Challenges and Potential Solutions for Network Slicing Mobility Management

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***Abstract*—Mobility management extends its scope beyond base stations and radio access technologies within the realm of network slicing. Inclusive of vertical and horizontal handovers, it's imperative to also account for inter-slice and intra-slice mobility management. Especially in dynamic scenarios like vehicular environments, effectively managing mobility in network slicing presents a substantial challenge. Addressing these mobility-related issues demands innovative solutions that align with the latest iterations of the Third Generation Partnership Project (3GPP) standards. In this context, this manuscript underscores significant challenges concerning network slice mobility management. Additionally, it outlines comprehensive potential solutions to these challenges, thereby delineating avenues for future research endeavors.**

***Index Terms*—5G, 5G-Advanced, Network Slicing, Mobility management, Slice Handover, Resource Management.**

I. INTRODUCTION

Network slicing has emerged as a transformative technology to accommodate diverse Quality of Service (QoS) needs from users. By logically segmenting network functions and resources into distinct network slices within a shared physical infrastructure, network slicing addresses the intricate challenge of catering to varying QoS demands. This innovation, acknowledged by the research community, not only presents a solution for Vehicle-to-Everything (V2X) requirements but also establishes a paradigm where multiple independent end-to-end networks coexist on a common platform [1]. Particularly relevant is network slicing's role in ensuring seamless service for mobile user equipment in dynamic 5G networks. By dividing the network into virtualized digital networks, each tailored to unique capabilities, network slicing facilitates uninterrupted services as users move, eliminating the need for constant QoS adjustments. This strategic partitioning underscores network slicing's capacity to revolutionize service provisioning in the modern mobile landscape.

In the realm of 5G Vehicle-to-Everything (V2X) network slicing, the formidable challenge of preserving seamless service continuity amidst the rapid mobility of high-speed vehicles emerges as a paramount concern. This intricate quandary unfolds due to the Point of Attachment (PoA), where vehicles connect to the network, which keeps changing frequently as vehicles move through the network area [2]. Since the vehicle moves from one cell to another, the services offered by the previous cell may not be entertained in a cell where a vehicle has moved, leading to service interruption or QoS degradation. The crux of the challenge lies in the instantiation of entirely new network slices at the destination, necessitating the orchestration of novel radio resources, backhaul components, computational nodes, and storage resources to aptly cater to the users that are moved to a new cell. This necessitates real-time resource allocation adaptation techniques within the network slice framework to overcome the service disruption due to mobility [3].

Recognizing the intricacies of mobility management within a sliced network, the need for novel protocols has become evident. Extensive research endeavors have been dedicated to addressing slice mobility management, yet a standardized framework or protocol for ensuring consistent slices across the entire Registration Area (RA) and seamless service for highly mobile users remains absent. Key challenges necessitating immediate focus encompass; uneven distribution of slices within the RA, intra and inter-slice mobility management, and efficient management of resources after slice handovers (HO) [4]. These challenges underscore the pressing need for comprehensive solutions that enable smooth mobility, resource optimization, and a harmonious network slicing environment.

II. MOBILITY MANAGEMENT CHALLENGES IN NETWORK SLICING

In this section, we highlight some prominent challenges encountered in network slice mobility management.

A. Non-homogeneous Deployment of Network Slices

The 3GPP standards permit the deployment of a set of network slices within a defined geographical region [1]. These standards additionally stipulate a homogeneous deployment approach for slices within a designated Registration Area (RA) to ensure smooth user equipment (UE) slice mobility, especially for UEs employing multiple slices concurrently [1]. Consequently, all network slices accessible to a UE must be deployed across all nodes within the UE's RA. However, the slices are not uniformly deployed throughout the RA as this approach leads to an escalation in both capital as well as operating expenditure. Moreover, adhering to the 3GPP slice deployment specifications imposes significant demands on the capabilities of 5G base stations (gNBs) when accommodating a higher number of slice deployments. Fig. 1 exhibits the non-homogeneous deployment of slices throughout the RA.

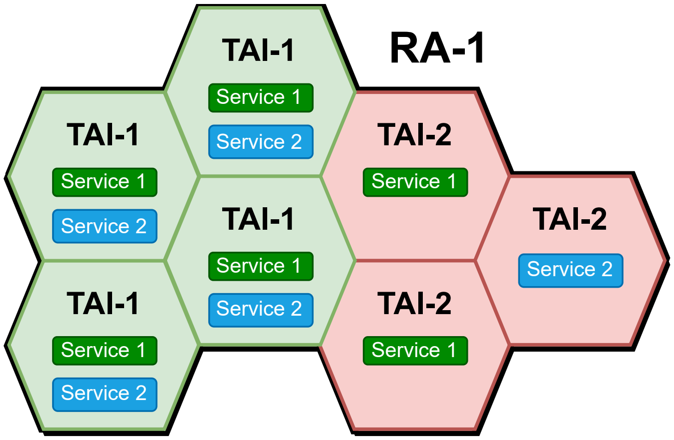

Fig. 1. Non-homogeneous Deployment of Slices within an RA.

B. *Inter-slice and Intra-slice Mobility Management*

Handover mechanisms ensure uninterrupted connectivity as subscribers transition from one cell to another. Notably, alongside vertical handovers (inter-technology) and horizontal handovers (inter-cell/base station), challenges of two categories of slice handovers (inter-slice and intra-slice) must be addressed in the context of network slicing.

Intra-slice handover emerges when a user changes their Point of Attachment (PoA) to a new PoA within the same operator domain, thereby maintaining a connection to the same slice. Conversely, inter-slice handover occurs across distinct operator domains, necessitating a switch to a new network slice. In such instances, the target slice conducts admission control to determine the acceptance of the incoming handover request.

Moreover, factors such as session continuity, timely slice selection, handover initiation, concurrent management of slice handovers with both horizontal and vertical handovers, and the security of slice handovers carry significant importance and warrant thorough consideration.

C. *Resource Management of Network Slices*

From a resource perspective, a network slice instance encompasses end-to-end services along with their associated computational, storage, and network resources, including radio resources. These resources span both edge and central data centers, facilitating distributed configurations. Consumption demands are contingent upon service type, user count, end-user devices, and geographical user dispersion. As users transition, resource consumption shifts with variations in communication path lengths and user loads impacting servers providing the service. Consequently, the original resource allocation of a network slice necessitates realignment to reflect actual consumption and latency, giving rise to the concept of network slice mobility, and entailing the re-provisioning of network connectivity and servers.

The pragmatic importance of slice mobility management solutions necessitates their alignment with established industry norms. In this context, solutions addressing intricacies such as non-homogeneous slice deployment, intra-slice and inter-slice handover challenges, and resource management must conform rigorously to the standardized tenets of the network slicing framework, as specified by the Third Generation Partnership Project (3GPP).

III. POTENTIAL SOLUTIONS

This segment explores prospective solutions for the primary mobility management challenges encountered within network slicing.

A. *Intelligent Slice Remapping*

The non-uniform slice deployment issue of network slicing causes service interruption for users moving between different tracking areas (TAs) within an RA. To ensure seamless service to users within an RA, deploying new resources is a costly solution, instead, alternative solutions can be explored. One of the feasible solutions in this regard is the extension of the slice remapping work in 3GPP Release-17 [5]. Slice remapping is the process of reselecting the resources including the bandwidth, Virtual Network Functions (VNFs), and communication links. As 3GPP is moving towards introducing intelligence in networking operations in its Release-18, machine learning-based algorithms can be employed to enhance the slice remapping work of Release-17. Advanced machine learning-based solutions including Reinforcement Learning (RL) and Deep Reinforcement Learning (DRL) algorithms are suitable in this regard, especially for the generation of remapping policy in real-time. This will allow the remapping of resources based on the real-time traffic of users whether the remapping policy is per Packet Data Unit (PDU) session or per UE.

B. *Preemptive Handover Measures using Prediction Learning*

To effectively tackle the handover challenges inherent to network-triggered inter-slice and intra-slice transitions, a centralized handover manager can execute essential functions including target slice selection, initiation of slice handover, scheduling of handover events, as well as the gathering and exchange of pertinent handover information. To establish this capability, a dedicated network function (NF) within the Service Based Architecture (SBA) of the 5G infrastructure can be proposed.

This designated NF has the potential to capitalize on existing functionalities within core NFs, with particular emphasis on the Network Data and Analytics Function (NWDAF). For instance, harnessing data and analytics derived from NWDAF, predictive learning methodologies can be employed to anticipate the necessity for slice handover within specific Tracking Areas (TAs) before user entry. Among viable predictive techniques, Long Short-Term Memory (LSTM) and Gated Recurrent Unit (GRU) models stand out. By applying these methodologies, the demand for handover can be projected, enabling proactive resource adjustments. An illustrative prediction-based solution is presented in Fig. 2. It's important to note that the realization of such an approach would necessitate synchronized coordination among cells within neighboring TAs.

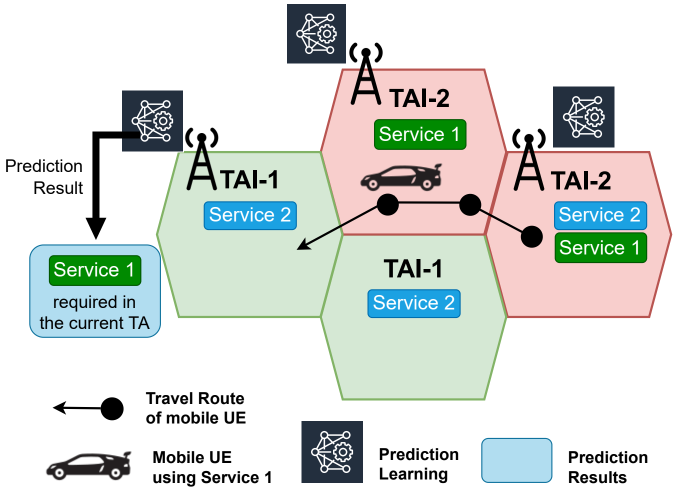

Fig. 2. Prediction-based solution for slice handover.

C. *Efficient Resource Management using Machine Learning*

Network slicing facilitates the delivery of diverse services, yet resource constraints mandate effective resource management techniques to cater to a broad spectrum of advanced heterogeneous service demands while upholding Quality of Service (QoS). In scenarios involving high-mobility users, the dynamic modification of original slice resource allocation in real-time becomes crucial. Reinforcement Learning (RL) and Deep Reinforcement Learning (DRL)-based approaches prove especially potent, particularly within intricate real-time contexts like vehicular environments.

An exemplary solution is outlined in [6], wherein authors advocate infusing intelligence into the management entity of the standard network slicing architecture. This augmentation targets the Network Slice Subnet Management Function (NSSMF), responsible for orchestrating network slice life cycles. Intelligence is incorporated through an Actor-Critic-based algorithm, empowering NSSMF to make informed decisions. Furthermore, exploration of advanced deep learning-driven methodologies such as Deep Deterministic Policy Gradient (DDPG) and Twin-Delayed DDPG (TD3) holds promise for resource management within dynamic, stochastic, high-mobility environments.

IV. CONCLUSIONS

This manuscript delineates prominent challenges concerning network slice mobility management. Key challenges encompass non-uniform slice deployment, slice handover intricacies, and resource management within network slicing. Furthermore, the manuscript presents prospective solutions for these highlighted challenges while outlining potential avenues for further research exploration.

V. ACKNOWLEDGEMENT

This work was supported in part by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education under Grant NRF-2018R1A6A1A03025109.

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