Real time testbeds for 5G NSA and SA mobile architectures to provide VoLTE and VoNR services over IP Multimedia Core Network Subsystem

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***Abstract*—The contribution of this work is the deployment of real time testbeds for the 5G NSA (Non-StandAlone) and the 5G SA (StandAlone) mobile architectures to provide both Voice over LTE (VoLTE) and Voice over New Radio (VoNR) services. In addition, an IMS (IP Multimedia Subsystem) core network was deployed to provide voice over IP services. The delay, the throughput and the jitter quality of services metrics are also computed, which allow analyzing and comparing the results between both 5G network architectures.**

***Index Terms*—5G, IMS, VoNR, VoLTE**

I. Introduction

The fifth generation (5G) of mobile communications introduces a new radio interface i.e. the New Radio (NR) TR 21.915 [1], which offers high throughput, low latency, massive connections and it is capable to connect with Long Term Evolution (LTE) Core Network. 5G can be deployed in two scenarios, according to TR 23.799 [2]: Stand-alone (SA) and Non-Stand Alone (NSA).

On one hand, in an NSA architecture, 5G Radio Access Network (RAN) is used in conjunction with 4G Core Network and 4G RAN. Consequently, NSA offers dual connectivity, which is also known as E-UTRA-NR Dual Connectivity (EN-DC) TR 21.915 [1]. EN-DC means that the User Equipment (UE) has simultaneous connectivity to both 4G RAN (E-UTRAN) and 5G RAN (NR).This scenario can be seen as an initial 5G deployment since, only LTE services are supported, but with some 5G features such as, lower latency and higher throughput. On the other hand, in an SA architecture, the 5G Radio Access Network (RAN) is connected to the 5G Core Network, which consist of a "full 5G deployment" i.e. 5G services are already supported, as mentioned in TR 21.915 [1].

As seen in TR 29.949 [3], VoLTE (Voice Over LTE) has the capability to provide voice, video and SMS messages (Short Message Service) using the LTE architecture of the 4G mobile network. On the other hand, according to TS 23.501 [4], VoNR (Voice Over New Radio) provides the aforementioned services using the New Radio radio interface, which offers to the mobile user a much better real time experience and a higher Quality of Service. Both 5G architectures use packet switching approach, as well as, the IMS (IP Multimedia Subsystem) network in order to provide the multimedia services. The IMS network uses mainly SIP (Session Initiation Protocol) to establish, modify and terminate VoLTE and VoNR sessions.

The contribution of this work is to show how a 5G network works by comparing the IMS voice call flows on 5G NSA and 5G SA architectures. In addition, both VoLTE and VoNR voice call services are evaluated as a function of the quality of service metrics i.e. throughput, delay and jitter. The challenges of this work were to set properly the virtualized 5G network nodes, to configure the base stations accordingly to the mobile network and do a post-processing of the data collected.Section II explains key concepts of the article for instance, 5G SA and 5G NSA architectures, how IMS works in 5G network, SIP protocol. Section III presents the configuration setup and the results of the real time testbed are explained in detail. Furthermore, the call flow over the 5G SA and the 5G NSA networks, and the quality of service metrics are analyzed.

II. Key 5G Concepts

A. 5G NSA and SA

The 5G architecture shall support data connectivity and different types of requirements for instance, Enhanced Mobile Broadband (eMBB), Critical Communications (CC) and Ultra Reliable and Low Latency Communications (URLLC).The 3GPP defines two different 5G architectures, which are: 5G

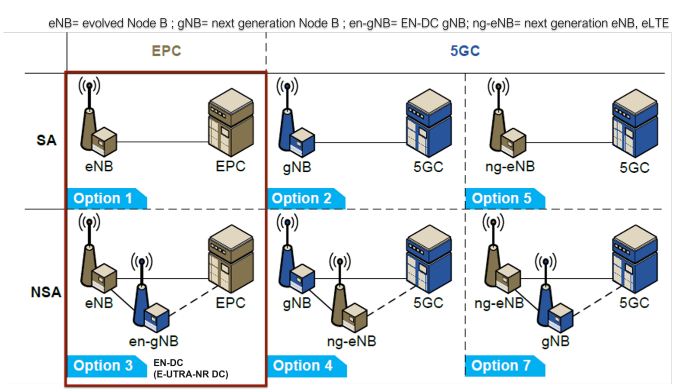

Fig. 1: 5G Architectures

NSA and 5G SA [2]. There are different configuration as illustrated in Fig. 1. Both architectures option 2 and option 5 correspond to a 5G SA implementation, using a complete 5G Core (5GC). In addition, the base stations are the gNode B (gNB) and the ng-eNB (next generation eNB, enhanced LTE) for Option 2 and Option 5, respectively. For option 2, the gNB is connected to a 5GC, hence, the gNB is able to communicate to the UE without any 4G assists. In contrast, for Option 5, the ng-eNB is connected to the 5GC using an enhanced LTE base station. In this work, the SA option 2 was deployed.

Options 3, 4 and 7 are related to 5G NSA architectures. Option 3 (also knows as EN-DC i.e. E-UTRA-NR DC), the en-gNB is connected to a 4G Core and uses the LTE air-interface. Furthermore, the dual connectivity concepts is introduced, which consist of using a master RAT (Radio Access Technology) i.e. an eNB and a secondary RAT i.e. an en-gNB (EN-DC gNB), which corresponds to a 5G base station. For Option 4, the eNB needs to be upgraded to the ng-eNB in order to connect to the 5GC or gNB. At last, for Option 7 the eNB works as the anchor RAT and gNB as the master RAT. The option used in this work is the NSA option 3 family i.e. option 3x. The TS 23.501 [4] presents 5G architecture elements as network functions (NF), which are: the Access and Mobility management Function (AMF), the Session Management Function (SMF) and the User Plane Function (UPF).

B. IMS - IP Multimedia Subsystem from 5G

The IMS network is a must-have mobile network evolution for mobile operators that want to derive value from future applications (4G, 5G, and so on). It allows services to operate independently from the IP-CAN (IP Connectivity Access Network) technology.In addition, IMS network delivers multimedia communications services e.g. Voice over LTE (VoLTE), Voice New Radio (VoNR) [6]. In 5G, Protocol Data Unit (PDU) session are established to deploy the default and dedicated bearers. Fig.2 shows the step by step communication procedure.

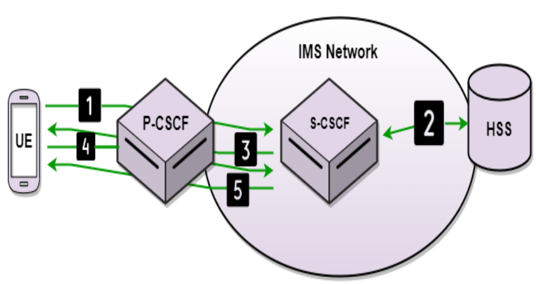

Fig. 2: High-level IMS flow in 5G

1) The User Equipment (UE) sends a registration request to the IMS network, where the P-CSCF (Proxy CSCF) verifies the security of the end-to-end routing of SIP messages;
2) The general control of the IMS service is done by the S-CSCF (Serving CSCF), which sends requests to the HSS for security information on authentication;
3) Next, the S-CSCF returns with an authentication challenge to the UE;
4) While the UE is waiting to receive the result of the authentication challenge, it tries to register again;
5) The device is registered and had access to services provided by the IMS network, such as, VoLTE and VoNR, only if the authentication challenge is satisfied.

C. SIP - Session Initiation Protocol

The SIP protocol is responsible for the establishment, modification and termination of voice calls over IP using an IMS network. SIP messages are classified into two groups: requests and responses. According to RFC 3261 [5], the purpose of a SIP message is defined by the method that has been assigned to the message. The SIP methods are: REGISTER, INVITE, ACK, CANCEL, BYE, and OPTIONS. In the SIP protocol, the responses are sent as replies to SIP requests and consist of a Status-Code, which is a 3-digit integer, and a Reason-Phase, whose describes the status code in a short sentence, such as, 200 OK. The SIP messages are divided into a header containing the SIP method and a unique Call-ID, and a body containing the SDP message (Session Description Protocol). Table I describes the main methods.

TABLE I: SIP Methods

Method	Description
INVITE	Indicates that the UE is being invited to participate in a call session.
ACK	Confirms that the INVITE method has been received
REGISTER	Enables a UE to register the address listed (typically of the form ”user@domain”) in the ”To” header field with a SIP Server.
BYE	Terminates a SIP session.
CANCEL	Used to tear down a session before it has been established.
OPTIONS	Used to query the server capabilities.
NOTIFY	Used to notify that the event requested by an earlier SUBSCRIBE method has occurred.

D. QoS flows

Unlike 4G LTE, 5G NR is not only developed for broadband applications; in addition it’s also developed for various types of applications on a single protocol. In this way, the QoS flow architecture is more complex since, each service is part of a specific type of PDU (Protocol Data Unity). The NG-U tunnel, also called N3 GTP-U, is an encapsulation header where the QFI (QoS Flow Identifier ranks the index of packages) is carried.

In the QoS stream, the data flow from a DN (Data Network) to the user (UE). In this context, the UPF (User Plane Function) maps the packets of each QoS flow, which is based on the 5QI classification rules. Each of these data packets will pass through a specific PDU and DRB (Data Radio Bearer).

Then, each stream will have different levels of priority, data rate, and latency, as can be seen in Fig. 3.

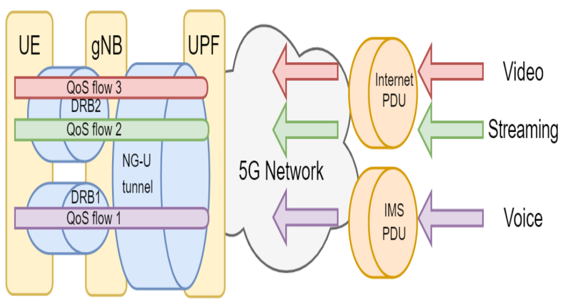

Fig. 3: 5G QoS Flow

As mentioned in the 3GPP TS 23.203 [7], the 5G NSA architecture has several QoS Class Identifier (QCI) levels, whose intervals are from 1 to 80. In this case, the voice call is VoLTE and has a QCI equal to 1.

In contrast, for the 5G SA architecture and VoNR, according to 3GPP TS 23.501 standard [4], it has a 5QI equal to 1. The 5QI levels vary from 1 to 90, showing that more categories of applications have been included in comparison with 4G network.

E. Quality of Service Metrics

As mentioned in [8], the following Quality of Service Metrics are highlighted:

- Latency: refers to the time it takes for packets to arrive from the sender to the receiver;
- Jitter: refers to the variation in delay time between two packets, i.e. the difference between the expected waiting time for the arrival of the packet and the time at which it actually arrived, which exists only in packet-based networks;
- Throughput: refers to the measure of the actual amount of data and packets that are being sent over the network per unit of time.

Fig. 4 and Fig. 5 show the difference between latency and jitter concepts. Moreover, a comparison between throughput and a data stream of a given bandwidth concepts is presented in Fig. 6.

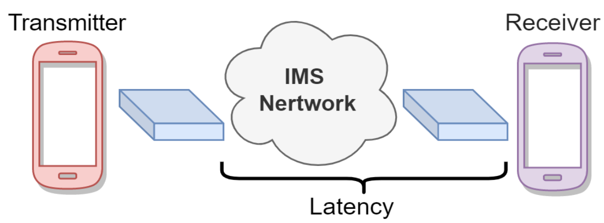

Fig. 4: Latency

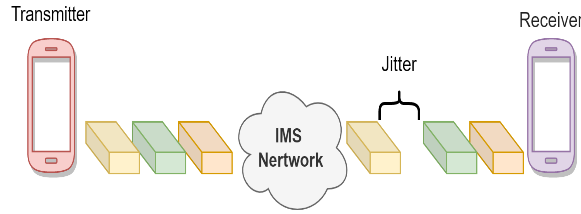

Fig. 5: Jitter

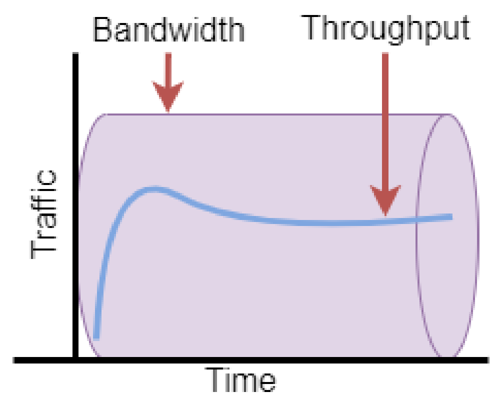

Fig. 6: Bandwidth vs Throughput

III. Results

A. Experimental setup

The testbed was developed using the SmartStudio software [9] considering an eNB and a gNB operating at LTE band 7 (2.6GHz) and 5G N-78 (3.5 GHz) frequency, respectively. Therefore, two base stations were configured for this experiment. Bandwidth values equal to 20 MHz and 100 MHz were set for LTE and NR, respectively. The testbed deployed virtualized 4G and 5G mobile networks elements.

Fig. 7 shows a high-level implementation of the 5G SA/NSA testbed.

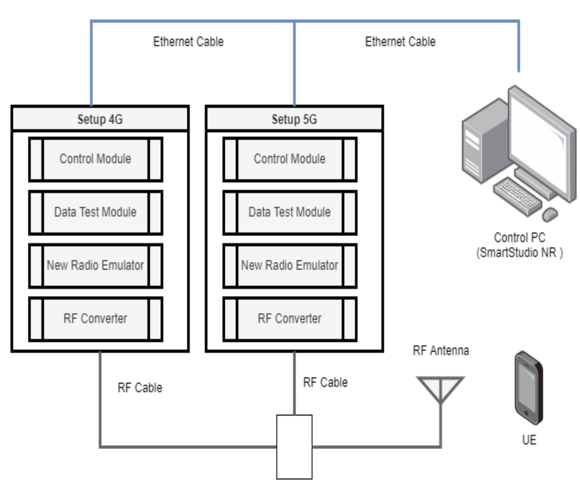

Fig. 7: High-level 5G setup configuration

The setup modules are described as follows:

- In the control module, the network parameters are modeled to generate a bit stream;
- In the Data test Module, the bit stream passes through a series-parallel converter and then, they are transferred to the Baseband Module;
- In the Baseband module, the sequences of parallel bits are modulated using e.g. a 64-QAM digital modulation, so the bits are then represented by complex symbols where each symbol carries 6 information bits;
- The RF module adds the cycle prefix and finally, the signal passes through a parallel-to-series converter. The Base RF module's output signal is modulated to RF signal and then, it is conducted by a RF cable to the antenna, and lastly propagated.

B. VoNR Call flow

The initial registration procedure starts when the UE sends a REGISTER request and, then, it receives a 401 Unauthorized message that contains a challenge. Next, the UE shall send an integrity-protected REGISTER request that includes the challenge response and the P-CSCF has to respond with a 200 OK message. However, the UE shall only initiate a new registration procedure when it has received whether a final response from the registrar for the ongoing registration or the previous REGISTER request has timed out. Fig. 8 shows the registration process.

A packet analyzer software [10] was utilized to assess the SIP messages traffic. To subscribe to the registration event, the UE sends a SUBSCRIBE request and shall receive back a 200 OK message. After establishing the subscription and once, a NOTIFY request message is received, we are able to evaluate the body of the NOTIFY message. As depicted in Fig. 9, this message shows the registration element with its state attribute is ”active”. This state indicates that the UE shall store the indicated public user identities as registered.Both the 5G NSA and the 5G SA mobile architectures show that the flow of the SIP messages from the INVITE process to the call stages is similar, as 4G voice calls do. See Fig. 10.

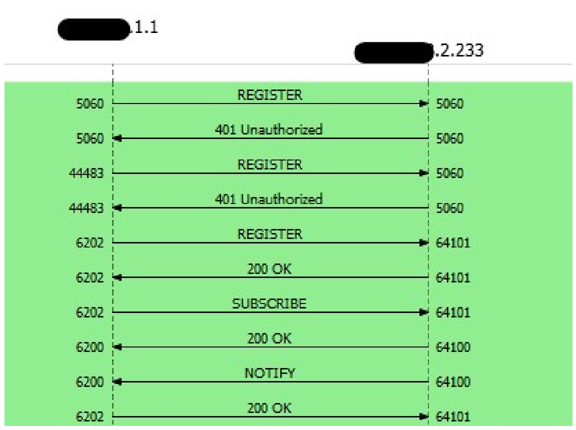

Fig. 8: IMS Registration

Fig. 9: NOTIFY message body

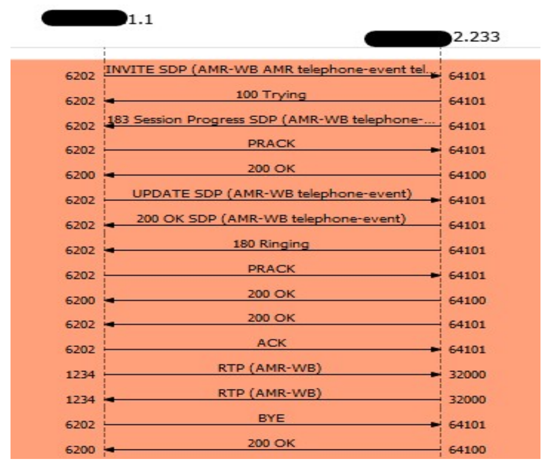

Fig. 10: Invite request message during a 5G call

Fig. 11 shows the SIP messages header exchanged between the UE and the IMS network i.e. New Radio (NR) using the TDD spectrum technique. The P-Access-Network-Info header indicates to the IMS network over which radio access interface technology the UE is attached to. This way, the access-type field identifies the radio access technology received in the RAT-Type attribute.

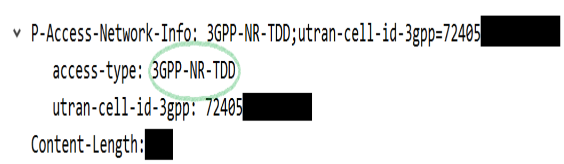

Fig. 11: Radio interface access type

C. Quality of service Metrics for the setup

Fig. 12 shows the smartphone RF interface, the voice call over IMS which is related to and the network which the mobile user is connected to. As shown in the image, VoLTE and VoNR over IMS are utilized for 5G NSA and SA, respectively.

Considering the configuration setup presented in Fig. 7, the throughput and jitter values are presented for a VoLTE and a VoNR calls between two users. The throughput values during an NSA VoLTE call and an SA VoNR call are shown in Fig. 13 and Fig. 14, respectively. The higher throughput value

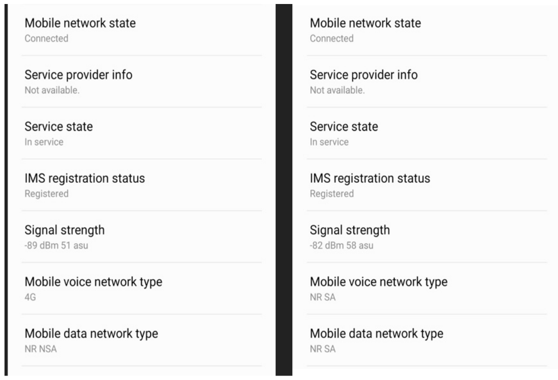

Fig. 12: 5G mobile user RF interface: left side) NSA deployment ; right side) SA deployment

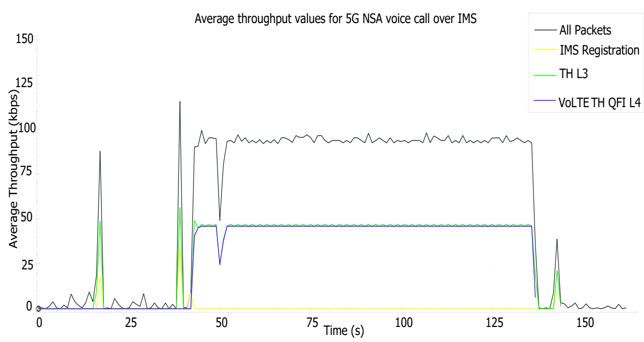

Fig. 13: 5G VoLTE Call throughput

was approximately 100Kbps. As expected, for a voice call the NSA option 3x should have similar results to the SA option 2, once the NR interface is also deployed for the option 3x configuration.

Fig. 15 shows the evaluation of jitter value for 5G NSA and SA voice calls over IP Multimedia Core Network Subsystem. The results satisfy the requirement value which is 20 ms, as explained in [7]. Along the different transmission and receptions stages exist a transmission delay time, propagation delay time, queuing delay time and a processing delay. In this context, Fig. 16 presents the delay time results during the 5G voice calls. The RTP protocol, RTCP Sender Report (SR) message and the SSRC (synchronization source) identifier were used to analyze and compute the delay time. The SSRC identifier is used to identify the source of a stream of packets from a synchronization source in order to prevent two synchronization sources from having the same SSRC identifier in the same session. Since RTCP SR packets are sent very rarely in comparison to RTP data packets; therefore, the number of RTCP packets are lower than RTP. Fig. 16 shows the transition delay results, as we can realize, there are negligible delay values for both 5G voice call services.

IV. Conclusion

The scientific article was able to obtain the results of battery of tests for the 5G NSA and the 5G SA mobile architectures

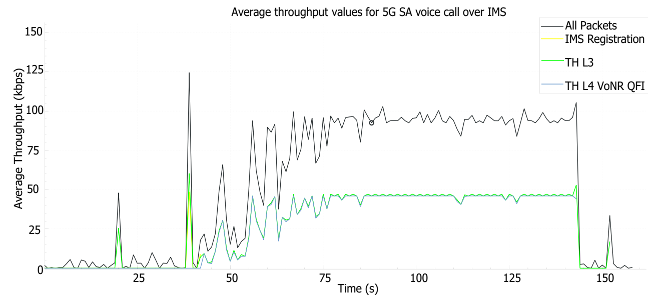

Fig. 14: 5G VoNR Call throughput

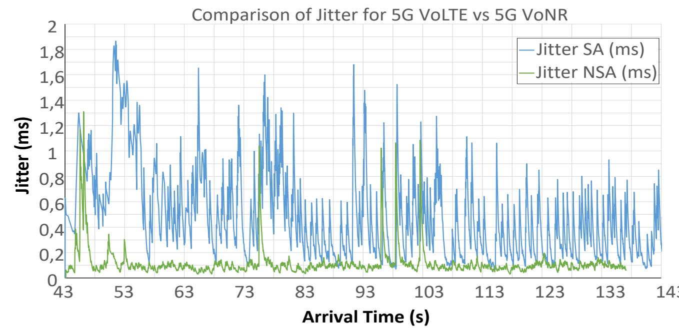

Fig. 15: Jitter values for the 5G calls over IMS

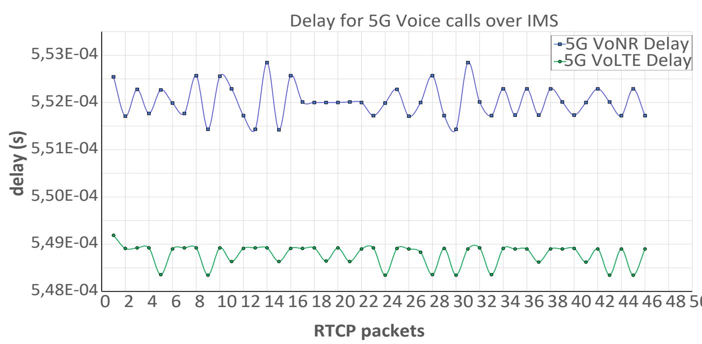

Fig. 16: Transition delay for 5G voice calls over IMS

over IMS. Additionally, the configuration setup were capable of providing VoLTE and VoNR services to the mobile users. During the call sessions, it was realized that no matter how different the voice call technologies are, the SIP signaling and IMS registration processes are according to Table 6.1.3.2-1 and Table 7.4.3.2 -1 of the TS 34.229 [11] specification. The process described in TS 34.229 corresponds to what is described in TS 24.229 [12], hence, the IMS registration and voice call stages have similar processes between 5G and LTE networks.

The 5G NSA testbed considered the option 3X configuration in which the master node and the secondary are the eNB and the gNB (en-gNB), respectively. In this context, a higher throughput values are obtained, as shown in Fig. 13. By analyzing the quality of service flow for both mobile architectures, the jitter values are below 20 ms that satisfy the standards requirements defined by TS 23.203 [7].

The RTP and RTCP protocols were used to analyze and compute the delay time. As we can observe in Fig. 16, there are negligible values for both 5G voice call services i.e. VoLTE and VoNR. These results can also be shown since, jitter is the variation in the amount of the delay and it satisfies the requirement value which is below 20ms. (see Fig. 15).

Future studies and research intend to support more investigation considering 5G NSA and 5G SA mobile architectures, as well as a deeper analysis of the quality of voice over IMS service.

Acknowledgment

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