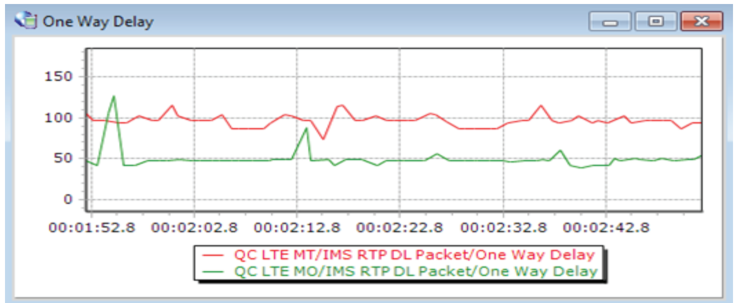

Figure 17. One-way delay measurements

Both passive and active voice-quality measurements can be performed. This determines the POLQA MOS and can be simply done by injecting a sample sound file into one handset, capturing the audio on the second handset, and creating a POLQA score by comparing the result with the reference.

Measuring from the Network

To get an end-to-end view, one should also be able to capture and analyze traffic in the network and use the insight to troubleshoot service issues as well as optimize the overall customer experience. Being able to capture and analyze the IMS flow gives a perspective not only of VoLTE but also of all IMS-based services. There are also many others protocols to consider beyond SIP: Diameter, radius, DNS, RTP, RTCP, and H.248 as well as the LTE transport protocols themselves. Real-time correlation, together with highly-granular resolution, are key considerations when analyzing VoLTE—the quality of a call can vary considerably, so if a call has great quality in the first half and very poor quality in the second half, suggesting that the overall quality was average will not accurately indicate the overall customer experience.

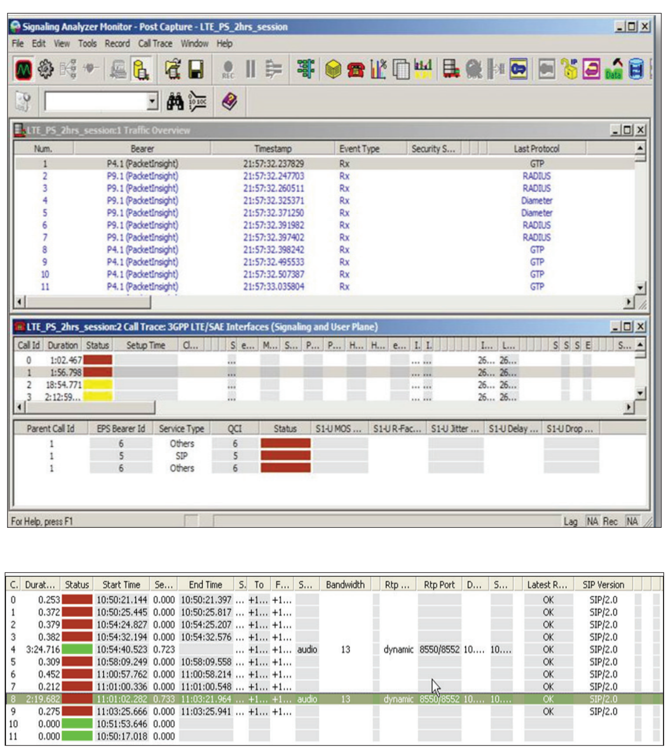

Figure 18. Session capture information

The session captures shown in Figure 18 show the protocols employed and the signaling and user plane together with the bearer information.

Some of the important VoLTE indicators and quality metrics to consider include:

- Call control and user experience
  - Call setup success rate
  - Call setup time
  - Registration success rate
  - Registration time
  - Call drop rate
  - CSFB success rate
  - CSFB setup time
  - SRVCC success rate
  - SRVCC speech connection gap
- Voice quality (RTP)
  - Packet loss
  - Inter-packet delay
  - Inter-packet jitter
  - MOS (from delay, loss, and jitter)

Knowing many of these values during the call helps give an understanding of true voice quality. For example, an averaged voice quality may look acceptable, but the first half of the call may have been very poor with the second half of the call being excellent. As a result, the overall customer experience would not be reflected in the average measurement.

VoLTE Customer Experience Assurance

Proactive management of IP services lets operators focus on key service-affecting issues and prioritize accordingly. A dashboard of the service with the ability to drill down provides the operator with an end-to-end view. A real-time, visual representation is needed to deliver this with flexible KPI presentation. This, coupled with sophisticated correlation technology, links the customer experience to underlying network and service performance. In addition, this provides a workflow that helps users quickly identify problems with the biggest impact to the customer experience and guides them through the analysis steps until root cause is uncovered.

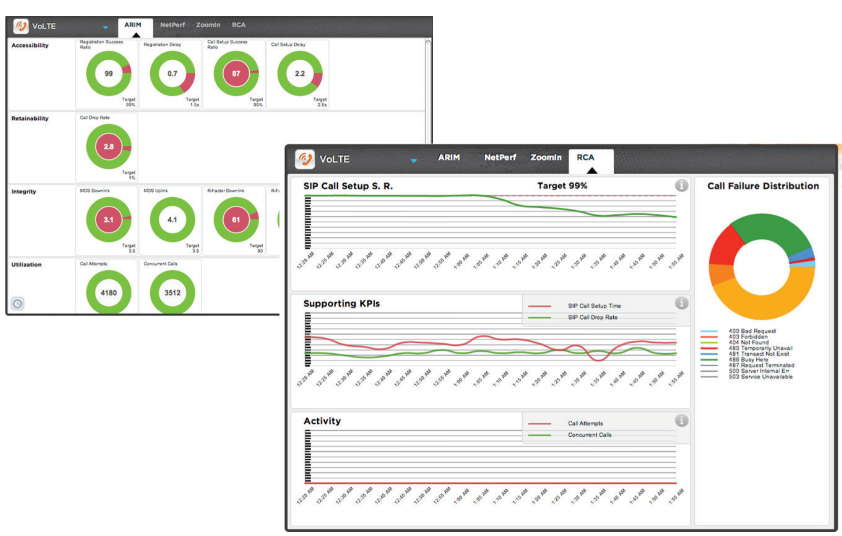

Figure 19. Typical VoLTE dashboards

The information shown in Figure 19 is an example of how a VoLTE dashboard gives a visually impactful representation of the service.

Conclusions

Voice is, and will continue to be, a core mobile service. VoLTE is the voice service of the future, embracing better quality, faster connection times, and the integration of rich communication services. VoLTE delivers many operator advantages as well as user advantages over today's voice services. However, as we have seen, VoLTE is not without its challenges. To be successful in delivering a good VoLTE customer experience, operators will need to be able to test, troubleshoot, manage, and optimize both the network and services to ensure they meet user expectations.

With VoLTE expected to deliver $2B for operators by 2016, and as a foundation for operator differentiation, VoLTE should not be left to chance.

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