Improved Handover Signaling for 5G Networks

Akshay Jain, Elena Lopez-Aguilera and Ilker Demirkol
Dept. of Network Engineering
Universitat Politènica de Catalunya
Barcelona, Spain 08034
Email: akshay.jain@upc.edu, elopez@entel.upc.edu, ilker.demirkol@entel.upc.edu

***Abstract*—Mobility management is a critical component for any new wireless standard to be ubiquitous. While 4G-LTE and prior wireless standards utilized vendor specific hardware and software on which mobility management (MM) functionality was implemented, recent 5G architecture releases by 3GPP indicate a complete departure from the same. 3GPP in release 14 and the upcoming release 15 has stressed upon the utilization of Software Defined Networking (SDN) and Network Function Virtualization (NFV) as the drivers of 5G technology. Consequently, new challenges related to MM and specifically handover management will be encountered owing to the inter-working setup between the 5G Next-Gen Core (NGC) and the Evolved Packet System (EPS) core. In this paper, we exploit the SDN to enhance the signaling of the HO methods proposed by 3GPP. Although the proposed approach can be applied to any HO method, in this paper we specifically evaluate the scenario wherein a dedicated interface between the Mobility Management Entity (MME) in the EPC and the Access and Mobility management Function (AMF) in the 5G NGC, i.e., N26 as specified by 3GPP, is non-existent. Such a scenario is reasonable during the initial deployment phases of 5G networks. We show that the proposed mechanism is efficient as compared to the 3GPP handover strategy in terms of latency, transmission and processing costs.**

***Index Terms*—5G, Next Generation Core, Handover, Mobility Management, 3GPP, Latency**

I. Introduction

According to recent surveys [1], the number of new mobile broadband subscriptions has risen by 15% while the global traffic demand has increased by 55% in 2017 as compared to 2016. And with the rapid growth of the Internet of Things (IoT) space, 3GPP has proposed a new generation of wireless networks, i.e., 5G, to tackle the multitude of challenges being faced by the current networks.

3GPP through its recent standardization efforts [2]–[4] has already established the foundations of the upcoming 5G networks. These efforts have been primarily focused on the 5G New Radio (NR) aspect, as well as the 5G Next-Gen Core (NGC) architecture. However, an additional and equally important aspect that has been discussed by 3GPP during the ongoing standardization efforts is the aspect of handling mobility within 5G networks. Note that, for a new wireless standard to be ubiquitous it has to be able to permit unrestricted mobility for the users as well as perform efficient management of the same. Methods such as those discussed in [5] aim to provision this efficient management via techniques emphasizing on demand based mobility management. Further, an important component within mobility management is the aspect of handover (HO) management. The reason being, HOs permit users to switch the network attachment point whilst maintaining service continuity during mobility events in current cellular networks. Hence, given the highly heterogeneous and ultra-dense nature of 5G networks, efficient HO management will be extremely critical.

The HO management process comprises of two major steps, i.e., handover decision and handover signaling. While the handover decision phase has been significantly studied and optimized by utilizing techniques such as machine learning, fuzzy logic, multi-attribute decision making algorithm, etc. [6]–[10], handover signaling phase optimization still remains a challenge. Certain studies such as [11], [12] utilize the Software Defined Networking (SDN) and Network Function Virtualization (NFV) paradigm to optimize the handover signaling. However, such techniques do not consider the transitional nature of current wireless networks towards 5G, and hence, the issues of manageable Capital Expenditure (CAPEX), nor they consider the proposed 3GPP 5G NGC and Evolved Packet Core (EPC) inter-working architecture [4]. Consequently, the current research efforts into HO signaling optimization are insufficient to address the scenarios that will be prevalent based on the current 3GPP 5G proposals.

Thus, in this paper we study the handover signaling proposed by 3GPP for 5G networks in detail. Concretely, we focus on the HO preparation phase within the complete HO signaling step. Since it is during this phase that resource allocation and negotiation for an impending HO occurs, in an ultra-dense and heterogeneous network environment it will be critical to have an efficient signaling mechanism for HO preparation.

Further, for our current study, we consider an inter-working scenario, defined by 3GPP, wherein a direct interface (N26 interface) between the mobility management units (Mobility Management Entity (MME) in EPC and Access and Mobility management Function (AMF) in 5G NGC) does not exist. Such a consideration is reasonable, given the initial deployment scenarios wherein the 5G and legacy networks will be loosely integrated.

Henceforth, the rest of this paper is organized as follows: In Section II, we present some significant studies on HO signaling as well as the 3GPP proposed 5G HO signaling and inter-working architectures. In Section III, we present the proposed network architecture and how it facilitates the integration of legacy and 5G networks without the requirement of an N26 interface. Section IV then presents the HO signaling optimization methodology, which is then followed by a discussion on the analytical framework and results in Section V. The paper is then concluded in Section VI.

II. Background Study

In this section we present some important background studies in the area of handover signaling. Consider [13] wherein, the 5G service based architecture as proposed by 3GPP in [3] alongside a mechanism to optimize the handover signaling has been proposed. The main contribution of this work is to evolve the 3GPP proposed AMF block to manage the radio resource control (RRC) and management (RRM) functions as well. This allows the next generation NodeB (gNB) to be a purely data plane entity, while reducing the control plane (CP) signaling between the gNB and the core network (CN) during HOs. The reason being, now the RRC and RRM steps are executed in the core network and hence, any interaction between the RRM-RRC and AMF blocks is now accomplished at the same physical location. However, such a setup will hamper network reactivity during highly dynamic scenarios. Further, the study performed in [13] considers LTE signaling as a reference, which is significantly different from the 5G CN signaling [4]. And while the focus of [13] is on faster handover signaling, it does not focus on the HO preparation phase. Lastly, the handover scenario being considered is an intra NG-RAN (Next Generation Radio Access Network) HO, which again does not capture the challenges that will be experienced during the inter-RAT (Radio Access Technology) HO processes.

In addition, studies such as [11] consider a fully SDN based network and utilize the principle of Distributed Mobility Management (DMM) for enhancing the HO signaling. In particular, in [11] the signaling cost as well as the HO latency have been analyzed during mobility events. While marked improvements have been observed as compared to the partial and fully distributed approaches, the proposed approach entails a complete departure from current network architecture which would lead to high CAPEX for the operators. Consequently, such an approach does not meet the guidelines laid down for the future generation of wireless networks, wherein manageable CAPEX and Operating Expenditure (OPEX) is a critical factor.

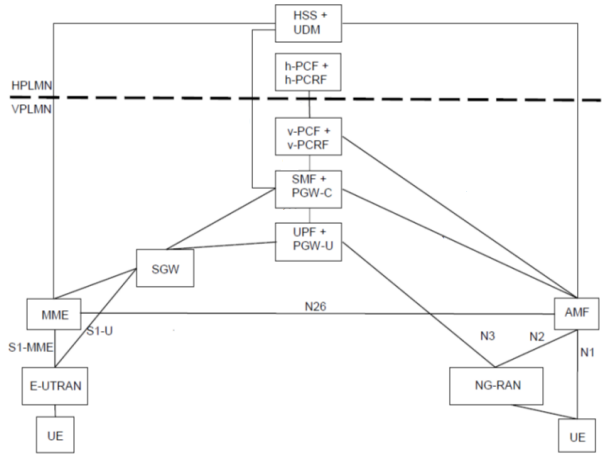

Fig. 1. 5G NGC and EPC Inter-working scenario proposed by 3GPP, adapted from [3].

Next, 3GPP through its standardization efforts [2]–[4] has developed the HO signaling mechanisms for scenarios involving not only the 5G NGC itself, but also 5G NGC alongside legacy networks such as 4G LTE, 3G, 2G and non-3GPP networks such as Wi-Fi. To accomplish the inter-RAT HOs, which are challenging due to the interaction of two fundamentally different networks, 3GPP has proposed an inter-working architecture, illustrated in Fig. 1. For the sake of brevity, in the illustrated inter-working scenario we only mention the interfaces that hold significance to the discussions in this paper. And so, as can be seen from Fig. 1, both the EPC and the NGC are connected to a set of inter-working entities via the MME/E-UTRAN for the EPC and NG-RAN and AMF for the NGC, respectively. Note that, the EPC, via its existing interfaces, permits user mobility from NGC to 2G and 3G networks as well [2]. Further, the proposed inter-working scenario by 3GPP consists of an N26 interface between the MME and the AMF. This interface although essential for inter-working between the legacy and 5G networks, might not be present in the initial deployment scenarios due to multiple reasons such as longer adoption times, CAPEX, etc. Given this scenario, the inter-RAT HO signaling involved will be significant and thus an efficient signaling mechanism will be critical. Hence, in this article we focus on the scenarios where the N26 interface is non-existent and inter-RAT HOs occur.

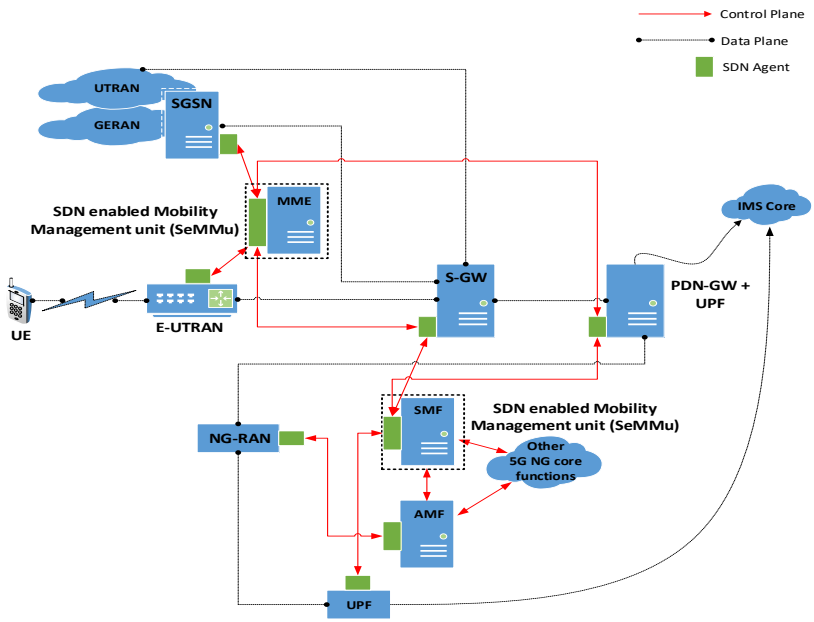

Fig. 2. Proposed 5G NGC and EPC inter-working network.

Lastly, in our previous work [14], a new HO preparation signaling methodology alongside an evolutionary architecture has been proposed. This evolutionary architecture assists in providing a transitional approach to the operators from current day networks to the 5G networks. Further, via the utilization of the SDN principles and intelligent message handling procedures, the proposed HO preparation signaling demonstrated latency improvement of up to 49.42% and, transmission and processing cost improvements of up to 40% and 28.57% respectively. It must be stated that, in [14] inter-RAT HO scenarios entailing mobility of user from LTE to 3G and 2G networks, and vice versa has been considered. And so, in this paper, we extend the aforesaid principles to 5G NGC and study the HO preparation phase signaling scenarios in 5G networks where an inter-RAT HO in the absence of an N26 interface occurs.

III. Proposed Architecture

The architecture proposed in [14] utilizes the principle of SDN as well as the fact that CAPEX has to be manageable for the operators. In this anterior work, the proposed architecture comprises of the EPC CN entities that have been integrated with an SDN agent. The SDN agent is integrated such that it is transparent to these CN entities. This permits the operators to transition towards the envisioned softwarized network without having to drastically transform their current network layout. Based on the aforesaid design principle, in Fig. 2 we illustrate the proposed 5G NGC and EPC inter-working network.

The proposed inter-working network consists of a new mobility management unit, namely the SDN enabled Mobility Management unit (SeMMu). The SeMMu consists of the SDN agent, which is then coupled with the entity that manages mobility within their respective networks. While in the EPC it is the MME, in the 5G NGC we consider the Session Management Function (SMF) coupled with the SDN agent as the SeMMu. This is a significant yet achievable transformation from the 3GPP guidelines, wherein the AMF in 5G NGC is deemed equivalent to the MME in EPC. The reason for the proposed integration being, the AMF engages only with the NG-RAN and not with the other CN elements during mobility events. Contrarily, the SMF works with the CN entities, such as the user plane function (UPF) elements, to enable seamless mobility. Hence, the aforesaid integration will enable the network to enhance the HO preparation phase signaling within the CN. We defer the discussion on the HO signaling enhancement until Section IV.

Within the proposed network architecture other CN entities as well as the E-UTRAN and NG-RAN are integrated with the SDN agent, thus permitting the SeMMu to execute the HO signaling presented in Section IV. For the purpose of brevity, in Fig. 2 it is assumed that the CN entities have necessary and appropriate CP connections to the HSS+UDM[1] and PCRF+PCF[2] entities. Next, here we do not specify

[1]In EPC, HSS is the *Home Subscriber Server*, and in 5G NGC, UDM is the *User Data Management* entity.

[2]In EPC, PCRF is the *Policy and Charging Rules Function*, and in 5G NGC, PCF is the *Policy Control Function*.

the N26 interface between the AMF and the MME. However, when required, the N26 interface can be implemented as a CP connection between the SeMMu in EPC and the SDN agent attached to the AMF in the 5G NGC. Such flexibility is a consequence of the uniform interface that now exists due to the presence of the SDN agents, while remaining transparent to the CN entities defined by 3GPP. Thus, in the next section we utilize this architectural framework and present the proposed HO preparation signaling mechanism.

IV. Handover Signaling Optimization

In this work we consider the scenario where there is an inter-RAT HO, and the N26 interface between the 5G NGC and EPC is non-existent. For the considered scenario, 3GPP through its standardization efforts in [4] has specified the HO signaling that would be required. Specifically, and for the sake of brevity, we consider here the example of inter-RAT HO when the user moves from 5G NGC to EPC (or the evolved packet system (EPS)). The HO preparation phase signaling for the scenario considered here is illustrated in Fig. 3.

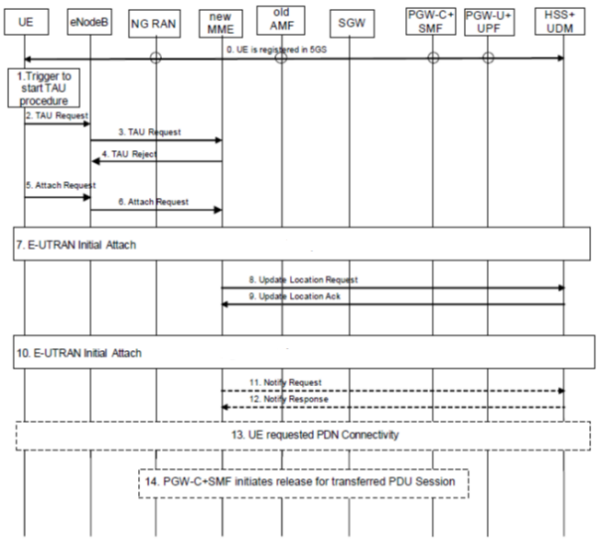

Fig. 3. 5G NGC and EPC inter-RAT HO in the absence of N26 interface, adapted from [4].

Concretely, the 3GPP proposed HO preparation signaling consists of three major phases, i.e., *Tracking Area Update process with EPC*, *Initial attach procedure with the E-UTRAN* and *UE requested PDN Connectivity*. Since, the aim of the HO preparation signaling enhancement process is to optimize the signaling within the CN during a mobility event, the second half of the *Initial attach procedure with the E-UTRAN* (Step 10 in Fig. 3) and *UE requested PDN Connectivity* (Step 13 in Fig. 3) are identified as two possible areas for improvement. The reason being, other processes will be mostly concentrated towards the access side of the network with some message exchanges with the CN and hence, do not present an opportunity to optimize the HO signaling further. And while Step 10 involves handshakes [15] that can be optimized for HO preparation signaling, in this paper we focus on Step 13 as it involves the transfer of PDU sessions from 5G NGC to the EPC during the handover process. Note that, the transfer of PDU sessions from 5G NGC to EPC, whilst maintaining the IP address/prefix, will be extremely critical for guaranteeing service continuity and better Quality of Service (QoS) during mobility events. Thus, we next illustrate the legacy and the enhanced *UE requested PDN connectivity* step in Figs. 4 and 5, respectively.

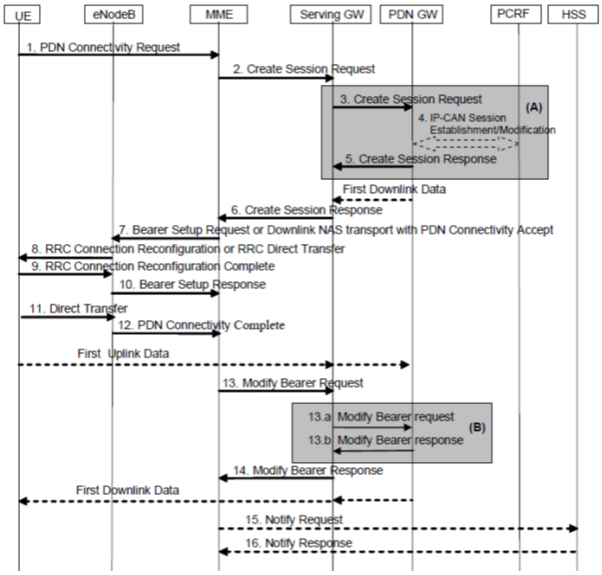

Fig. 4. Legacy *UE requested PDN Connectivity* request procedure, adapted from [15].

The enhanced PDN connectivity procedure, presented in Fig. 5, eliminates the handshakes that are prevalent within the legacy signaling procedure (Fig. 4). Further, utilizing the SDN agent capabilities, the SeMMu is able to parallelize the execution of certain CP messages thus facilitating further enhancement of the HO preparation signaling process. To accomplish the aforesaid enhancements a two stage process has been adopted. The two stages of this process are discussed in brief as follows:

- *Analyze:* In the analysis phase, all the messages of the legacy *UE requested PDN connectivity* signaling, shown in Fig. 4, are studied in detail. Each of these messages may consists of multiple Information Elements (IEs) within them. And so, in the analysis performed it must be determined whether the IEs contained within a particular message are redundant or essential. It must be

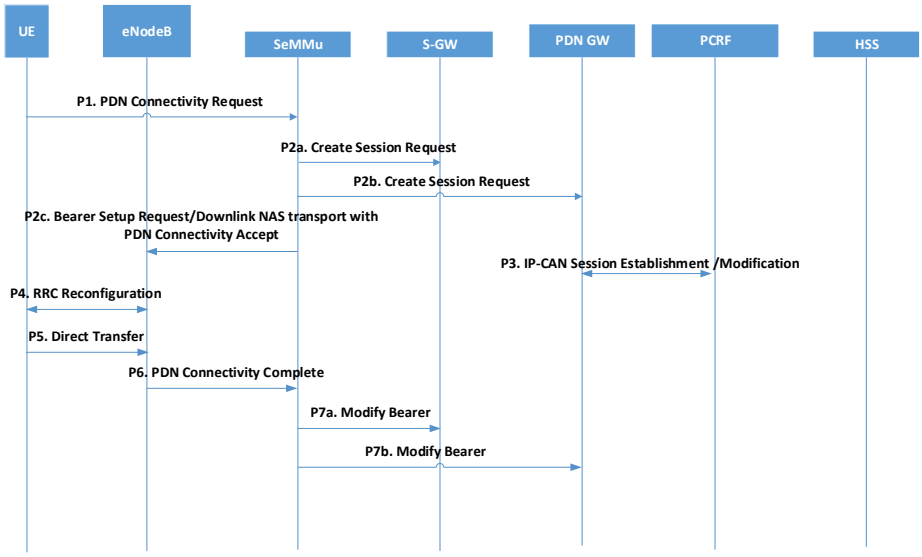

Fig. 5. Enhanced *UE requested PDN Connectivity* request procedure.

noted that, during this process, no additional IEs should be added to any of the messages. However, it is determined that the IEs be either shuffled from their original message to a different message or removed if they are redundant, in the new messaging scheme. This process essentially helps to compress the signaling scheme, while maintaining feasibility of implementation, as it helps to eliminate handshakes as well as the redundant IEs. By feasibility of implementation we mean that, the format and content of the IEs is not altered and it does not impact the operation of the UP and CP amongst other network entities except for the CP connections with the SeMMu.

- *Restructure:* This stage involves merging the IEs together to form a condensed message ensemble that executes the HO preparation function similar to the legacy mechanism. Further, alongside creating the new message ensemble, the corresponding order of the messages needs to be determined so as to minimize the latency (or obtain the maximum improvement over the legacy mechanisms) as well as the transmission and processing costs.

And so, utilizing the aforesaid *analyze-restructure* process the enhanced *UE requested PDN connectivity* signaling during the HO preparation has been developed and subsequently implemented, as shown in Fig. 5. Concretely, the SeMMu firstly parallelizes the execution of the *create session request* message to the S-GW and PDN GW. Additionally, the response messages have been eliminated from the legacy signaling mechanism as they consist of redundant IEs. Consequently, messages 2, 3, 5 and 6 of the legacy signaling process are compressed to messages P2a and P2b in the proposed signaling scheme. Next, the *modify bearer* messages are transformed such that instead of a handshake involving 4 messages (13, 13a, 13b and 14), they are compressed to messages P7a and P7b in the proposed signaling scheme. These messages, with the assistance of the SeMMu's SDN capabilities, are executed simultaneously. As a last enhancement to this signaling phase, legacy messages 10 and 12 in Fig. 4 are combined and executed as message P6 in the proposed signaling mechanism. The reason being, legacy message 10 consists of IEs which can be effectively merged with the IEs of message 12 thus streamlining the HO preparation mechanism and reducing the latency, transmission and processing cost of the same.

Lastly, it is imperative to state that, while we present the HO preparation signaling enhancement methodology for *UE requested PDN Connectivity* phase, the enhancements for the signaling involved in *E-UTRAN Initial Attach* phase (Step 10 – Fig.3) can be performed by adopting the same *analyze-restructure* methodology.

V. Analytical Framework and Results

Similar to our previous work [14], in this paper we consider latency, transmission and processing costs as the parameters for performance evaluation. While, latency will be critical in determining how fast the handover preparation phase is executed, transmission and processing cost will determine the amount of time the network is occupied for transmitting the messages and processing them at their destination respectively.

To perform the analysis, firstly we define the link delays between the network elements of the proposed

network architecture (Fig. 2) in Table I. These link delays are determined by utilizing the data of a Japanese telecom operator presented in [16] and the link delay values adopted in [14]. Note that, assumptions such as the two AMFs considered as being geographically distinctly apart, and hence having a 15 ms link delay, are essential to determining a set of reasonable link delay values given the lack of real data. Further, we also assume that the 5G CP network functions such as the AMF, Application Function (AF), etc., and the SeMMu (PGW-C + SMF alongside an SDN agent) in the 5G NGC are located at the same geographical location (possibly in a data center). Hence, the delay between these network entities is considered to be 1ms. Additionally, the delay between the SeMMu in the EPC and the AMF in the NGC is chosen as 1ms by extending the co-location principle of SGSN and MME, utilized in our previous work [14], to the 5G NGC. Lastly, the delay to the PCRF+PCF network function element is adopted as the maximum link delay within an SeMMu domain.

TABLE I
LINK TYPE AND CORRESPONDING DELAYS IN PROPOSED ARCHITECTURE

	Link Type	**Link Delay**
1.	UE to NG-RAN	1ms
2.	NG-RAN to AMF	7.5ms
3.	AMF to SeMMu (PGW-C + SMF)	1ms
4.	AMF to SeMMu	1ms
5.	SeMMu to S-GW	7.5ms
6.	SeMMu (PGW-C + SMF) to PGW-U + UPF	7.5ms
7.	SeMMu (PGW-C + SMF) to PCRF+PCF	7.5ms
8.	AMF to AMF	15ms
9.	SeMMu to PGW	7.5ms
10.	SeMMu to E-UTRAN	7.5ms
11.	E-UTRAN to UE	1ms
12.	PGW to PCRF	7.5ms
13.	S-GW to PGW	7.5ms

In addition to the aforesaid link delays, throughout the analysis we adopt the processing delay at each network element to be 4 ms. This assumption for the processing delay is stimulated by the processing delay values experienced during the *UE idle to active* procedure discussed in [17]. Next, for the analytical framework we adopt the formulation presented in our previous work [14] for the latency, transmission cost and processing cost computation. For the purpose of brevity we summarize the formulation as follows:

$$\text{Latency} = \sum \text{Parallel Link Delays} + \sum \text{Proc. Delays}. \tag{1}$$

$$\text{Transmission Cost} = \frac{\sum \text{Link Delays}}{1\text{ms}}. \tag{2}$$

$$\text{Proc. Cost Saving} = \frac{MSG_{Legacy} - MSG_{Proposed}}{MSG_{Legacy}} * 100\%, \tag{3}$$

where Parallel Link Delays in (1) refers to the maximum delay amongst the set of simultaneously executed messages; MSG_{Legacy} in (3) is the number of messages in the legacy approach for HO preparation; and $MSG_{Proposed}$ in (3) is the number of messages in the proposed approach for HO preparation.

And so, plugging the link delays from Table 1 into (1)-(3), we analyze the scenarios of inter-RAT HO without the presence of the N26 interface for the signaling sequences of the legacy and proposed method (Figs. 4 and 5, respectively). Consequently, we analyze the two major scenarios, i.e. inter-RAT HO from 5G NGC to EPC and vice versa. The analytical results obtained for the scenarios under consideration, for latency, transmission and processing cost parameters, have been presented in Table II. From the results it is observed that the proposed enhancements to the signaling mechanisms helps to reduce the overall handover preparation latency in excess of 24%, while the transmission and processing costs are reduced by up to 34.40% and 27.78% respectively. These incurred performance improvements thus reinforce the utility of the *analyze-restructure* phase, adopted to develop and implement the proposed HO preparation signaling, as well as the proposed network architecture (Fig. 2) in enhancing the overall HO preparation performance.

VI. CONCLUSION

Given the highly heterogeneous and ultra-dense nature of 5G networks, it is clear that the HO preparation phase signaling will be critical in permitting seamless mobility to the users. Henceforth, in this paper we have firstly analyzed the existing works on HO preparation signaling as well as the proposed signaling by 3GPP in its release 14 and 15 discussions. Next, we presented a network architecture that integrates the SDN agent with the CN entities such that it is transparent to the entities. Further, we define a new CN entity, namely the SeMMu, which facilitates the implementation of the enhanced HO preparation signaling.

Next, in this work, we consider the HO scenarios wherein inter-RAT HO occurs but in the absence of N26 interface. The reason behind considering scenarios without the N26 interface is that, initial deployment phases might not have the interface due to issues such as longer adoption times. The enhancements to the HO preparation signaling for the considered scenarios is then discussed elaborately. Following which, we have also presented the *analyze-restructure* phase for developing the new message ensemble for the enhanced signaling. Consequently, we then specify an analytical framework and the corresponding assumptions. Utilizing this framework we have performed a performance

TABLE II
PERFORMANCE IMPROVEMENT ANALYSIS FOR INTER-RAT HOS IN THE ABSENCE OF N26 INTERFACE

Handover Type	Latency			Transmission Cost			Processing Cost		
	Legacy	Proposed	Percentage Reduction	Legacy	Proposed	Percentage Reduction	Legacy	Proposed	Percentage Reduction
5G NGC to EPC	181ms	89ms	50.82%	109ms	71.5ms	34.40%	18	13	27.78%
EPC to 5G NGC	171.5ms	129.5ms	24.49%	91.5ms	76.5ms	16.39%	20	18	10%

improvement analysis based on latency, transmission and processing cost. And from the presented analytical results, it has been deduced that the proposed enhancements to the HO preparation signaling phase result in significant gains across all three performance parameters for the considered HO scenarios. This will consequently enhance the 5G network performance during inter-RAT HO scenarios.

Lastly, and from [4], it is observed that the discussed enhancements can also be adopted when a HO occurs from a non-3GPP access to 5G networks. Thus to conclude, the mechanisms and network architectures we have presented in this paper are versatile as well as effective towards enhancing 5G network performance. Hence, as future work, we will be extending the discussions carried out in this paper to other HO scenarios discussed by 3GPP during the 5G standardization process.

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