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SHEM: Handover Mechanism to meet Low-Latency application Requirement in 5G

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Abstract: One of the main objectives of Fifth Generation (5G) mobile communication networks is to support low latency applications up to 1ms E2E. To enable Low-Latency Communications (LLC), 5G adopts improvements such as Network Slicing (NS) and gNB densification. Although these two solutions allow better resource management, it generates frequent gNB/slice changes (Handover Management - HM) due to the mobility of the user equipment (UE). Consequently, this HM in the 5G network has two difficulties to enable LLC. First is the uncertainty in meeting the QoS requirements of the application in the target gNB/slice, given the unknown availability of resources in the gNB/slices. Second, the interruption of up to 3900 ms in UE communication, given the HM process. Therefore, the 5G network alone is deficient in performing the HM and meeting the LLC requirement. For this reason, we introduce **S**licing **H**andover Manag**E**ment **M**echanism (SHEM) to proactively select the target gNB/slice, taking into account the available resources as the LLC requirement of the application. The evaluation results show that SHEM reduces the HM latency by approximately 3700 ms and achieves 73.5% effectiveness in meeting the LLC requirement of the application.

Keywords: 5G; LLC; Handover Management; Network Slicing; SDN; NFV; SHEM.

1. Introduction

Fifth-Generation of mobile communication networks (5G) support emerging application requirements that demand seamless handovers to satisfy Low-Latency Communication (LLC) requirement [1]. To enable LLC, 5G improves resource management through resource virtualization and network densification. Network virtualization is enabled by SDN/NFV decoupling[1] that allows the creation of customized logical networks (slices) according to specific QoS requirements [8,9]. On the other hand, network densification increases network coverage and capacity by deploying numerous Access Points (APs - also called gNBs[2]) with multiple slices [1,11]. However, these improvements increase the probability of MH between the user equipment (UE) and the gNBs/slices, generating: i) the associated signaling overhead, decreasing or even canceling the gains from network densification [12]; and i) long handover delays (e.g., delays higher than 150 ms [13]), that degradation of the QoS

[1] The central concept of Software-Define Networking (SDN) is decoupling the control plane, and data plane in the network layer, compared with traditional networks where control and forwarding functionalities are coupled within the switches [2,3]. On the other hand, Network Functions Virtualization (NFV) decouples the entire classes of network node functions (i.e., Network Functions (NFs)) from the network hardware to customize and instantiate the Virtualized NFs (VNFs) such as routing, load balancers, and firewalls [4–7].

[2] The AP in 5G is known as gNB or gNodeB, meaning for Next-Generation NodeB and is a successor term to eNB, of 4G networks [10]

provided to the UE [14]. Furthermore, these handover delays constitute a limitation for LLC use cases as Augmented Reality (AR), where latency requirement is 10 ms since the long lag between images can cause user disorientation [15–18]. Therefore, 5G needs an HM capable of meeting UE QoS regardless of network conditions or UE mobility.

In 5G, the MH consists of the preparation, execution, and completion phases [10,19]. In preparation, the UE scans the available wireless channels to find and select the target gNB for handover. In the execution phase, the UE performs authentication and association with the target gNB. And in the termination phase, the UE and target gNBs update the mobility information and routing paths. In addition, the UE disassociates from the source gNB to release the resources associated with UE. According to [20,21], in WiFi the HM duration exceeds 1500 ms, where the setup phase can represent up to 90%. Apart from that, if the RAT implements robust authentication procedures such as WiFi Protected Access 2 (WPA2), the HM time will increase by up to 500 ms [110]. Therefore, to achive an MH that meets the LLC QoS requirements, it is necessary to improve each of the MH phases, especially the preparation phase.

In 5G, WiFi[3] will play a key role since it represents an affordable, faster, and reliable communication alternative[4]. WiFi addresses compliance with LLC requirement in HM through three amendments: Service Differentiation (DiffServ - 802.11e standard), Radio Resource Management (RRM - 802.11k standard), and Fast Transition (FT - 802.11r). DiffServ classifies network traffic into four service classes (Background, Best Effort, Video, and Voice) to give different access times to the medium without reducing the handover delay [24,25]. RRM simplifies the proactive search for the destination AP by creating a list of available channels from neighboring APs [21]. This way, RRM reduces the handover delay in the preparation phase up to 120 ms [13]. FT allows the AP to store the encryption keys of all network APs [26]. Thus, the devices diminish the authentication delay and achieve a minimum handover delay of 50 ms. Although WiFi still lacks mechanisms that optimize HM to improve network resources management and meet LLC requirement.

Recent research in HM proposes mechanisms such as Resource Allocation, Proactive Service Replication, and Network Virtualization to meet LLC requirement. Resource Allocation [27–30] operates by reserving available network resources based on competing application demands (e.g., link Bandwidth (BW) and buffer space in APs). Nevertheless, all demands are impossible to meet since some applications may receive fewer network resources, increasing the latency in LLC. Proactive Service Replication [7,31–33] operates by application instances[5] deployment in nearby APs before handover using Mobile Edge Computing (MEC) cloud capabilities (processing and storage). Nonetheless, application instances must be continuously updated, resulting in inefficient use of network resources (besides the storage occupied by the instances) and hence the degradation of overall network performance [31,32]. Network Virtualization [34–38] works by custom network slices creation with Virtual AP (VAP). However, the slice creation requires the resource reallocation in each AP, generating a high downtime[6] (>500 ms) that fails the LLC requirement. In conclusion, the previous mechanisms by HM evidence the difficulty of meeting LLC requirement in 5G.

In this paper, we present **S**licing **H**andover ManagEment **M**echanism (SHEM) to meet Low-Latency application Requirements in an NS-based 5G network. We built a prototype using a heuristic algorithm that proactively and passively selects the target gNB/slice. Moreover, we implemented the prototype in an NS-based 5G network for a remote driving scenario. In this way, SHEM considers the available resources in the gNBs/slices and the LLC requirement of the vehicle

[3] WiFi (802.11 standard developed by the Institute of Electrical and Electronics Engineers (IEEE)) comprises a set of standards for controlling access to the medium and physical characteristics of wireless local area networks (WLANs) [22]. Consequently, WiFi is considered a radio access technology (RAT).
[4] Furthermore, it is estimated that by 2023, there will be 628 million global public WiFi hotspots, 4X more than in 2018 [23].
[5] Virtual machines (VMs) or Dockers (>10 MB) that can store both application and connection information [31].
[6] Disconnection time caused by the delay of resource reallocation.

application. We analytically evaluate SHEM prototype to verify: i) the reduction of HM latency, and ii) the effectiveness in selecting the target gNB/slice to meet the latency requirement of the vehicle application. The results show that SHEM successfully reduces the HM latency by about 3700 ms and achieves 73.2% effectiveness in selecting the target gNB/slice.

The rest of the paper is organized as follows. Section 2 reviews the related work on this proposal. Section 3 provides an overview of SHEM. Section 4 presents the implementation of SHEM in a NS-based 5G network. Section 5 presents the evaluation of SHEM, where the obtained results are discussed. Finally, Section 6 summarizes concluding remarks and arguments for future work.

2. Related Works

This section presents a review of related work according to HM that focus on reducing HM latency together with meeting the QoS requirements of applications. These works were classified into three subsections. Subsection 2.1 presents the works that Allocate Resources by reserving available network resources. Subsection 2.2 presents the works that perform Proactive Service Replication by deploying application instances on nearby APs. Subsection 2.3 presents work that implements Network Virtualization to create customized network slices. Finally, this section ends by summarizing the related works in Table 1, exposing their differences with our Mechanism. From there we derive our observations on these works and highlight what our solution needs to meet the objectives proposed above.

2.1. Resource Allocation

In [27], the authors designed an HM scheme based on BW reservation policies sensitive to the traffic class. This scheme reserves the BW in each AP according to service classes (e.g., Best Effort, Background, Video, and Voice) and handover processes. However, if the BW is unused, it must remain available. In this way, the handover traffic always has the necessary BW and achieves handovers without data loss with a minimum delay of 60 ms. This scheme has the following limitations: i) low scalability of the network due to the disuse of network resources, and ii) high handover delay for LLC requirements, because of the insufficient traffic classes, the lack of efficient resource management.

In [28], a dynamic QoS based IP HM procedure was proposed to handle the applicati-on-centric mobility management. Such QoS based handover process ensures the required quality level for the on-going connections according to the policies enforced by the SDN controller. This HM procedure uses SDN to identify (before handover) the appropriate route to provide the required bit rate according to the applications QoS. At the same time, SDN allows the IP address to be maintained to avoid disconnection during the handover. In this manner, this proposal omits the association phase and reduces the delay up to 50 ms. However, the handover delay is still excessive for LLC requirements which needs handover delay less than 10 ms.

In [29], the authors presented a proactive approach to radio channel assignment in conjunction with HM. This approach determines the channel queue and channel occupancy time in AP. For when a handover occurs, the approach selects the objective AP with the lowest channel occupancy. Thus, this approach avoids handover blocking. Although it can generate critical delays for LLC-type applications as a result of receiving traffic flows without differentiating whether it is delay-sensitive or not.

In [30], the authors proposed a Machine Learning based method to find an optimal handover mechanism. This method allows us to predict whether the handover that is going to happen will maintain the throughput, optimizing resource allocation between APs. However, to maintain an algorithm with predictive levels of acts, at first, we need data to train this algorithm. Therefore, there will be quite an amount of wrong decisions about handover prediction causing QoS degradation.

2.2. Proactive Service Replication

In [31], the researchers propose the proactive replication of stateless application instances in neighbouring AP. This proposal maintains and updates instances in the neighbouring AP with application and connection data. When the handover occurs, the instance must update less amount of data (>10 MB). Although devices perform handovers without data loss, there is a downtime of more than 500 ms. Therefore, this proposal violates the LLC requirements.

In [32], the authors optimized the proactive copying of application connection information through dockers in the neighbouring APs. This proposal uses mobility prediction algorithms to minimize containers in neighboring APs. This way, this work achieves an excellent rate of 97.5% for seamless handover (with at least 4 APs). However, this proposal ignores the evaluation of handover delay. At the same time, the high waste of network resources used in dockers, makes the present solution inefficient to meet the rigorous LLC requirements.

In [7], researchers introduced the full-state application migration mechanism based on a predefined path. The mechanism uses Checkpoint-Restore in User Space (CRIU) to save the executing application state in a container before handover. Subsequently, the container is copied to the destination AP, and the application is restarted according to the CRIU checkpoint. Although this mechanism conserves all application data, it has a downtime (>1000ms) that impairs the continuity of applications with LLC requirements.

In [33], the authors proposed a vehicular MEC architecture instead of simply offloading LTE infrastructure. Routing all the packets with the MEC network achieves Vehicle to Infrastructure (V2I) communications with very low packet delay (10 - 30ms). Also, this architecture provides seamless handover with Distributed Mobility Management (DMM) in the MEC network. Nevertheless, in order to achieve seamless handovers with low delay, this architecture makes use of requests on servers close to the user. When the servers for the services are far away from the vehicle, any request outside the MEC network will have adverse effects on the seamless handover and delay times.

2.3. Network Virtualization

In [34], the authors propose BYON to create network slices with dedicated resources according to a set of QoS requirements. BYON has an SDN controller to configure each slice in an additional AP interface. Furthermore, the SDN controller enables APs to store flows to avoid packet loss during handover. BYON achieves handovers without packet loss in less than 65 ms. However, BYON has high handover delay that degrades LLC requirements. Furthermore, it is few scalable, given the difficulty of adding the necessary interfaces in each AP.

In [35], the authors propose ADE2WiNFV to provide NaaS, i.e., to offer custom network slices according to a set of QoS requirements. ADE2WiNFV combines SDN and NFV to virtualize/assign APs, network resources and NFs, and thus offer independent network slices. Additionally, ADE2WiNFV implements Protocol-Oblivious Forwarding (POF) to route flows to their corresponding VAP, even when the handover occurs. In this manner, ADE2WiNFV meets the applications QoS with a minimum handover delay of 220 ms. However, ADE2WiNFV has the following disadvantages: i) excessive handover delay compared with LLC requirements, ii) lack of resource reallocation in physical APs (given the handovers of the devices), and iii) high downtime (>500 ms). To sump up, ADE2WiNFV degrades the Qos requirements as LLC.

In [36], the authors present Odin to introduce the concept of Light Virtual AP (LVAP) based on SDN. LVAP gives the illusion that each device has its own AP. For when the handover occurs, the SDN controller only has to change (in LVAP) the registry of the linked AP. Thus, the devices skip the authentication phase and reduce the handover delay up to 1 ms. However, a more significan number of devices considerably increases the handover delay due to rising control traffic. Therefore, although Odin achieves delays according to the LLC requirements, it needs to improve its handover mechanism.

In [37], the researchers proposed an open enterprise WiFi solution based on virtual APs, managed by a central WLAN controller. It allows seamless handovers between APs in different channels, maintaining the QoS of real-time services. This is achieved by omitting the discovery and authentication phases of the handover. The scheme assigns each device a VAP and each AP an additional interface. Furthermore through an SDN controller, the virtual APs employ the additional AP interface to discover the available channel (for handover) in the neighbouring APs, and authenticate the device with the discovered channel. In this way, The device thinks it's still in the same AP, reducing the handover delay up to 22 ms. However, this virtual APs scheme degrades compliance with the LLC requirements due to the high handover delay.

In [38], researchers propose a new architecture for LTE and WiFi networks to achieve low latency. This solution use SDN and NFV to create LVAPs. In order to meet low latency, they use a Packet Data Network Gateway (P-GW)[7] that serves to download and extract the data to a Wireless Access Gateway. The LVAP decreases the handover latency using the same BSSID with all the LVAPs, making the device think it remains in the same network. However, the network ignores the available resources in the destination AP when it triggers a handover. This may generate latency in case there are many users or few resources in the destination LVAP.

2.4. Conclusions

Table 1 presents the summary of related works to HM. First, Resource Allocation presents problems like limited network resources. Second, Proactive Service Replication shows a lacks in inadequate utilization of network resources, and finally, Network Virtualization increases delays at slice/instance creations. Finally, the table 1 shows that achieving seamless handovers alone is deficient in meeting LLC requirement. Therefore, our HM proposal proposes timely HM and seamless handovers (based on SDN/NFV) to meet LLC requirement.

Work	Type	HM		Seamless Handover	LLC	SDN	NFV
		Proactive	Reactive				
[27]	RA		✓	✓			
[28]	RA	✓		✓		✓	
[29]	RA	✓				✓	
[30]	RA	✓		✓			
[31]	PSR		✓	✓			
[32]	PSR	✓		✓			
[7]	PSR	✓		✓		✓	✓
[33]	PSR	✓		✓			
[34]	NV	✓		✓			
[35]	NV	✓				✓	✓
[36]	NV		✓	✓	✓	✓	
[37]	NV		✓	✓		✓	
[38]	NV		✓	✓		✓	✓
Our proposal		✓		✓	✓	✓	✓

RA: Resource Allocation - PSR: Proactive Service Replication - NV: Network Virtualization

Table 1. Related works

3. NS-based SHEM Mechanism for LLC Applications

This section introduces **S**licing **H**andover ManagE**m**ent **M**echanism (SHEM) in a 5G network based on Network Slicing. In particular, this section presents the motivation scenario, and SHEM overview.

3.1. Motivation Scenario

For the design of SHEM, we use the motivational scenario presented in Figure 1, which is an LLC mobility scenario in a 5G network based on NS. Specifically, the scenario is of remote driving, where the vehicles are controlled by a Vehicle-to-Network (V2N) application through the gNBs. Therefore, the network has three applications on remote servers, two applications are V2N, and one application is for

[7] P-GW allows traffic mapping from LTE to WiFi, and a Wireless Access Gateway interacts with the user as an LVAP

general purposes. For optimal performance, these applications demand QoS requirements, abbreviated in Table 2 [39,40]. To meet those requirements, the network implements a slice for each application. In this way, each slice in each gNB (gNB/slice) has sufficient resources (for a given number of vehicles) to meet the QoS requirements of the corresponding application. However, the HM of the vehicle between gNBs threatens the fulfillment of the latency requirement [20,21]. For this reason, SHEM is introduced into the network to perform HM, meeting the latency requirement.

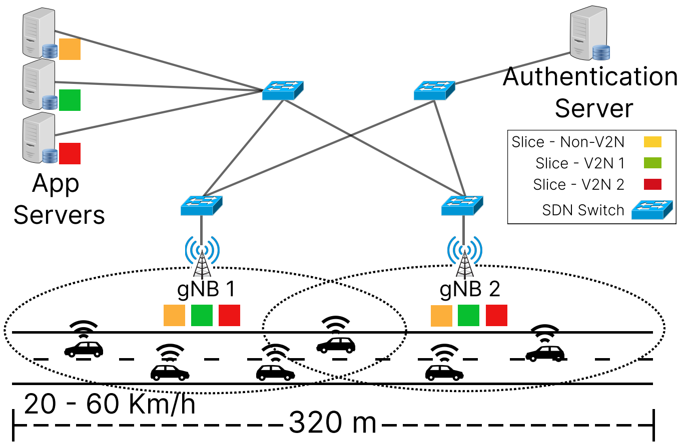

Figure 1. Overview of the Motivation Scenario

APP \ QoS Requirement	Latency E2E [ms]	BW x Vehicle [Mbps]
Non-V2N application	50	10
V2N Application - 1	20	25
V2N Application - 2	10	35

Table 2. QoS requirement of applications

3.2. SHEM Mechanism Definition

Of the HM phases, we propose to address the preparation phase since it represents most of the latency of the HM. Thus, we introduce SHEM that realizes the preparation phase proactively, i.e., before the vehicle loses communication with the connected gNB/slice. In this way, SHEM proactively determines the best target gNB/slice, considering the 5G network conditions and the QoS requirements of the vehicle application. For this, we propose that SHEM includes three modules (see Figure 2): Monitoring, Evaluator, and Actuator.

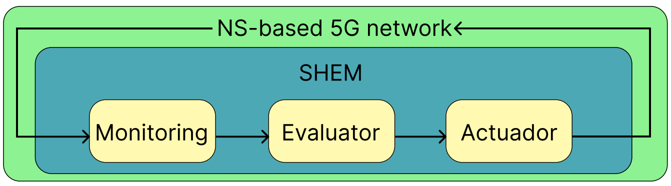

Figure 2. SHEM Overview

- **Monitoring module** has the function of determining the condition status of the 5G network and the vehicle application. For this, the monitoring module collects specific metrics from the gNBs/slices and the vehicle. Thus, we propose to collect the following metrics from each neighboring gNB/slice: mobility metric, NS metric, application metric, and network resource usage metric. Mobility metric corresponds to the variation of Received Signal Strength Indicator (RSSI) between vehicle and gNB/slice. NS metric corresponds to the latency between the vehicle and the application server. Application metric corresponds to the latency requirement of the

application executed on the vehicle. Network resource usage metric corresponds to the variation of vehicles connected to the gNB/slice. In addition to the above metrics, the vehicle attaches its MAC address, and the MAC address of the connected gNB/slice. Thus, when the monitoring module collects these metrics from the neighboring gNB/slice, it delivers them to the evaluator module.
- **Evaluator module** is responsible for determining the appropriate HM decision for the vehicle. For this, the evaluator module analyzes data sent by the monitoring module. In this way, the evaluator module determines the handover decision for the vehicle, i.e., whether the vehicle should perform: i) an intra-slice HM[8]; or ii) an inter-slice HM[9]; or iii) remain in the current gNB and slice. Afterward, this decision is reported to the Actuator module.
- **Actuator module** has the function of executing the decision determined by the evaluator module. Thus, if the decision involves performing the HM, this module will initiate the execution phase between the vehicle, source gNB/slice, and target gNB/slice.

3.3. SHEM Mechanism Built

This subsection presents the SHEM prototype built using heuristic programming with Python. In this way, we build the Python script of the SHEM prototype, which is presented in the GitHub repository [41]. Next, we present the algorithms of the built SHEM prototype.

Where:
- j: gNB ID, k: slice ID, and v: vehicle ID.
- n: Number of neighboring $gNB_{js}/slice_{ks}$.
- $[js, ks]$: Referring to **s**ource gNB/slice.
- $[jt, kt]$: Referring to **t**arget gNB/slice.
- $[jtL, ktL]$: Referring to **t**arget gNB/slice that meets the **l**atency requirement of the vehicle.
- th: Referring to **th**reshold.
- $Lat_{\{x\}}$: Latency value referring to x.
- $Load_{\{x\}}$: Load value referring to x. Number of connected vehicles.
- $mac_{\{x\}}$: MAC address referring to x.
- $[RSSI_{t-1}, RSSI_t]_{j,k}$: Variation RSSI between vehicle and gNB/slice j,k.
- $[Load_{t-1}, Load_t]_{j,k}$: Variation of vehicles connected to the gNB/slice j,k.

Algorithm 1 presents the Monitoring module. The Monitoring module receives the metrics (s(t) and c) sent by the vehicle through the SDN controller. Then, if the vehicle has changed gNB/slice, the Monitoring module calculates the HM times. Subsequently, the Monitoring module sends s(t) and c to the Evaluator module.

Algorithm 1: Monitoring Module - SHEM

Require: $Load_{th}$, $RSSI_{th}$

/* Monitoring module */

Receives the c and s(t) from the SDN Controller;

/* s(t)=$[RSSI_{j,k}(t-1), RSSI_{j,k}(t),\ Lat_k,\ Load_{j,k}(t-1), Load_{j,k}(t)]_n$ */

/* c=$mac_v, mac_{js,ks}, id_v,\ Lat_v$ */

if *vehicle changed gNB/slice connected* **then**

  calculate HM time;

end

Evaluator(s(t), c, $Load_{th}$, $RSSI_{th}$);

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[8] Intra-slice HM indicates change of slice without changing gNB.

[9] Inter-slice HM indicates the change of connection to a slice in another gNB.

Algorithm 2 presents the Evaluator module. From s(t) and c, the Evaluator module checks if the vehicle is under the RSSI threshold (line 2-10) or the current slice has exceeded the load threshold (line 11-16). Being below the RSSI threshold leads to performing an inter-slice; however, it must be verified if the vehicle is approaching that target gNB/slice. On the other hand, exceeding the load threshold may lead to an inter-slice or intra-slice. Subsequently, the Evaluator module determines two target gNB/slice for the MH. One gNB/slice meets the latency requirement of the vehicle application, while the other gNB/slice does not. To determine the gNB/slice that does not meet the latency requirement, the Evaluator module selects only the gNB/slice with the lowest load. While to determine the gNB/slice that meets that latency requirement, the module adds a condition that the latency required by the vehicle application is less than or equal to the latency offered by the gNB/slice. Subsequently, the Evaluator module sends these two targets gNB/slice together with the MAC address of the vehicle to the Actuator module.

Algorithm 2: Evaluator Module - SHEM

`/* Evaluator Module */`
1 **Function** *Evaluator(s(t), c, $Load_{th}$, $RSSI_{th}$)*:
`/* HM for degraded RSSI */`
2 **if** $RSSI_{js,ks}(t) \leqslant RSSI_{th}$ **then**
3 **if** *Vehicle moves away from the $gNB_{js}/slice_{ks}$* **then**
`/* Determine the` $gNB_{jt}/slice_{kt}$ `and` $gNB_{jtL}/slice_{ktL}$ `*/`
4 **foreach** $gNB_j/slice_k \in s(t)$ **do**
`/* Inter-Slice HM. Considers only the gNBs different than` gNB_{js} `*/`
5 **if** gNB_{jt} != gNB_{js} **then**
6 *Find $gNB_{jt}/slice_{kt}$ with lowest load;*
7 *Find $gNB_{jtL}/slice_{ktL}$ with lowest load, considering $Lat_v \leqslant Lat_k$;*
8 **end**
9 **end**
10 **end**
11 **else if** $Load_{js,ks}(t) > Load_{th}$ **then**
`/* HM for excess vehicles */`
`/* Determine the` $gNB_{jt}/slice_{kt}$ `and` $gNB_{jtL}/slice_{ktL}$ `*/`
12 **foreach** $gNB_j/slice_k \in s(t)$ **do**
`/* Intra-Slice and Inter-Slice HM. Considers alls the gNBs/slices */`
13 *Find $gNB_{jt}/slice_{kt}$ with lowest load;*
14 *Find $gNB_{jtL}/slice_{ktL}$ with lowest load, considering $Lat_v \leqslant Lat_k$;*
15 **end**
16 **else**
`/* Retain current` $gNB_{js}/slice_{ks}$ `*/`
17 pass;
18 **end**
19 Actuator($gNB_{js}/slice_{ks}$, $gNB_{jt}/slice_{kt}$, $gNB_{jtL}/slice_{ktL}$, mac_v);
20 **return** None;

Algorithm 3 presents the Actuator module. The Actuator module initially verifies that the target gNB/slice that meets the latency requirement of the vehicle application is different from none and the source gNB/slice. If the above is true, the Actuator module initiates the vehicle's MH to this gNB/slice. Otherwise, the Actuator module initiates the HM to the other target gNB/slice, as long as it differs from none. In case of omitting the MH initiation, the vehicle maintains the connection with the source gNB/slice.

Algorithm 3: Actuator Module - SHEM

/* Actuator Module */
Function *Actuator*($gNB_{js}/slice_{ks}$, $gNB_{jt}/slice_{kt}$, $gNB_{jtL}/slice_{ktL}$, mac_v)**:**
  if ($gNB_{jtL}/slice_{ktL}$!= $gNB_{js}/slice_{ks}$) $\wedge$($gNB_{jtL}/slice_{ktL}$!= *None*) **then**
    HM of mac_v to $gNB_{jtL}/slice_{ktL}$;
  else if $gNB_{jt}/slice_{kt}$!=*None* **then**
    HM of mac_v to $gNB_{jt}/slice_{kt}$;
  else
    /* Retain current $gNB_{js}/slice_{ks}$ */
    pass;
  end
return None;

4. Implementation of SHEM Prototype

This section presents the implementation of the SHEM prototype in a 5G network based on NS. The implementation is presented in three subsections. Subsection 4.1 presents an overview of the 5G network architecture together with SHEM prototype. Subsection 4.2 presents the requirements and tools for the prototype implementation in the 5G network. Subsection 4.3 presents the operation of SHEM prototype in the 5G network HM based on NS.

4.1. 5G Architecture Overview for Prototype Implementation

In this subsection, we propose the high-level architecture of the prototype that implements the SHEM mechanism based on the motivation scenario of subsection 3.1. The architecture is based on the three-layer model (infrastructure layer, virtualization layer, and service layer) plus the cross-cutting MANO layer [8,9]. The above layers are aligned with the SBA 5G and its key enablers, i.e., SDN and NFV [8,42].

4.1.1. Architecture Components

The three layers of the high-level architecture and the corresponding components are illustrated in Figure 3 and discussed briefly below.

The infrastructure layer comprises the entire physical infrastructure, including computing, storage, and network hardware. However, our prototype will only use network hardware that comprises the following elements: UEs, RAN nodes, MEC servers, and the transport network.

- UEs are vehicles controlled remotely through a V2N application. Moreover, the vehicles have a wireless interface to connect to the RAN nodes.
- RAN nodes represent the gNBs. Optionally, the RAN nodes could be SDN-enabled.

  Moreover, although the infrastructure layer applies to any RAT, we chose WiFi. From the WiFi amendments, we consider 802.11g, 802.11i, and 802.11r. In summary, 802.11g enables a BW of up to 54 Mbps between the gNBs and vehicles [43]. The 802.11i enables Robust Security Network Association (RSNA) using WPA2 and 802.1X authorization framework [44–46]. And 802.11r (or FT) allows to reduce the WPA2/802.1X authentication process [47].
- MEC servers. MEC is an emerging technology with the main idea of implementing content-oriented intelligence. MEC brings content, NFs and resources closer to the end user, extending the conventional data center to the edge of the network [48]. MEC by locating closer to where data is generated and consumed, enables improvements such as high BW, ultra-low latency, and real-time RAN location awareness and information. Thus, these improvements provide cloud computing capabilities to host the V2N application, supporting your QoS requirements [49].

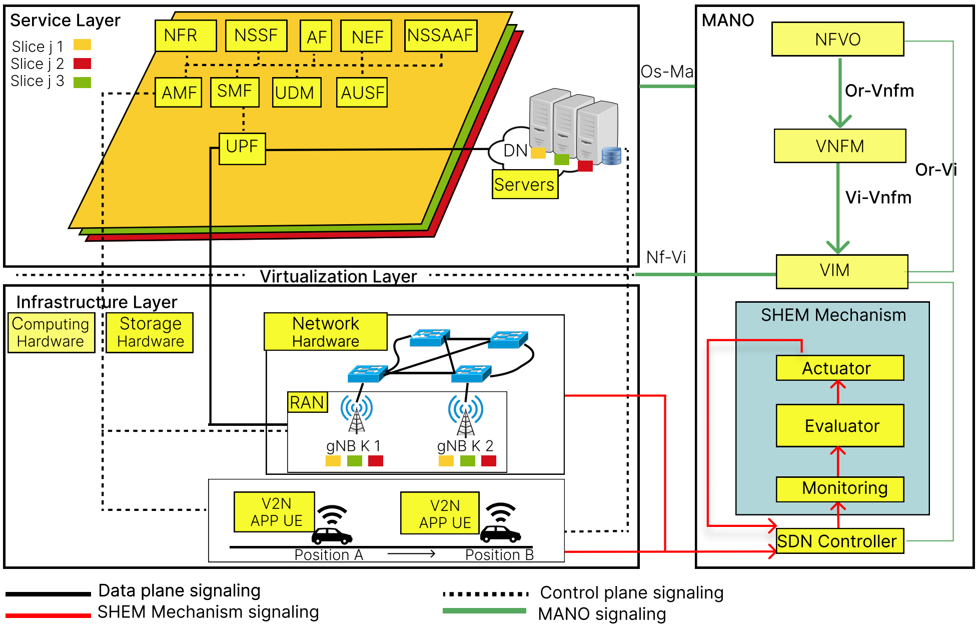

Figure 3. Overview of the Motivation Scenario Architecture

- The transport network interconnects the RAN nodes with the CN and DN using SDN devices such as switches and routers.

The virtualization layer creates an abstract view of the infrastructure layer resources and provides these resources/resource pools to the service layer for use. The virtualization layer not only virtualizes network resources such as RAN but can also virtualize compute and storage resources for the service layer. In this way, the virtualization layer can divide and isolate the virtual resources into several subgroups and assign each of the resource subgroups to a virtual network or network segment. Creating these network segments is also possible with the MANO cross-layer management.

The service layer includes the 5G Service-Based Architecture Network Core (SBA-CN) that is independent of 4G LTE networks [50]. CN is the composition of various VNFs, with a defined separation between Control Plane functions (CP)[10] and User Plane Functions (UPF). UPFs play a critical role in the data transfer process, providing the interconnection point between the UE and the Data Network (DN). On the other hand, CP functions represent all the signaling[11] used to support the functions that set and maintain the UPFs. Below is a summary of each of the VNFs of 5G SBA-CN.

The CP functions correspond to:

- Access and Mobility Management Function (AMF) provides UE-based authentication, authorization, mobility management, etc.
- Authentication Server Function (AUSF) stores data for UE authentication.
- Unified Data Management (UDM) stores UE subscription data.
- Session Management Function (SMF) is responsible for session management and also selects and controls the UPF for data transfer.
- Policy Control Function (PCF) can instruct different routing policies.

To specifically address the cloud-native design and the paradigm shift from an entity-based network (4G) to a function-based network, 5G introduces the following NFs.

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[10] The CP is itself a forwarding path to exchange information for service operation.
[11] Signaling refers to the exchange of information to enable, however, not to provide the end-to-end communication service itself.

- Network Repository Function (NRF) provides registration and discovery functionality, allowing NFs to discover mutually and communicate through open Application Programming Interfaces (APIs), in contrast to LTE, which uses predefined interfaces between elements. For example, the AMF service exposes information regarding mobility-related events and relevant statistics to other NFs.
- Network Exposure Function (NEF) provides the means to securely collect, store and expose the services and capabilities of 3GPP network functions (e.g., to third parties or between NFs).
- Application Function (AF) represents any additional CP functions that may be required, e.g., to implement network fragmentation.

While to enable NS, 5G introduces the following CP functions.

- Network Slice Selection Function (NSSF) helps with the selection of Network Slice instances and AMFs that will serve a particular UE.
- Network Slice Specific Authentication and Authorization Function (NSSAAF) enables support for Network Specific Authentication and Authorization according to specified with an Authorization, Authentication, and Accounting Server (AAA-S).

The Management and Orchestration layer (MANO) performs all management, coordination, and automation tasks specific to virtualization [51]. This layer includes NFV Orchestrator (NFVO), Virtualized Infrastructure Manager (VIM) and the VNFs Manager (VNFM). In addition, this layer integrates the SHEM mechanism (proposed in Section 3) with the SDN controller.

- NFVO. This is a central management entity responsible for orchestrating the resources used concerning the infrastructure layer and the virtualization layer. It is also responsible for orchestrating network services, i.e., the functions deployed at the service layer.
- VNFM. Performs configuration and lifecycle management of VNFs in your domain.
- VIM. It helps manage NFV Infrastructure (NFVI) resources, i.e., infrastructure layer resources.
- SHEM mechanism. It is implemented in the MANO layer because it has faster and more direct communication with the SDN controller. In this way, the SDN controller sends the input variables (network and vehicle statistics) required by the SHEM in less time. Analogously, SHEM can send the output variable (target slice to perform the handover) to the SDN controller, according to the design proposed in Subsections 3.2 and 3.3.
- SDN controller. Through the SDN controller, traffic routes (of transport network) are established and can be automatically reconfigured to manage traffic engineering requirements (and network resources) or to react to possible network failures and changing conditions (e.g., HM).

4.2. Implementation

To implement the NS-based 5G network architecture presented in the previous subsection, it is clear that all network layers must be emulated or simulated. However, the 5G network implementation presents two sets of implicit requirements that must be considered. These two groups are the mobility requirements and the NS requirements.

4.2.1. Mobility Requirements

To implement mobility and vehicle-RAN interaction, network 5G must support the following requirements:

1. Simulation of a vehicular system that allows to configure parameters such as:
    - Speed
    - Address
    - Position
    - Trajectory

2. Emulation of gNB and vehicles that allows to configure the following parameters:
    - Position
    - 802.11g, 802.11i, and 802.11r amendments.
3. Implementation of an authentication server that supports the 802.1X framework.

4.2.2. NS Requirements

The SHEM prototype considers NS at both the service and infrastructure layers. In our implementation, however, NS at the infrastructure layer is only realized in the RAN. Therefore, the implemented 5G network must satisfy the following requirements to support NS.

1. Deploy the service layer functions that enable mobility management and NS in the 5G network.
2. Abstraction of network resources.
3. Establish MEC servers with QoS requirements such as latency and BW for the corresponding V2N application.
4. SDN-based switching capability required for network routing configuration.
5. Orchestration and visibility of the SDN network.

4.2.3. Tools

Based on the 5G architecture in Figure 3 and the implementation requirements in the previous subsections, each layer of the architecture is described below and in Figure 4 with the tools that implement it. Additionally, the implementation files are exposed in the GitHub repository [41].

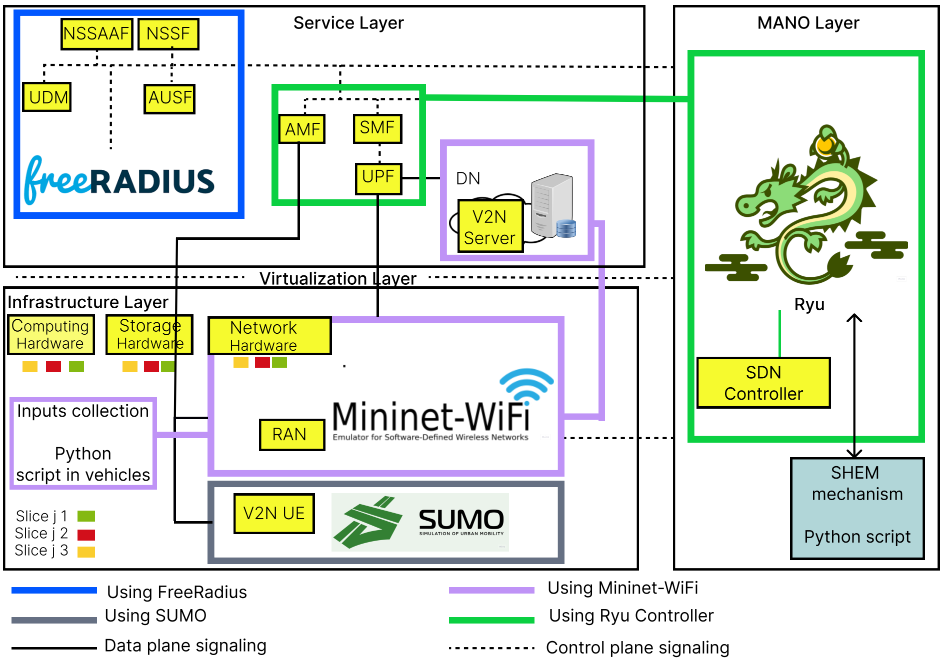

Figure 4. Interaction between tools

- Service layer is implemented through FreeRadius[52] and Ryu[53]. FreeRadius is an 802.1X authentication server using the RADIUS[12] protocol, which manages the access and use of network resources. Therefore, FreeRadius reproduces the behavior of NFs correspond to NSSAAF, NSSF, UDM, and AUSF, that collectively manage access to slice resources [50,54]. On the other hand, Ryu implements the VNFs (AMF, SMF, and UPF) related to mobility management.

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[12] Remote Authentication Dial-In User Service

- The virtualization layer is implicitly implemented by FreeRadius and Ryu, i.e., these tools internally configure the computational and storage resources needed for the VNFs of the service layer. With respect to network resources, these are virtualized by Mininet-WiFi and Ryu.
- MANO layer integrates SHEM mechanism and Ryu. Although this layer includes the entities NFVO, VNFM, and VIM, their implementations are null in this prototype. Given the scope of our work, we focus on the HM in terms of latency without resource management for the slices.
- The infrastructure layer is implemented thanks to Mininet-WiFi[55], and Simulator for Urban MObility (SUMO)[56]. Mininet-WiFi emulates all the network infrastructure, i.e., wireless stations (vehicles), access points (gNBs/slices), MEC servers (V2N servers), switches, and links, together with 802.11g/i/r amendments. Meanwhile, SUMO simulates the traffic of the vehicles emulated by Mininet-WiFi. In addition, Mininet-WiFi must connect with the service layer and the MANO layer, i.e., with FreeRadius and Ryu.

  Additionally, the collection of the necessary inputs for the SHEM mechanism must be done in this infrastructure layer. This collection is performed by each vehicle through a Python script called inputs_collection. Subsequent to the collection, the vehicle sends the inputs to the SHEM mechanism through the Ryu.

4.3. HM Process

Previous to the HM process, the emulated 5G network must realize the 802.11i RSNA establishment between the vehicle and the gNB/slice. Subsequently, the vehicle can realize the HM together with our SHEM mechanism. The HM can be inter-slice or intra-slice. To continue, we first detail the 802.11i RSNA establishment, and later we detail the inter-slice and intra-slice HM.

Figure 5 shows the 802.11i RSNA establishment that starts with the preparation phase. The preparation phase starts when the vehicle sends the probe request to the neighboring gNBs/slices. With the probe responses, the vehicle chooses the gNB/slice to connect to. Here, the preparation phase ends, and the execution phase starts. In the execution phase, the vehicle initially realizes open authentication and association with the gNB/slice. Thus the vehicle is authenticated and associated with the gNB/slice. However, even access to the gNB/slice continues blocked, until meeting the set of security capabilities of the 802.11i amendment. This set comprises 802.1X authentication and 4-Way Handshake and Group Handshake key generation and caching. Therefore, when the Group Handshake terminates, the 802.1X port is deblocked, allowing the vehicle to access the gNB/slice resources. Finally, the vehicle informs the target gNB/slice that the 802.11i RSNA establishment has been successful, thus ending the execution phase and initiating the completion phase. In the completion phase, the gNB/slice requests the AMF to update information on mobility, session (in SMF), and routing (in UPF) of the RSNA establishment performed between the vehicle and the gNB/slice. Consequently, the 802.11i RSNA establishment is completed.

Regarding inter-slice and intra-slice HM, these are supported by SHEM. The purpose of SHEM is to improve the preparation phase, proactively selecting (previous to the loss of communication with the source gNB/slice) the best target gNB/slice, considering the 5G network conditions and the QoS requirements of the application. For this purpose, SHEM includes three modules: Monitoring, Evaluator, and Actuator, defined in Subsection 3.2. Figure 6 evidences the operation of the modules of SHEM. In summary, the preparation phase starts when the vehicle finds the neighboring gNBs through beacon[13] capture. Having identified the neighboring gNBs, the vehicle collects and sends the SHEM inputs (defined in Subsection 3.2) to the Ryu application called mechanism_integration. Thus, this Ryu application sends these inputs to the monitoring module, where it verifies and delivers the inputs to the Evaluator module. Evalutor module determines the handover decision for the vehicle,

[13] Beacons are frames transmitted periodically by gNBs, with the purpose of informing vehicles about nearby gNBs along with the channel status [22].

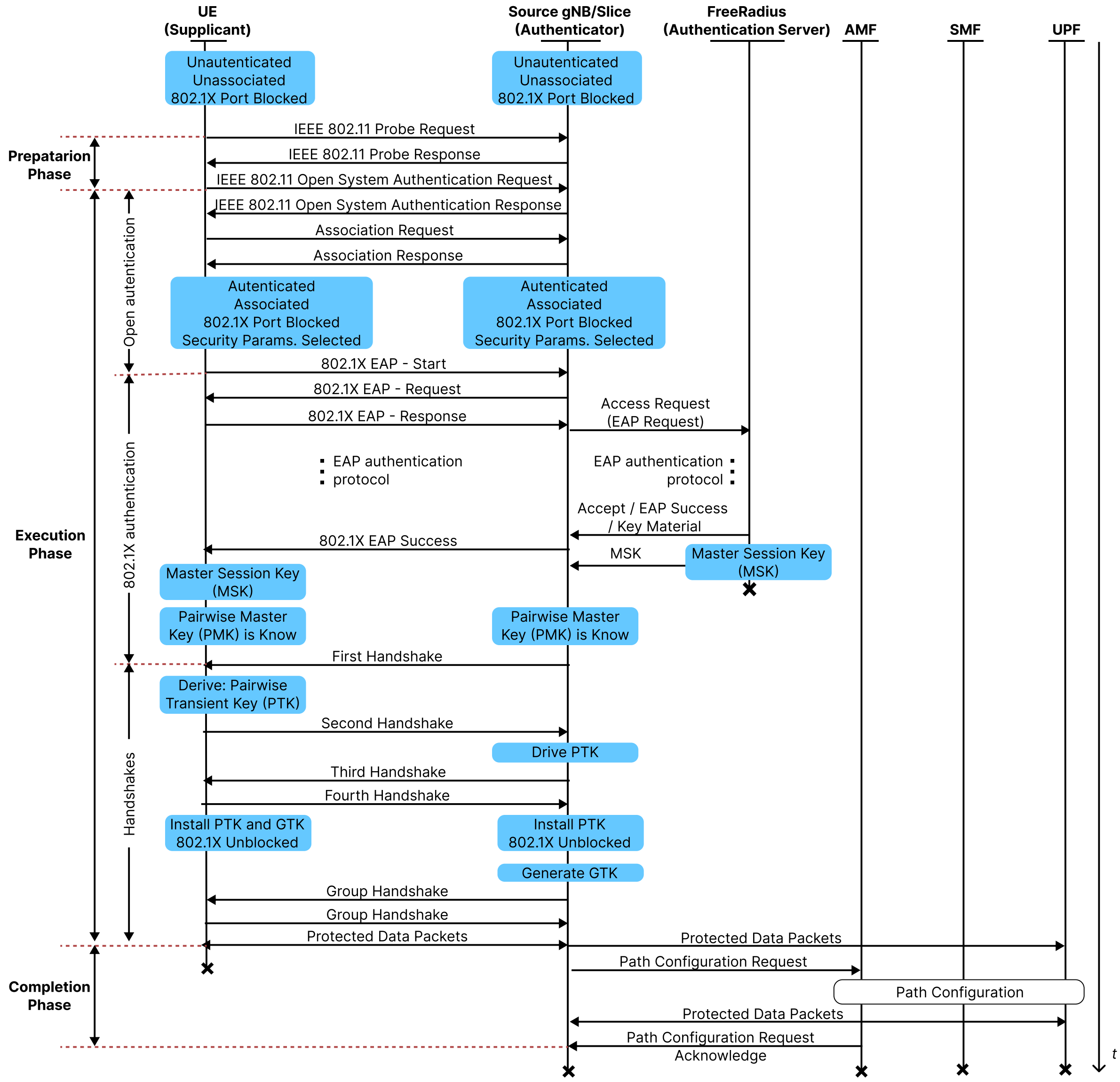

Figure 5. 802.11i RSNA establishment

i.e., whether the vehicle should execute: i) an intra-slice HM; ii) an inter-slice HM; or iii) remain in the current gNB and slice. Subsequently, this decision is sent to the Actuator module, which sends the handover decision to the vehicle. Thus, the preparation phase ends, and the execution phase starts.

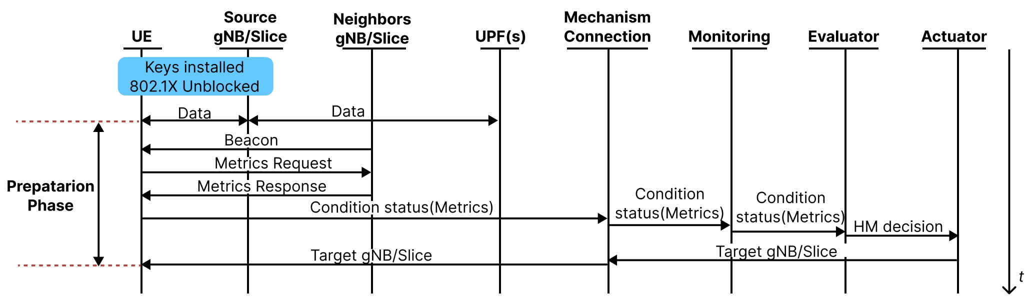

Figure 6. SHEM operation

Regarding the execution and completion phases, firstly, we explain the inter-slice HM, and secondly, we explain the intra-slice HM.

Figure 7 shows the execution and completion phases of the inter-slice HM. The execution phase employs the cached keys to omit 802.1X authentication between the vehicle and the target gNB/slice. Thus, the execution phase starts with the 4-Way Handshake process and the Group Handshake. Referring to the completion phase, the target gNB/slice performs two actions: i) inform the source gNB/slice to disassociate the vehicle to liberate the resources; ii) request the AMF to update information on mobility, session (in SMF), and routing (in UPF) of the HM realized between the vehicle and the target gNB/slice.

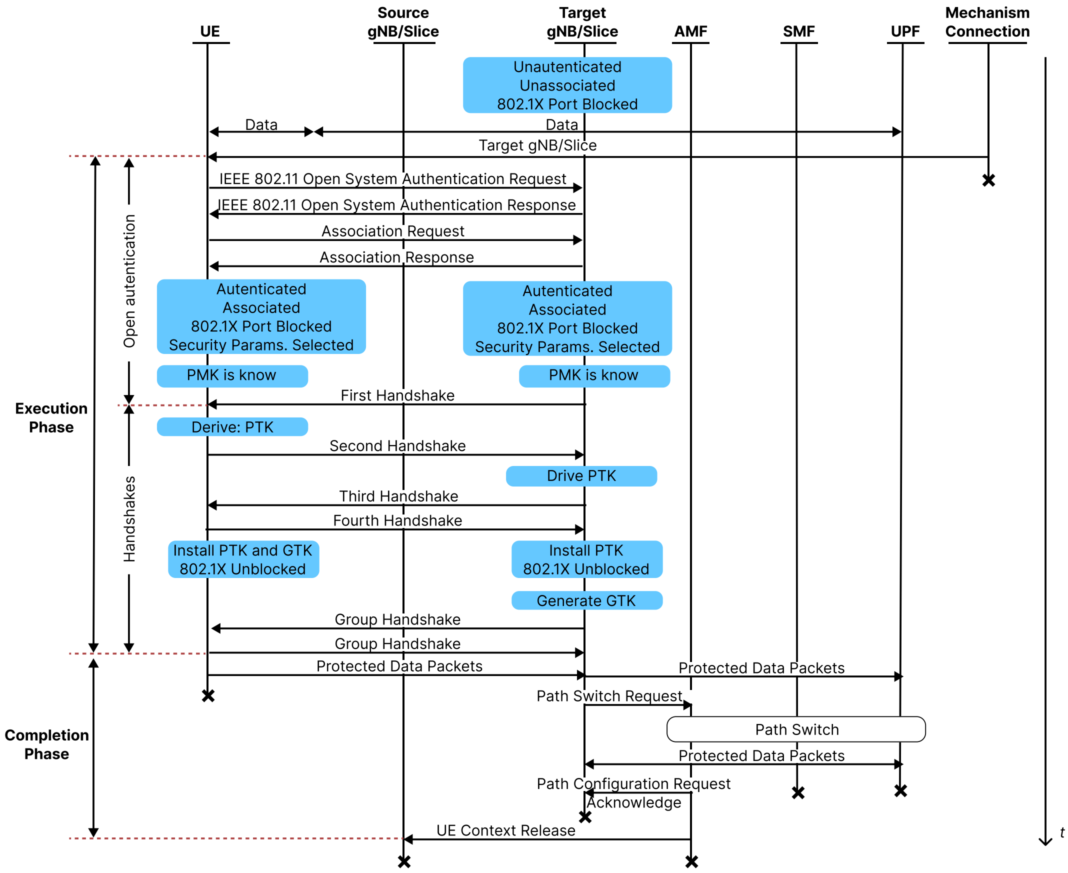

Figure 7. Inter-slice HM procedure

On the other hand, intra-slice HM in the execution phase omits 802.1X authentication and Handshakes (see Figure 8). This is because the HM is within the source gNB. Thus the 802.11r amendment can derive the complete set of 802.11i security capabilities previous to reassociation. Hence, the 802.11r amendment introduces a fast reassociation that incorporates handshakes into open authentication (also known as FT authentication) [47].

5. Evaluation

This section presents the evaluation of the SHEM prototype implemented in the 5G network. First, we describe our testbench. Second, we present the results obtained. Third, we analyze the results obtained.

5.1. Testbed

We analytically evaluate the prototype of SHEM to verify the latency in HM in the emulated 5G network. For this evaluation, we configured the 5G network implementation tools on a VirtualBox VM with Ubuntu 18.04.6 LTS, Linux Kernel 5.8.18, 7GB RAM, and quad-core Intel i5 12600K. To realize the

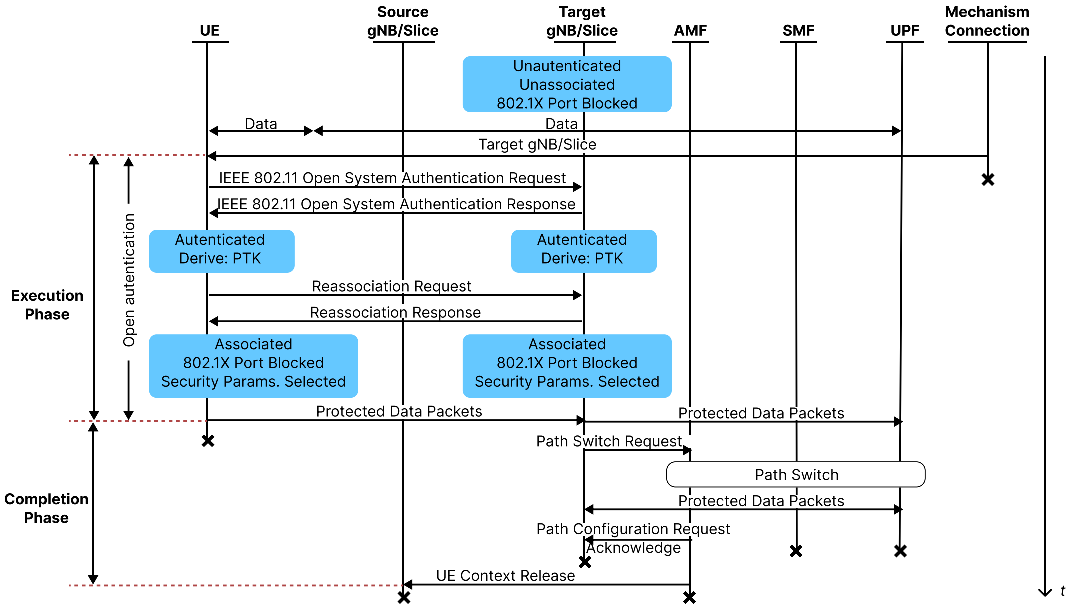

Figure 8. Intra-slice HM procedure

evaluation, we initially configured the parameters of both the 5G network and SHEM, according to Table 3. Subsequently, we realize the evaluation is composed of three tests. The first test verifies the NS implementation, corroborating the bandwidth of each slice. The second test verifies the contribution of SHEM to the latency reduction in the HM of the 5G network. Moreover, the third test verifies the compliance of the latency requirement of V2N and Non-V2N applications after the HM.

Parameter		**Value**
SHEM	RSSI threshold	-65 dBm
	Slice load threshold	2
Network 5G	# gNBs	2
	# slices x gNB	3
	gNB coverage radius	250 m
	Beacon interval of gNB	50 kus
	Total number of vehicles	12
	# LLC vehicles	6
	# Non-LLC vehicles	6
	Speed of LLC vehicles	60
	Speed of non-LLC vehicles	20-40

Table 3. Testbed parameters

5.2. Results

5.2.1. Test 1: NS

In this test, we checked the BW of the gNB slices, configured according to Table 2. For this, using the iPerf[57] tool, a vehicle transmitted 100 UDP flows (of 54 Mbps BW) through the WiFi slice interface to the corresponding application server. At the end of the transmission of each flow, iPerf delivers the server report, indicating the BW achieved in the transmission. In total, we obtained 600 reports, given that the network has two gNBs, and each gNB has three slices. In the reports summarized in Figure 9, we can evidence that the flow BW was reduced close to the configured BW.

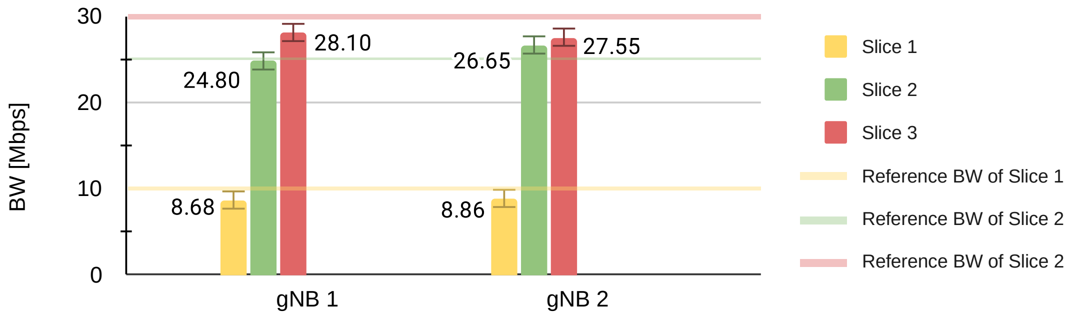

Figure 9. Test 1: Verification of BW assigned to each slice

5.2.2. Test 2: HM latency

To evaluate the contribution of SHEM to reducing the HM latency of the emulated 5G network, we consider the HM process described in Subsection 4.3. From there, we evidence that the HM latency integrates the durations of the preparation, execution, and completion phases (Equation 1). Regarding the preparation phase, this is performed by SHEM except in the 802.11i RSNA establishment. With respect to the execution phase, it includes the durations of the authentication and open association, 802.1X authentication, 4-way handshake, and group handshake, as shown in Equation 2. Moreover, for intra-slice HM, the durations of 802.1X authentication, 4-way handshake, and group handshake are zero. In summary, Table 4 presents the above parameters that make up the HM latency.

$$L_{HM} = T_{prep} + T_{exec} + T_{comp} \tag{1}$$

$$T_{exec} = T_{open} + T_{802.1X} + T_{4way} + T_{g\_h} \tag{2}$$

Symbol	Definition
L_{HM}	HM latency
T_{open}	Duration of open authentication
$T_{802.1X}$	Duration of 802.1X Authentication
T_{4way}	Duration of 4-way handshake
T_{g_h}	Duration of the group handshake
T_{prep}	Duration of the preparation phase
T_{exec}	Duration of the execution phase
T_{comp}	Duration of the completion phase

Table 4. HM duration parameters

We used the vehicle logs to obtain the durations of the preparation and execution phases. While to obtain the duration of the completion phase, we obtained it directly through timestamps inside the Ryu application called mechanism_integration. In this way, we collected these results in a dataset. Furthermore, with this dataset, we obtained that SHEM allows omitting the preparation phase in the inter-slice and intra-slice HM (see Figure 10). Thus, compared to the 802.11i RSNA establishment, SHEM reduced about 3700 ms of the preparation phase.

5.2.3. Test 3: Verification of meeting the application latency requirement in the HM

In this test, we verify the effectiveness of SHEM in selecting the target gNB/slice that satisfies the E2E latency requirement of the application executed by the vehicle. For this purpose, we proceed from Table 2, that configures both the minimum E2E latency offered by each slice and the maximum E2E latency allowed by each vehicle. Thus, the vehicle E2E latency requirement will be met (effectiveness) as long as the E2E latency of the selected target slice is equal to or less than the E2E latency value required by the vehicle, as shown in Table 5. However, this selection is sometimes infeasible since

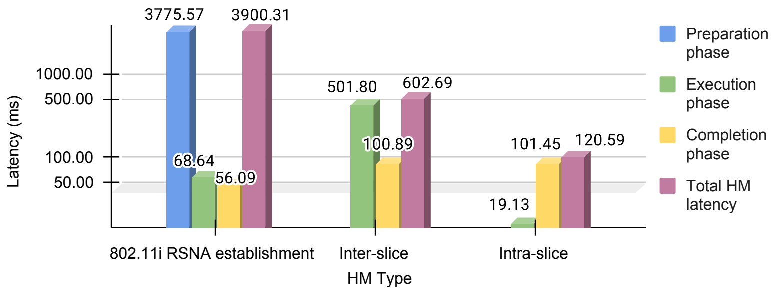

Figure 10. Test 2: HM Latency

the appropriate destination slice may be overloaded with vehicles. For this reason, we tested the effectiveness of SHEM in selecting the target gNB/slice.

Maximum E2E Latency Allowed by each vehicle	Minimum E2E Latency offered by each slice		
	Slice Non-V2N (50 ms)	Slice V2N-1 (20 ms)	Slice V2N-2 (10 ms)
Vehicle App (50 ms)	✓	✓	✓
Vehicle App (20 ms)		✓	✓
Vehicle App (10 ms)			✓

Table 5. gNB/slice target ideal for meeting the E2E latency requirement of the application run by vehicle

To check the effectiveness of SHEM, we analyzed the inter-slice and intra-slice HMs of the dataset generated in Test 5.2.2. In total, there are 844 HMs, 556 inter-slice, and 288 intra-slice. In each type of HM, we checked the effectiveness, obtaining that of the 556 inter-slice HM, 404 (72.7%) were effective. And of the 288 intra-slice HM, 214 (74.3%) were effective. Thus, SHEM obtained an average 73.5% effectiveness rate. Figure 11 summarizes the above results obtained by SHEM.

$$\%_{Effectiveness} = \frac{Total\ number\ of\ HM}{Number\ of\ effective\ HM} * 100 \tag{3}$$

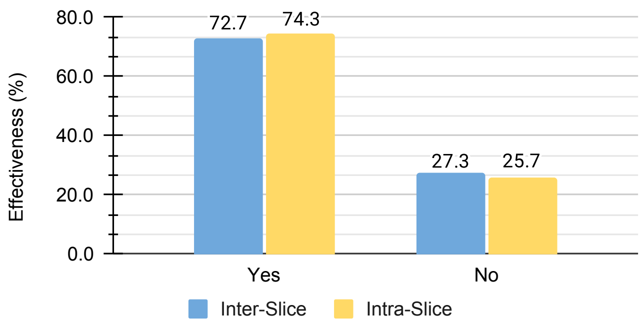

Figure 11. Test 3: Effectiveness percentage of latency meeting in HM

5.3. Final Remarks

From the tests, we observed that SHEM has two contributions to the HM of the emulated 5G network together with NS. The first contribution is the omission of the HM preparation phase, thus obtaining a reduction of about 3700 ms. The second contribution is the 73.5% effectiveness in determining the target gNB/slice in order to meet the latency requirement of the application executed by the vehicle. These contributions are due to the latency requirement that SHEM considers to determine the target gNB/slice proactively and passively. That is, before channel degradation and without interrupting the communication between the vehicle and the source gNB/slice. Furthermore, we found that SHEM is viable in both inter-slice HM and intra-slice HM.

6. Conclusions

This paper proposes SHEM, which aims to meet Low-Latency application Requirements in an NS-based 5G network. For this, SHEM determines the target gNB/slice proactively, passively, and aware of the latency requirement of both the UE and the one offered by the slice. SHEM is based on a three-module design (monitoring, evaluator, and actuator) that can operate in both inter-slice HM and intra-slice HM. Furthermore, we implement SHEM using heuristic programming. In this way, SHEM completely omits the HM preparation phase, thus significantly reducing the HM latency by about 3700 ms. Moreover, SHEM obtained good effectiveness of 73.5% in the selection of the target gNB/slice in order to meet the latency requirement of the application executed by the vehicle. Therefore, we can conclude that SHEM is a solution for HM latency reduction in NS-based 5G networks.

As future work, we intend to extend the design of the SHEM to be able to address: i) the execution phase and the completion phase of HM; ii) eMBB and mMTC usage scenarios, as well as emerging 6G usage scenarios; iii) NS in both the NC as in RAN; and iv) others QoS requirements. Moreover, implement SHEM using other techniques (e.g., machine learning) and over a physical 5G network. Finally, evaluate the performance of SHEM in terms of resource consumption.

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