Evolved MVNO Architectures for Converged Wireless Deployments

A Technical Paper prepared for SCTE by

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1. Introduction

With the advent of smartphones and widespread deployment of mobile technologies like 4G LTE (and now 5G NR), wireless connectivity is becoming an integral part of a connectivity service offering for multiple system operators (MSOs). Several MSOs that lack mobile network infrastructure have relied on the mobile virtual network operator (MVNO) model to supplement their connectivity offerings with wireless. New entrants like DISH in the United States and Rakuten[1] in Japan (who are deploying their own mobile infrastructure) are also taking advantage of MVNO arrangements to supplement their network coverage.

As the name suggests, an MVNO is a wireless service provider that does not own the end-to-end mobile network; instead, it leverages a portion of a mobile network operator (MNO) network via a business agreement. Typically, MVNOs focus on the marketing, billing, and customer facing aspects and rely on the MNO network and/or services infrastructure to deliver the connectivity and/or services.

The MVNO's payments to the MNO are typically based on usage by the MVNO's customers. Although voice usage has stabilized, data usage continues to grow at a compound annual growth rate (CAGR) of more than 25%.[2] This makes the offloading of data for MVNOs even more important to remain profitable in the long run. The continued success of MVNOs is also important to MNOs in terms of sustaining their wholesale revenues (resulting from the MVNO data usage).

Until now, MVNO offerings from MSOs have relied on Wi-Fi to offload data usage from the MNO's network. Shared spectrum such as the Citizens Broadband Radio Service (CBRS) is significantly reducing the barriers for new entrants and small operators to further offload data usage and improve the economics of an MVNO offering. Deployment of shared spectrum will require MSOs to build their own cellular infrastructure to enable offload using CBRS in areas of high usage.

As MSOs look to deploy their own wireless infrastructure, they will have to contend with three disparate sets of wireless infrastructures—the MSO's community Wi-Fi network, the MNO's 4G/5G network, and the MSO's own 4G/5G network. Maximizing offload via the MSO's own wireless assets, ensuring a consistent user experience, and enforcing uniform and personalized policies as users move in and out of coverage of these three networks will require deployment of new converged network architecture and related capabilities.

This paper is focused on describing options for these evolutionary converged architectures that can be utilized by the MSOs as they progress in building out their own 4G/5G networks.

2. Overview of MVNO Models

Globally, several different MVNO models have been implemented and can be broadly classified as depicted in Figure 1. The classification is based on the amount of mobile network infrastructure owned by the MVNO and the degree of control over the management of different aspects of MSO subscriptions and their service offerings.

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[1] "Rakuten Mobile Completes Connection of MMEs with KDDI Roaming Areas Through S10 Interface," press release, April 2020, Rakuten Mobile
[2] Figure 13 of "Ericsson Mobility Report," November 2020, Ericsson

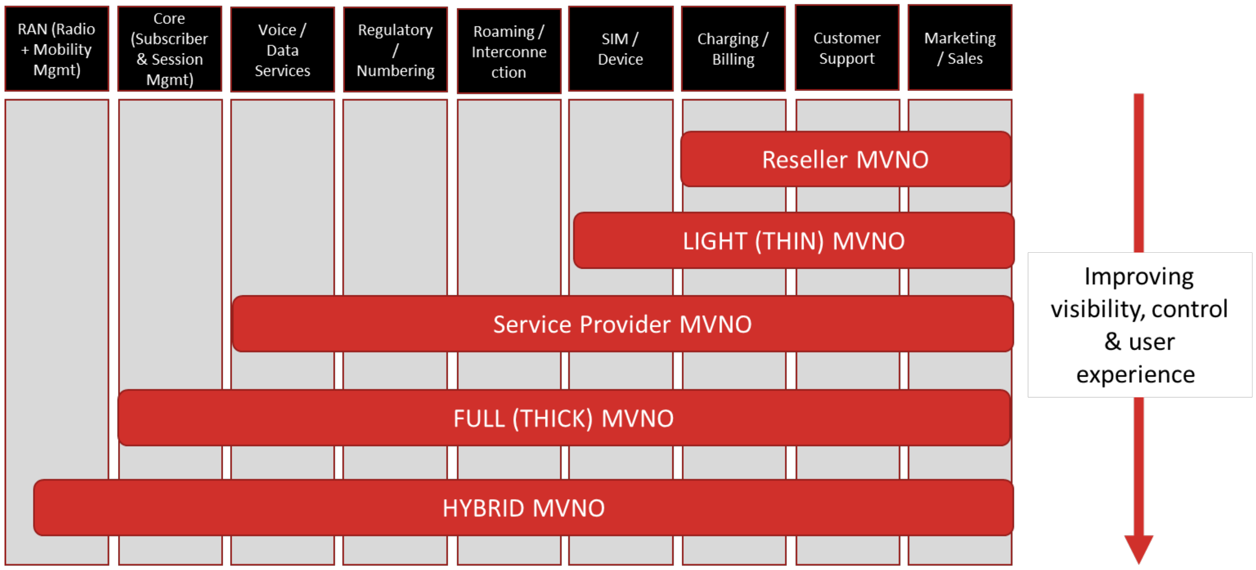

Figure 1: MVNO Types and Degree of Control

Reseller MVNO

A reseller MVNO manages the billing and customer network support functionality while utilizing an MNO for subscriber identity module (SIM) management, device management, core network, and radio infrastructure. The MVNO has no control over subscription, policy, and mobility management and lacks visibility into a subscriber's usage pattern to customize the service offering.

Light (Thin) MVNO

The light MVNO model is like the reseller model, except the SIM and handset are managed by the MVNO; all other aspects remain unchanged. The MVNO still has limited to no control on network policies, subscription, and mobility management of the subscriber on the cellular network and lacks visibility into data usage by its customers.

Service Provider MVNO

In comparison to the first two types of MVNOs, a service provider MVNO is responsible for deploying, operating, and managing its own service platform, thereby enabling the MVNO to differentiate its service offering from that of the MNO. However, the radio and core infrastructures still belong to the MNO, and the MVNO still has limited control on network policies, subscription, and mobility management of the subscriber on the mobile network.

Full (Thick) MVNO

In addition to the service platform, a full MVNO deploys certain mobile core network nodes, such as packet gateways and policy controllers, to have more control over the policy and session management of its customers while allowing the MVNO to leverage the MNO radio and mobility management infrastructure. The data traffic is routed back to the MVNO's mobile core network.

The MVNO manages billing, customer network support, SIM credentials, handset functionality, subscriptions, and policies and has full visibility into data usage. However, the MVNO has limited to no control over mobility management of the subscriber on the cellular network. This model is like the traditional home routed (HR) roaming model specified as part of 3GPP standards.

Hybrid MVNO

A hybrid MVNO (H-MVNO) is a relatively new model wherein the MVNO owns a mobile radio network deployed in specific geographic areas. These networks could be small cell hotspot deployments or traditional regional mobile deployments.

Like the full MVNO model, billing, customer network support, SIM credentials, handset functionality, subscriptions, and policies are managed by the MVNO. Additionally, the user device is prioritized to access and utilize the MVNO radio network when available and to use the MNO radio network only when it is outside the coverage of the MVNO radio network. This model can be of particular interest to many MSOs who may have or are planning to have hotspot and/or regional mobile deployments.

To deliver a seamless (converged) experience across the two wireless networks, a varying degree of convergence (interoperability) between the two networks is required. The degree of convergence and interoperability between the networks will depend on the type of applications used by the end users, types of services to be provided by the H-MVNO network, and the desired level of visibility into the subscriber usage to enable customized service plans, as well as the amount of operational coordination that is acceptable to both the H-MVNO and the MNO.

The hybrid MVNO model and associated converged architecture options are the focus of this paper. The next section covers the converged architecture options for evolving a traditional reseller or light MVNO into a hybrid MVNO.

3. Architecture Options for a Hybrid MVNO (H-MVNO)

The architecture options outlined below are categorized into two broad categories based on device capability regarding SIM support.

1. Architecture options for devices with dual SIM support
2. Architecture options extending support to single SIM devices

3.1. Architecture Options for Dual SIM Devices

In this section, we analyze the architecture options available to H-MVNOs for dual SIM devices.

3.1.1. Architecture Option 1: Independent Mobile Core Networks

Dual SIM devices have been around for some time. Traditionally, dual SIM devices were used to manage two separate phone lines with a single device (e.g., one for personal use and the other for business use or while traveling internationally). With the advent of embedded SIM (eSIM) technology, most smartphone manufacturers now support at least two SIMs—a physical SIM and an eSIM. With two SIMs in a device, the device can be configured to connect to two different networks from two different operators, making it a logical option for H-MVNOs to consider.

Most devices that operate in a dual SIM dual standby (DSDS) mode have two radio receivers but a single transmitter (although this may change with the proliferation of 5G), implying that the user can actively transmit data on only a single network at any given time. While on an active data session on one network, the DSDS device remains in standby mode on the second network, continuing to listen to paging messages. Upon receiving a page, based on service settings, the device either provides an indication of the incoming page to the user or automatically connects to the standby network while transitioning to standby on the first network.

Using DSDS-capable devices is the simplest way for an H-MVNO to maximize the use of its own network and utilize the MNO's network only when the user is outside the coverage of the H-MVNO's own mobile network. Figure 2 shows the network architecture for an H-MVNO utilizing DSDS, where both the MNO and H-MVNO have independent mobile cores and subscriptions. The MNO SIM is configured in the MNO Home Subscriber Server (HSS), while the H-MVNO is configured in the H-MVNO's combined unified data management (UDM) + HSS system. The transition between the H-MVNO and MNO networks in this architecture is controlled and managed by the intelligence in the device.

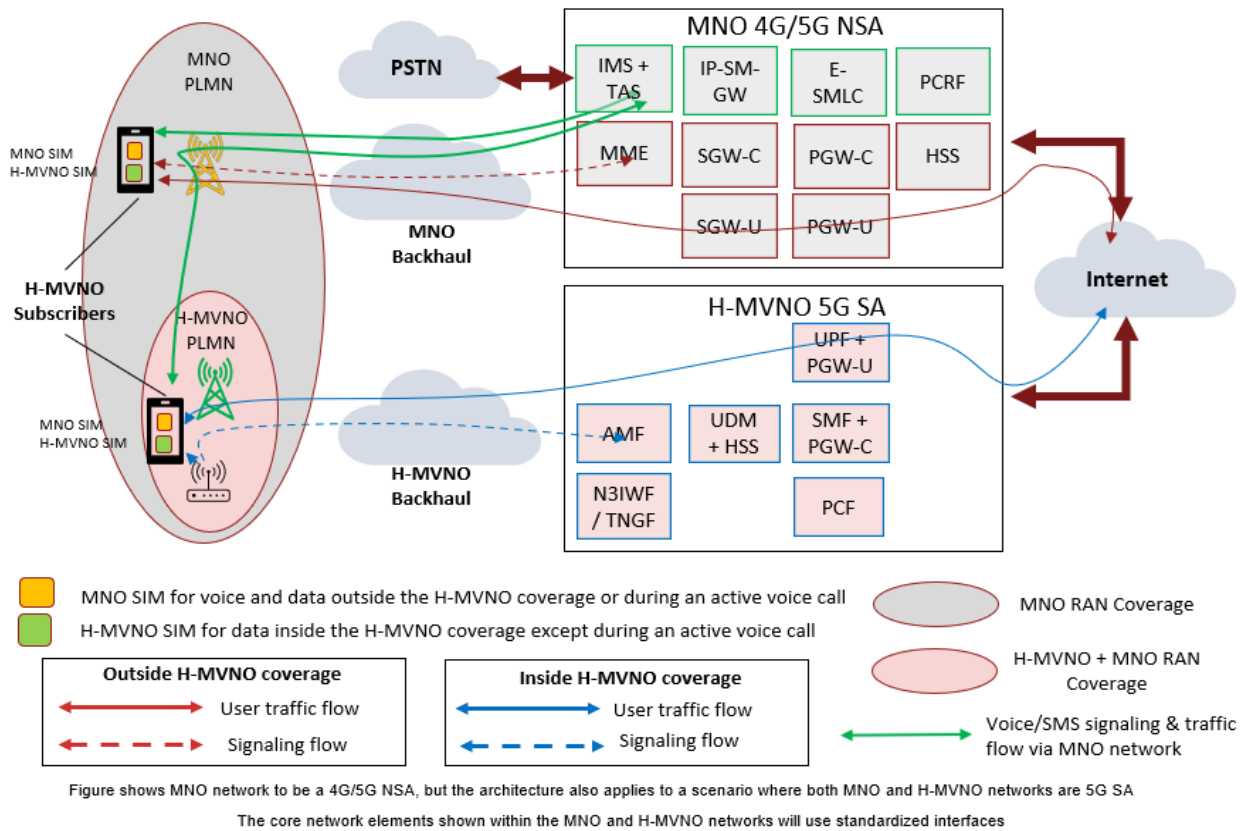

Figure 2: Hybrid MVNO Architecture Option 1—DSDS-Based Architecture

When the H-MVNO subscriber is inside the H-MVNO network coverage area, the user device connects to the H-MVNO network via the H-MVNO SIM (active SIM) to access the Internet while the MNO SIM is in standby, significantly reducing the time spent on the MNO network. On the other hand, when the H-MVNO subscriber is outside the H-MVNO coverage footprint, the H-MVNO SIM is not connected, and the device connects to the MNO network via the MNO SIM (active SIM) to access the Internet. Because of the limited coverage of an H-MVNO network and the lack of a seamless handover between the two networks in this architecture, voice service will be over the MNO network.

The transition between the two SIMs (and the associated networks) while a user is active on one network is critical. It occurs in two cases.

- Paging-based—the device inside H-MVNO coverage receives a paging message from the MNO network for voice related service, and the user accepts it.
- Coverage-based—the device active on the H-MVNO network moves outside H-MVNO coverage or the device active on the MNO network moves inside H-MVNO coverage.

In addition to having to depend on dual SIM devices, this H-MVNO architecture option faces the challenge of the DSDS switching between networks. The custom intelligence built into all dual SIM devices before the finalization of the 3GPP Release 17 (Rel-17) standard will have vendor-specific implementations, which can result in a variety of user experiences. In June 2019, CableLabs conducted testing[3] on a subset of commercially available dual SIM phones to analyze the behavior and impact on user experience with regard to network connectivity, data-session transition, and paging on a non-active network. The test observations and results indicated that user experience varies significantly depending on the vendors' implementations on the dual SIM devices. The implementations supported paging-based scenarios but were not efficient for coverage-based scenarios, requiring user intervention and impacting user experience when switching between the networks corresponding to the two SIMs .This is because the device implementation assumes overlapping coverage from both the networks.

An H-MVNO needs to work closely with device vendors to customize the devices for effectively managing the transition between the two networks, specifically for hand-in/hand-out of H-MVNO network coverage and paging-based scenarios.

The H-MVNO network also needs to be able to gracefully become aware of the DSDS switching events (responding to either a mobility event or the user accepting a voice call through the MNO network) so as to avoid degrading the key performance indicators (KPIs), perform internal context cleanup (discard buffered download data, delete bearer context, etc.), and avoid wasting system resources. 3GPP is trying to address some of these issues related to the use of multiple SIMs. However, because of the ongoing pandemic, finalization of 3GPP Rel-17 has been delayed, and the earliest availability of these standards-based features in devices and infrastructure will likely be in 2023–2024.[4]

The voice and messaging services, including emergency calling/texting, will be provided via the MNO network utilizing the MNO SIM. While in H-MVNO coverage, the data services are via the H-MVNO access network except when active on a voice call. While on the voice call, the data services will be via the MNO access network utilizing the MNO SIM. While outside the coverage of the H-MVNO network, the data services will be via the MNO's network.

Finally, H-MVNOs lacks real time visibility into their subscribers' data usage statistics and patterns over the MNO network and have no control over policy, subscriptions, mobility, and user experience management when its subscribers are outside the H-MVNO network coverage. To overcome these data visibility and policy challenges resulting from having two separate anchor points with their own policies, user traffic needs to be routed back to the H-MVNO network. One way this can be achieved is via an over the top (OTT) VPN-like solution comprising a custom device-side application (e.g., connection manager) and a server-side application located in H-MVNO's cloud platform (private or public). Another is a

[3] "Dual SIM—An Alternative to 3GPP-Based Roaming Models," technical brief, June 2019, CableLabs R&D Wireless
[4] 3GPP Release 17, Study on System Enablers for Devices Having Multiple Universal Subscriber Identity Modules (USIM), TR 23.761, v1.5.0 (June 2, 2021)

standards-based approach that does not require a custom device client. There are two different standards-based ways (that do not require a client-side application) to achieve this and are described in sections below.

3.1.2. Architecture Option 2: Enabling S8 Interface Between Networks

One evolutionary approach to overcome some of the limitations of the above architecture option is shown in Figure 3.

This architecture evolution relies on implementation of standards-based interfaces between the two networks. The H-MVNO subscriber traffic across both the H-MVNO and MNO SIM connections is always anchored within the H-MVNO mobile core (routed from the MNO to the H-MVNO via the S8[5]-based interface). This ensures full visibility into subscriber data usage, irrespective of which network is used. The H-MVNO and MNO SIMs continue to be configured in their subscriber databases (HSS for MNO and UDM+HSS for H-MVNO) within their own respective mobile cores. The mobility management entity (MME) within the MNO mobile core selects the H-MVNO packet gateway (SMF+PGW-C) based on the default access point name (APN) value specified in the connection request from the device and the APN subscription data from HSS. The DNS query from MME will include both the tracking area code (TAC) and the APN to pick the nearest SMF+PGW-C to the end user. The SMF+PGW-C then selects a corresponding UPF+PGW-U network element nearest to the end user (from a latency perspective). Termination of S6a and S8 in different administrative domains has not been contemplated within 3GPP and will have to be agreed to and coordinated between the MNO and the H-MVNO.

[5] Although MNO network is depicted as a 4G network, this can easily be extended in a similar way for a 5G System deployment

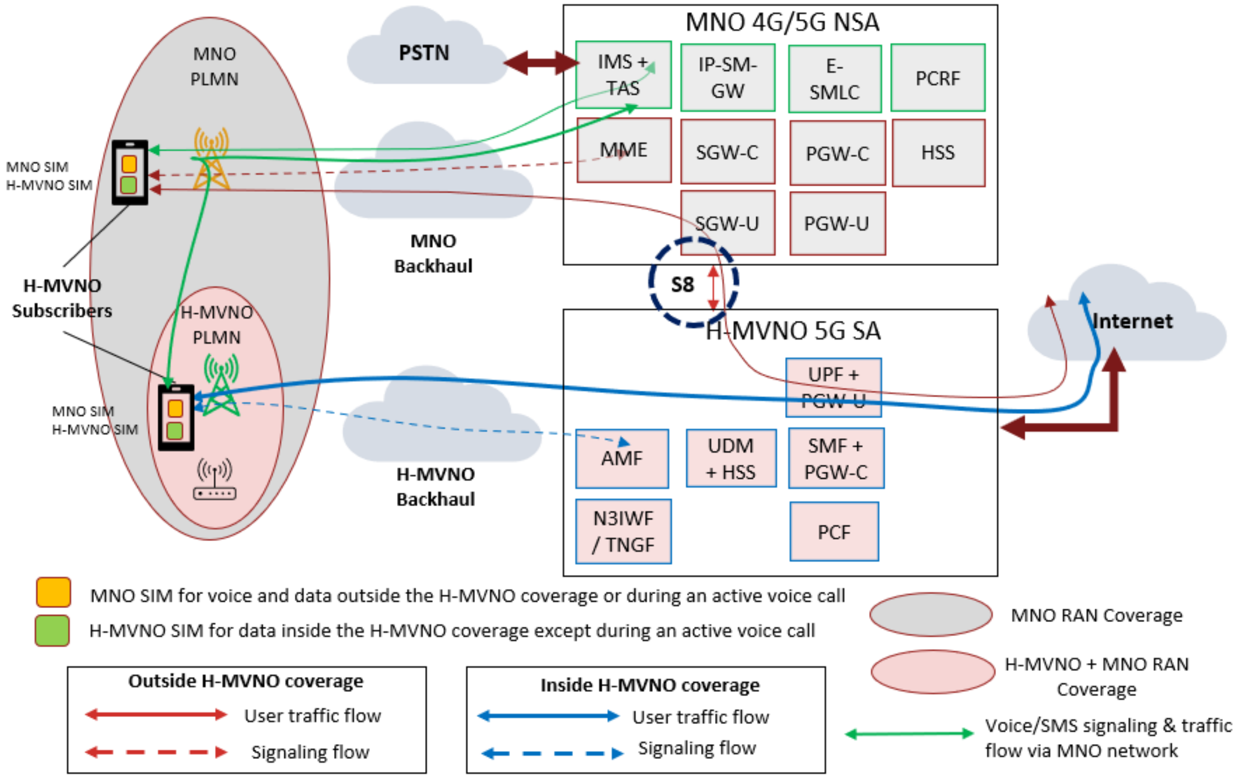

Figure shows MNO network to be a 4G/5G NSA, but the architecture also applies to a scenario where both MNO and H-MVNO networks are 5G SA
The core network elements shown within the MNO and H-MVNO networks will use standardized interfaces

Figure 3: Hybrid MVNO Architecture Option 2—Evolved DSDS Architecture

In this architecture option, like Option 1, the MNO SIM continues to be provisioned in the MNO HSS. Like Option 1, the voice and messaging services, including emergency calling/texting, continue to be provided via the MNO network utilizing the MNO SIM. While in H-MVNO coverage, the data services are via the H-MVNO access network except when active on a voice call. While on the voice call, the data services will be via the MNO access network utilizing the MNO SIM. While outside the coverage of the H-MVNO network, the data services will be via the MNO's network. However, unlike option 1, this architecture option uses a common data anchor point located within the H-MVNO network, thereby providing full visibility into the data usage patterns and statistics.

Some coordination to set up the connectivity between the MNO and H-MVNO networks will be required. Additionally, in this architecture, the MNO serving gateway (SGW-C) may have to generate the charging records for H-MVNO subscribers.

A key difference between the traditional 3GPP specified roaming architecture (home-routed) and this converged architecture (Option 2) is that while the roaming interface (S8) is utilized to interconnect the two domains for user data, the user subscription continues to be provisioned in the MNO HSS, resulting in continued use of intra-domain S6a interface for the control plane. The inter-domain interfaces between the MNO and the H-MVNO can be secured in the same way as they are done today for roaming, by using a secured connection.

Because the H-MVNO has control over the data traffic irrespective of which access network the subscriber is on (MNO or H-MVNO), it can implement uniform policies and functionalities in the H-

MVNO core network to manage steering/switching traffic, not only between the two 3GPP access networks, but also between the MNO's 3GPP network and the H-MVNO's non-3GPP (Wi-Fi) network.

In this architecture, it is possible to support access traffic steering, switching, and splitting (ATSSS) functionality across the H-MVNO's non-3GPP (untrusted, trusted Wi-Fi) network and the MNO's 3GPP network (even when the MNO 3GPP network is 4G[6]). While on the MNO's 4G network, the ATSSS traffic rules on the devices will be updated through the non-3GPP leg of connection. This will require some additional functionality within the H-MVNO infrastructure, as the SMF+PGW-C will have to retrieve information about the serving SMF+PGW-C and UPF+PGW-U and ensure that the same ATSSS anchor is assigned. The ATSSS capability will have to be enabled across both SIMs. However, unlike architecture option 1, no client-side application will be required.

By enabling ATSSS functionality across the H-MVNO's wireless (cellular and Wi-Fi) assets and the MNO's cellular network, a fully converged standards-based architecture could be realized, giving H-MVNOs tremendous flexibility in utilizing all available wireless access networks for user data transmission.

Additionally, capability to transfer the 3GPP leg of ATSSS-compliant Multi-Access Protocol Data Unit (MA-PDU) session from the H-MVNO's 5G network to the MNO's 4G network can also be contemplated as a custom capability within the H-MVNO mobile core; no enhancements are required in the MNO's 4G network. Depending on the implementation of the device IP stack, device side enhancements may not be necessary.

The next architectural option depicts a solution to enable ATSSS between the H-MVNO's Wi-Fi and the MNO's 4G network without requiring enhancements within the H-MVNO's core network or requiring ATSSS to be enabled across both SIMs. It also facilitates use of Wi-Fi connectivity when available, irrespective of whether the user is in the H-MVNO or MNO coverage.

3.1.3. Architecture Option 3: Enabling S6a and S8 Interface Between Networks

Figure 4 depicts further enhancements to architecture option 2. In this architecture option (option 3), the H-MVNO SIM is configured to roam onto the MNO's network when outside the coverage of its home network (H-MVNO network). Therefore, in addition to the S8 interface, this option requires support of inter-domain roaming S6a interface between the MNO and the H-MVNO networks for the H-MVNO SIM.

In this option, the data sessions are established using the H-MVNO SIM irrespective of whether the device is inside or outside the H-MVNO's network coverage area. The MNO SIM is utilized only for data sessions during an ongoing voice session. As in previous architecture options, the voice sessions continue to be established using the MNO SIM.

The roaming S6a interface is used by the MNO's core network to authenticate access via the H-MVNO's SIM. In the event an MA-PDU session was previously established, the anchor SMF+PGW-C is retrieved by the MNO's MME from the H-MVNO's network via the S6a interface. Otherwise, the PGW selection is done by the MME in the same way as described in option 1. The only time ATSSS MA-PDU will not be utilized is when the user is accessing data services during an ongoing voice call and Wi-Fi coverage is unavailable.

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[6] 5G defined ATSSS capability is transparent to the 4G from a signaling perspective and does not require any modifications to the MNO deployment

In this option, since data is via the H-MVNO SIM across both networks, this option requires ATSSS configuration only for the H-MVNO SIM. Additionally, no customization for ATSSS across multiple SIMs is required in the H-MVNO's core network to utilize Wi-Fi connection irrespective of whether the user is in the MNO or the H-MVNO coverage. Furthermore, since a single SIM is used for data across the two networks, data session management can be more gracefully managed as the device transitions in and out of H-MVNO coverage. However, in option 3, when UE switches between the two SIMs (based on network availability), UE has to de-register from the source network and register on the target network and may experience a longer interruption to reestablish the session as opposed to Option 2, where separate SIMs are used for data operation on each network and both SIMs are registered to the networks simultaneously.

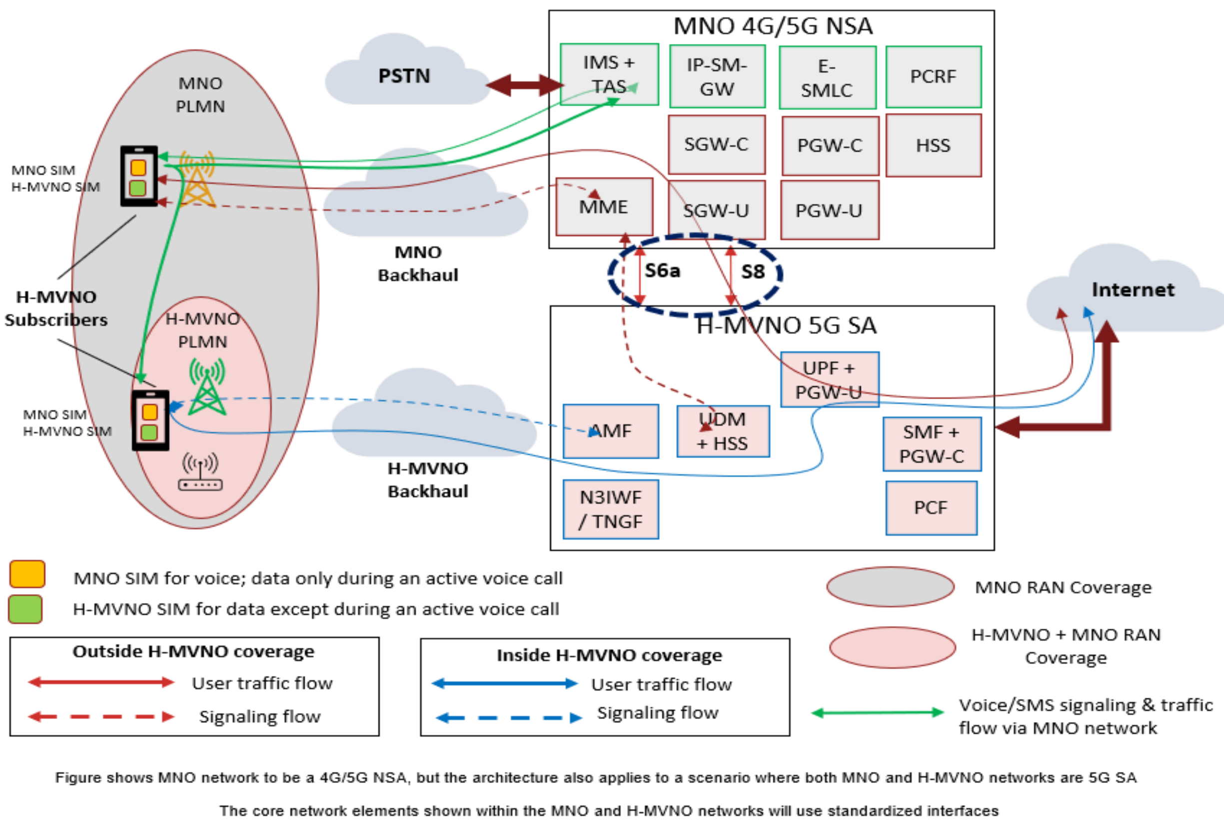

Figure 4: Hybrid MVNO Architecture Option 3—Evolved DSDS Architecture

Table 1 compares the key salient features of the DSDS and evolved DSDS architecture options.

Table 1: Comparison of H-MVNO Architecture Options 1, 2, and 3

Attributes	H-MVNO Dual SIM Architectures		
	Option 1 (DSDS)	Option 2 (Evolved DSDS)	Option 3 (Evolved DSDS)
Enforcement of uniform policies irrespective of the serving network without device/network customization	×	✓	✓
Uniform traffic policy management regardless of the SIM or associated network without device/network customization	×	✓	✓
Full visibility into data usage statistics and pattern irrespective of the network used without device/network customization	×	✓	✓
Use of standardized ATSSS feature to improve session continuity across all accesses	×	×	✓
No need of coordination of roaming interfaces between MNO and H-MVNO	✓	×	×

Though the evolved DSDS architectures solve the issues of converged policy, full visibility into subscriber usage statistics and patterns and leveraging Wi-Fi connection when available, the following challenges still remain.

- Support for dual SIM is needed across the H-MVNO's device portfolio. There are also related concerns (i.e., efficiently managing transitions between the two SIMs as the subscriber moves in and out of H-MVNO access network coverage, especially if two separate SIMs are used for data sessions across the H-MVNO and MNO networks).
- The device on the MNO network is unable to immediately switch back to the H-MVNO network as soon as it moves inside the H-MVNO access network coverage without customization on the device side. One approach to facilitate this transition in the evolved DSDS architecture is to build intelligence in the anchor point (PGW/SMF/UPF), either through custom signaling or further enhancements to standards based ATSSS signaling.

The next section presents additional standards-based architecture options to overcome these challenges.

3.2. Architecture Options Extending Support for Single SIM Devices

In this section, we analyze the architecture options available to H-MVNOs to enable low-latency handovers between their networks and that of MNO networks. Even though the architecture options presented below are focused on single SIM devices, they are backwards compatible with above DSDS architecture options and will also be able to support dual SIM devices.

3.2.1. Direct N26 Interface Between H-MVNO and MNO Networks

One way to facilitate seamless handover of devices between MNO and H-MVNO access networks is through the implementation of the standards-based N26 interface. This architecture option is depicted in Figure 5. In this architecture, the H-MVNO SIM is provisioned within the H-MVNO network. Through the roaming interfaces, S6a and S8, the device can obtain the service by connecting through either the MNO or the H-MVNO access network. What separates this architecture option from the previous options is the introduction of the mobility interface, N26, between the two networks. With this interface, the device will be able to seamlessly move between the two networks through the execution of inter-PLMN (public land mobile network) handover procedures. The networks will be able to control the mobility aspects (connected mode handovers and idle mode cell reselection) as the device moves in and out of the H-MVNO coverage footprint rather than relying on the device to switch the data sessions between the two SIMs, as was the case for the dual SIM architecture options 1 to 3.

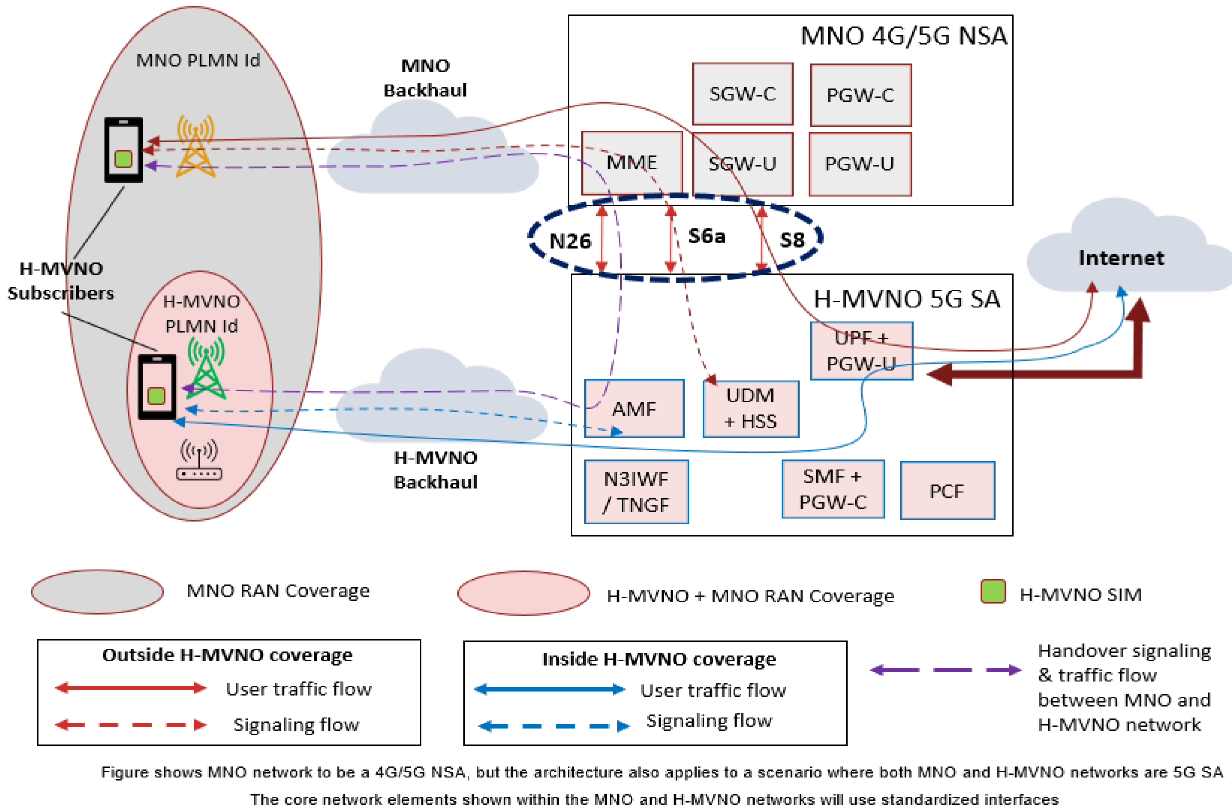

Figure 5: Architecture Option 4—Handover Interface Between MNO and H-MVNO

To enable option 4, several potential operational issues have to be addressed.

1. Securing the handover interface between the two networks
2. Having the appropriate mobility configuration and parameters (e.g., connected-mode and idle-mode configurations, event thresholds) for H-MVNO devices in the MNO network, taking into consideration the differences in the spectrum bands in the two access networks and the overlapping network coverage
3. Ensuring minimal impact to the MNO users from the additional signaling traffic in the core network caused by potential ping-ponging between the two access networks as the H-MVNO device frequently transitions in and out of the H-MVNO footprint
4. In case of multiple H-MVNO partners, the MNO core serving its subscribers having to interface with multiple core networks, creating significant operational challenges and risks

The first issue is similar to option 3 with regards to enabling secured connection with inter-domain S6a and S8 interfaces between the two networks. The same techniques used to interoperate and secure those interfaces also can be utilized for the N26 interface. The Rakuten network is based on this hybrid MVNO architecture option. Rakuten has an MVNO arrangement with KDDI and has enabled the S10 interface between its 4G core and KDDI’s 4G mobile core.

The second issue can be addressed with custom configurations within the radio access networks for access barring, handovers, and redirection using RAT Frequency Selection Priority ID (RFSP ID) that has been specified in the standards.

Regarding the third issue, the actual amount of increase in excessive handovers and ping-ponging in the MNO core network will depend on the degree of contiguous deployment in the region by the H-MVNO (i.e., the number of handover boundaries between the two networks). Indoor/outdoor transitions could also result in many handover boundaries depending on the type of spectrum (low- or mid-band).

One way to address this issue of ping-ponging and corresponding signaling overload on the MNO's core network is by using a dedicated core for the H-MVNO traffic. This use of dedicated core also allows us to address the fourth issue. This architecture option utilizing a dedicated core is described below.

3.2.2. *Dedicated Core for H-MVNOs*

The dedicated core architecture option depicted in

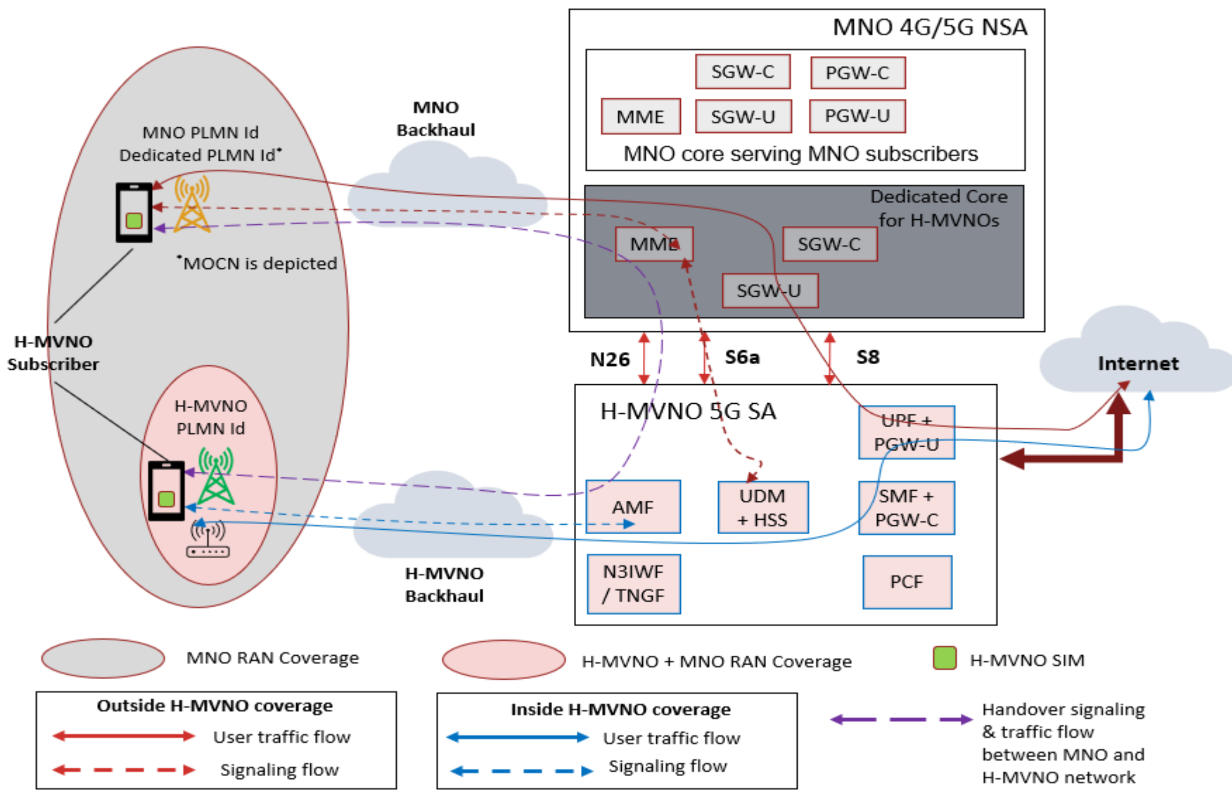

Figure shows MNO network to be a 4G/5G NSA, but the architecture also applies to a scenario where both MNO and H-MVNO networks are 5G SA
The core network elements shown within the MNO and H-MVNO networks will use standardized interfaces

Figure 6 helps alleviate the impact of ping-pong handovers and the risk to MNO core operation. The H-MVNO users' signaling, and user traffic streams will be processed within the dedicated core rather than the MNO's core, thereby isolating signaling load generated from the mobility of the H-MVNO's user devices from that of the MNO's user devices. The dedicated core comprises a dedicated mobility management entity (MME) and, optionally, an SGW (SGW-C + SGW-U).

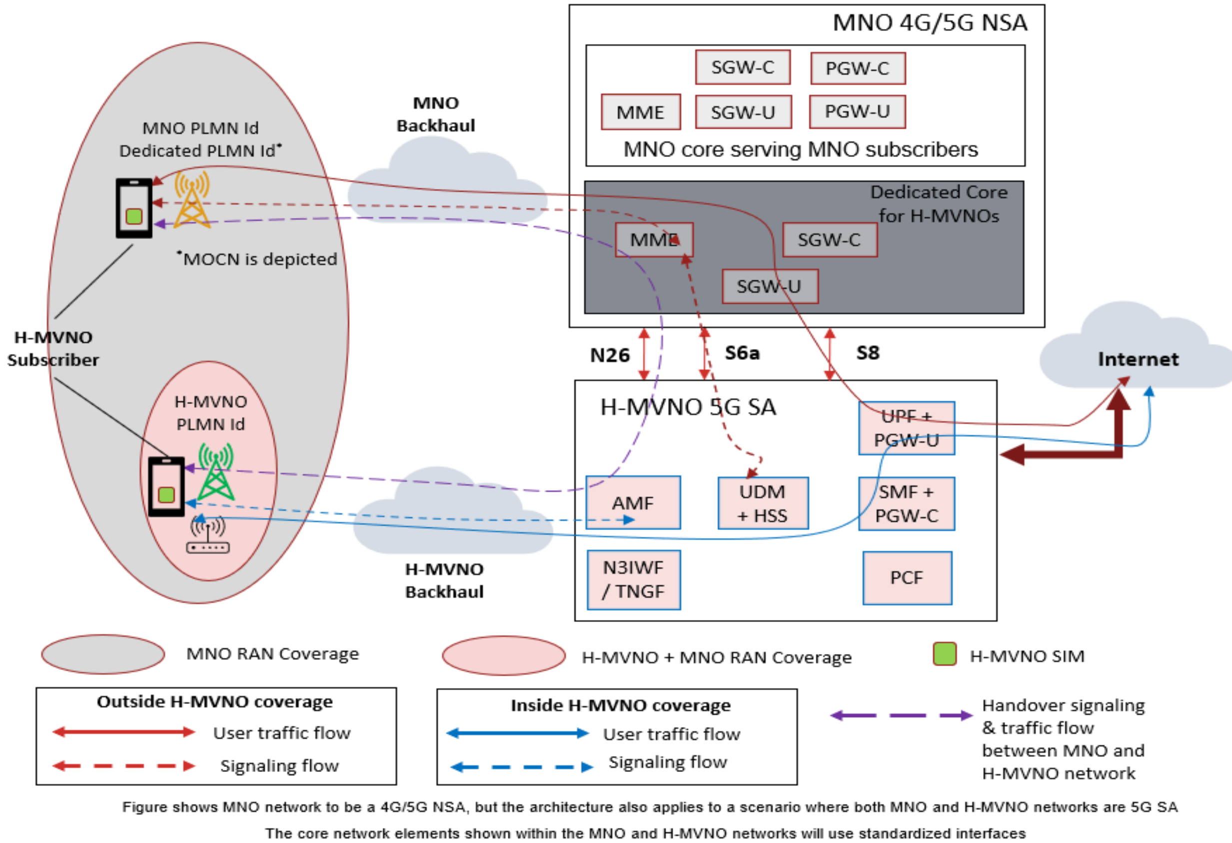

Figure 6: Architecture Option 5—Dedicated Core for H-MVNO

The dedicated core can be deployed and managed within the MNO network (as shown in Figure 6) or externally, depending on the MNO's operational policies. A key aspect of this architecture is that a single dedicated core can be shared across several H-MVNOs having an agreement with the MNO. The dedicated core would separate the traffic of each H-MVNO through the PLMN identity (part of the international mobile subscriber identity, IMSI) and route it to the appropriate anchor points in the H-MVNO home networks. The MME hosted within the dedicated core will perform a DNS query to select the SMF+PGW-C in individual H-MVNO networks, giving them full control over their subscribers' traffic.

Depending on the capabilities of the H-MVNO devices and the MNO access network, the dedicated core can be implemented using one of the following standards-based options.

Multi Operator Core Network (MOCN) specifications: In this option, the MNO access network broadcasts two PLMN IDs—one for its core network and one for the dedicated core. The dedicated core PLMN ID broadcast by the MNO is distinct from that used by the H-MVNOs in their home networks. The H-MVNO user devices are programmed to access the dedicated core PLMN ID when outside of H-MVNO access network coverage. As described previously, the dedicated core uses the home PLMN embedded in the IMSI to route the traffic to each H-MVNO network. The MOCN feature has been available since 3GPP Release 8 and is currently supported by most access vendors. Several advanced MOCN features, such as PLMN-specific configurations, parameters for access barring, handovers, and redirection, are likely to be available from access vendors, allowing for distinct handover settings for MNO and H-MVNO user devices. This can enable handover parameter configurations to be customized, facilitating handovers between MNO and H-MVNO networks that do not impact the handover operation and performance for MNO user devices.

- **Standardized 3GPP feature—Dedicated Core (DECOR) or Enhanced Dedicated Core (eDECOR):** Implementing the DECOR feature in the MNO core and access network redirects traffic to the dedicated core based on information received in the subscription profile from the H-MVNO HSS. eDECOR-aware user equipment provides the dedicated core network ID (DCN-ID) when it is accessing the MNO network, which uses it to route traffic to the dedicated core. A key advantage of this approach is that the MNO does not have to broadcast multiple PLMN IDs. However, MNO access and core networks need to support the DECOR redirection/routing capabilities to have H-MVNO users serviced by the core dedicated to the H-MVNOs. In addition, to isolate the handover configurations for MNO and H-MVNO devices, additional functionality will be required in the MNO access network. One standards-based approach is to tie custom handover configurations by using a standardized index called the RAT Frequency Selection Priority ID (RFSP ID). One limitation of DECOR, compared to MOCN, is that the MNO will be unable to configure separate access barring settings for H-MVNO user devices. It may not be critical, however, given that MNOs do not currently require separate access barring configurations for their MVNO user devices.

The selection of one of these options will be based on the capabilities of the MNO access and core infrastructure and the H-MVNO devices.

Note: These options can be viewed as precursors of the network slicing concept specified as part of 5G. In the MOCN option, the network slice identifier is the PLMN ID. In the DECOR/eDECOR option, the slice identifier is either the DECOR parameter specified in the user profile, or the dedicated core network identity (DCN-ID) provided by the device.

Table 2 compares the salient features of the inter-network handover and dedicated core architecture options.

TABLE 2: COMPARISON OF H-MVNO ARCHITECTURE OPTIONS 4 AND 5

Attributes	H-MVNO Single SIM Architectures	
	Option 4 (Inter-Network HO)	Option 5 (Dedicated Core)
Seamless handovers	✓	✓
Minimizes signaling traffic impact on MNO core serving MNO subscribers due to handovers	✗	✓
No additional complexity within the MNO network to support multiple H-MVNO networks	✗	✓

Though the dedicated core architecture solves issues related to seamless handovers, it does introduce the following operational overheads in terms of network planning and configuration.

- The MNO needs to enable either MOCN or DECOR to facilitate isolation of the signaling traffic and minimize signaling load (caused by potential ping-ponging between the MNO and H-MVNO networks) on the MNO core control functions.

- The MNO needs to verify interoperability between the MNO access network and the core dedicated for the H-MVNOs.[7]
- The H-MVNO needs to ensure interoperability of the N26 between the dedicated and the H-MVNO core networks.
- The MNO needs to configure H-MVNO-specific mobility parameters in its access network; the H-MVNO needs to configure MNO-specific mobility parameters.
- Support for additional interfaces for supporting voice calls and SMS (described in the following section).

3.2.3. Voice and SMS Services Implications

Voice and SMS services are expected to be an integral part of all mobile service plans; therefore, it is critical to evaluate the ability to support them in the context of architecture options 4 and 5. Voice and SMS services require additional architectural components in the mobile core network that are not required for data services. This additional functionality is required to support i) voice and SMS applications, ii) mobile number portability (MNP), iii) interconnection/ interwork with PSTN, and iv) emergency services as required by the local regulator.

Given the widespread deployment of voice over LTE (VoLTE), 3GPP has defined several ways to leverage it for enabling voice service over 5G NR. Voice services likely will be enabled using VoLTE until 5G deployments become more ubiquitous. 3GPP has specified redirection from the 5G network to the 4G network for voice sessions to facilitate use of VoLTE. One way to redirect is through handover at the time of the voice media setup procedure, and another way is through radio channel redirection. The method of deployment is left up to the MNO operators and will depend on their network capabilities and configurations.

Described below are several ways to facilitate voice and SMS services as part of architecture options 4 and 5 using MNO's LTE deployment.

3.2.3.1. Voice/SMS Services Architecture Option A

One option is for an H-MVNO to support voice and messaging services via its own or a partner's voice/messaging platforms, as shown in Figure 7. In addition to showing the architectural impact, Figure 7 also depicts voice and SMS data flows when the device is in the coverage region of H-MVNO+MNO and MNO-only networks.

i) The voice traffic flow after the redirection to the MNO network (i.e., when the user is inside the H-MVNO coverage) and/or when camped/connected to the MNO RAN (i.e., when the user is outside the H-MVNO network coverage) is depicted by the solid green line.

ii) The voice handover/redirection signaling flow when camped on the H-MVNO is depicted by the dashed purple line.

[7] Problems surrounding interoperability can be minimized by ensuring that the MME and the MNO radio access network is from the same vendor.

iii) The SMS traffic flow after the redirection to the MNO network (i.e., when the user is inside the H-MVNO coverage) and/or when camped/connected to the MNO RAN (i.e., when the user is outside the H-MVNO network coverage) is depicted by the dashed yellow line.

iv) The SMS traffic flow when camped/connected to the H-MVNO RAN is depicted by the solid yellow line.

In voice/messaging architecture option A, the mobile connection for voice and SMS is always anchored at the H-MVNO's UPF, irrespective of whether the UE is located within the coverage area of MNO or H-MVNO's RAN. One perceived disadvantage of this option is that H-MVNO will have to deploy the voice and SMS infrastructure and manage the additional functionalities around MNP, emergency calling and interconnection to the PSTN. Using a voice service partner capable of supporting mobile voice and messaging can overcome these drawbacks.

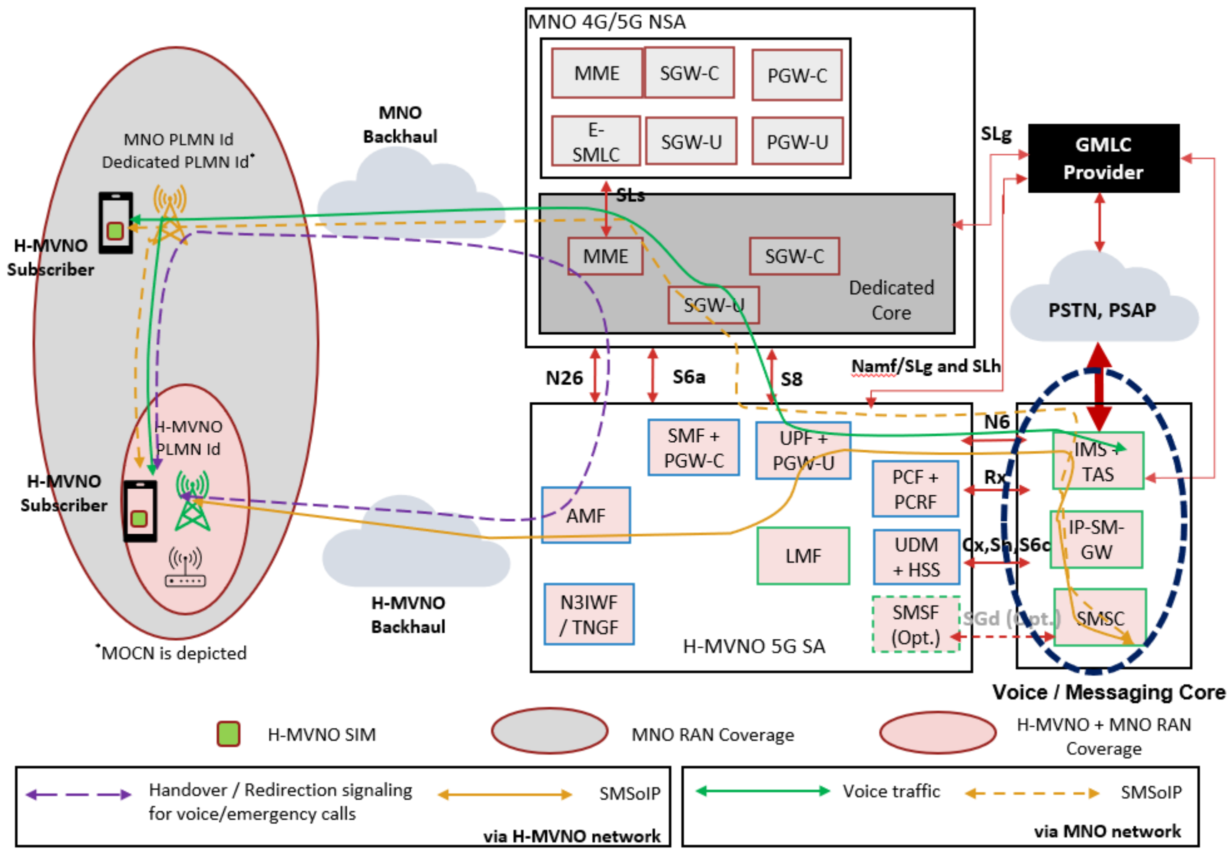

Figure depicts Single SIM Architecture (Option 5), but the voice option described is also applicable to Option 4*

Figure 7: Voice Architecture Option A for Single SIM Devices

An alternative to option A is to leverage MNOs' voice and messaging platforms (i.e., effectively, the MNO becomes their voice service partner). Given that all MNOs have a robust voice and SMS platform, this could be an attractive option for H-MVNOs, especially those who do not have the scale to deploy their own. As described below, there are two ways to leverage MNOs' infrastructure—voice/messaging architecture options B and C.

3.2.3.2. Voice/SMS Services Architecture Option B

As shown in Figure 8, in voice/messaging architecture option B, MNO's voice/SMS services platforms are used while the voice subscription and related credentials are configured in the H-MVNO UDM+HSS. In this architecture, additional 3GPP interfaces between the MNO's IMS, IP-SM-GW, and SMSC and the H-MVNO's UDM+HSS, PCF+PCRF, and SMSF are also configured as depicted in Figure 8. The MNO's voice and SMS platforms will use these interfaces to authenticate/authorize the user and retrieve the subscription and registration status/info (using the MCC+MNC from the IMSI of user device). This will ensure successful registration for voice and SMS services within the MNO's IMS and IP-SM-GW. It will also ensure proper forwarding of the incoming calls and text messages, irrespective of whether the user is camped on H-MVNO or MNO radio access network (RAN). Like in option A, the voice and SMS data connection will always be anchored in H-MVNO's UPF. The voice traffic and SMSs will be transferred from an H-MVNO's UPF to the MNO's IMS voice and SMS platforms through a secure data connection. The MNO's IMS will interface with the H-MVNO's PCF+PCRF (either directly or via a local MNO PCRF) through the Rx interface to set up dedicated bearers for the voice media traffic.

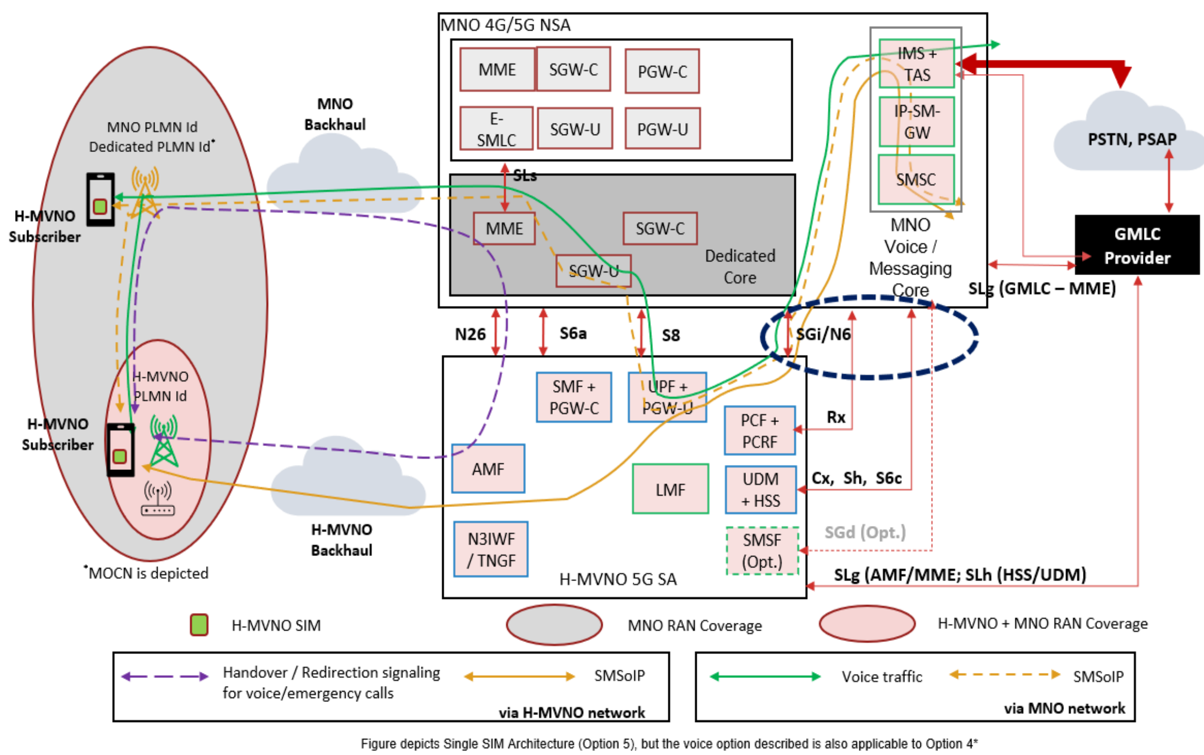

Figure 8: Voice Architecture Option B for Single SIM Devices

Like option A, Figure 8 depicts the voice and traffic flows related to voice handover/redirection signaling (dashed purple), voiced traffic (solid green), and SMS flows (solid and dashed yellow).

User Connected to H-MVNO RAN

The voice call will be initiated, then redirected or handed off to the MNO's RAN. If an emergency call is initiated by the user, it will be redirected to be initiated via the MNO's network. The data anchor will continue to be the H-MVNO's UPF via the dedicated core. The voice signaling and media will be routed from the H-MVNO's UPF to the MNO's IMS.

The text messages will not result in redirection or handover to the MNO's RAN. The text messages will be forwarded via the H-MVNO's UPF to the MNO's IP-SM-GW via the IMS, which will then forward it to the SMSC for delivery to the target user. If a 5G control plane (NAS) is used to transfer the SMS (in the event IP-SM-GW is unavailable), then an additional interface between the MNO's SMSC and the H-MVNO's SMSF will have to be configured.

One aspect of voice and text services is the ability to accurately determine the user location during emergency calls and texting. The Gateway Mobile Location Centre (GMLC) must be able to query the serving control node (AMF/ dedicated MME) from the UDM+HSS to request the location of the user device from the serving control node. The MNO's GMLC partner must be capable of routing the query to the H-MVNO's network. Alternatively, the MNO network must be able to forward or redirect the query from the GMLC provider to the H-MVNO's UDM+HSS.

For emergency voice calls, the dedicated MME will retrieve the location from the MNO E-SMLC to deliver it to the GMLC. However, for text to 911, the H-MVNO will have to deploy its own LMF in its core as the user will not redirected to the dedicated MME for text service while in the H-MVNO coverage.

User Connected to MNO RAN

Even when the user is in the coverage of the MNO's RAN, it will continue to be anchored in the H-MVNO's UPF via the dedicated core (architecture option 5) or through a direct interface (architecture option 4). The voice call and text will be routed back to the IMS via the H-MVNO's UPF to the MNO's IMS platform. IMS will continue to interact with the H-MVNO's PCF+PCRF to set up dedicated bearers for the user traffic. Similarly, SMSC will continue to query the UDM+HSS to identify the serving node (either SMSF or the IP-SM-GW) so that the incoming text can be sent to the serving control node for delivery to the user's device.

The location retrieval by GMLC for emergency calls will be performed in the same way as described above. The text to 911 will be delivered via the dedicated core and the location retrieved using dedicated MME and MNO's E-SMLC

3.2.3.3. Voice Option C

If the H-MVNO operator is using a separate ISIM instead of deriving the IMPU from the USIM, one could also consider provisioning the ISIM in a separate HSS located within the MNO network or in the dedicated core as shown in voice architecture option C in Figure 9. This will allow the MNO's IMS functions to authenticate locally without having to interact with the H-MVNO HSS. Furthermore, if the IMS APN is anchored in the MNO's PGW, it will also eliminate interaction between the MNO's PCRF and the H-MVNO's UPF for the setup of the dedicated bearer.

Like options A and B, Figure 9 depicts the voice/SMS signaling and traffic flows when the device is in the coverage of MNO and H-MVNO networks. The color scheme used for the traffic flows is identical to that for options A and B.

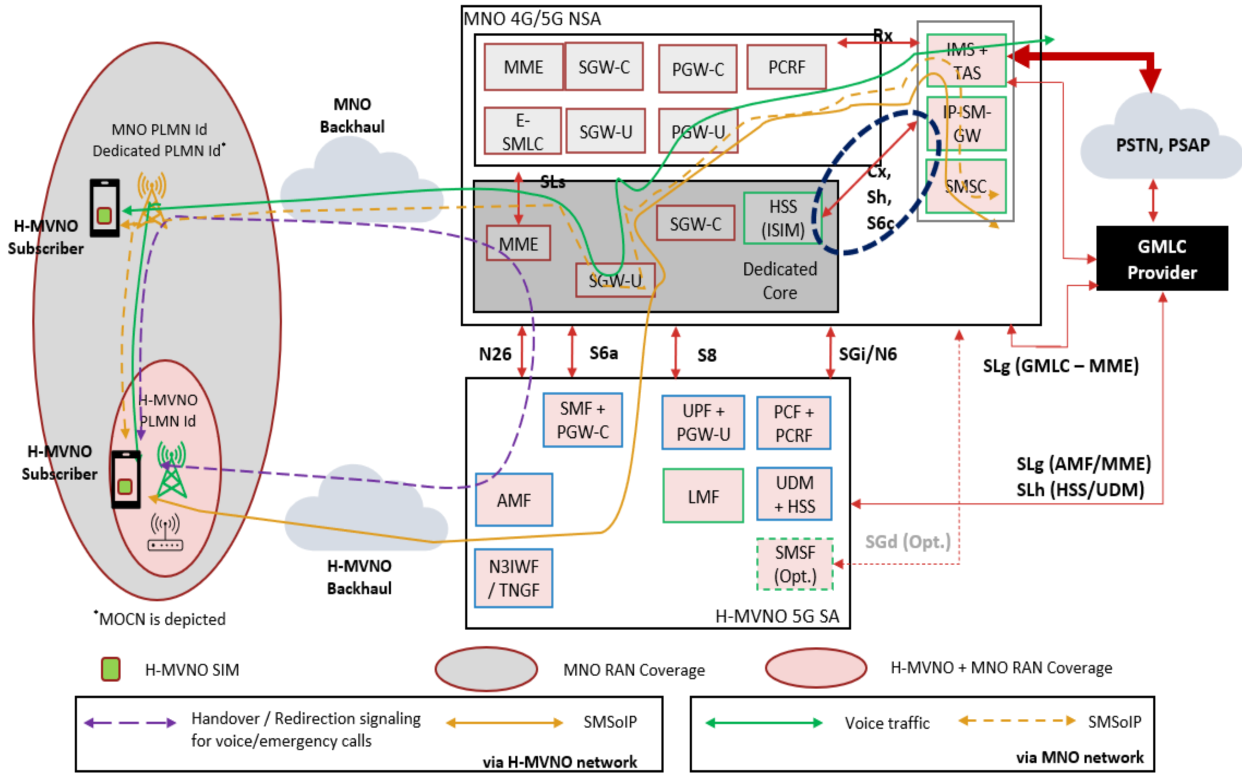

Figure depicts Single SIM Architecture (Option 5), but the voice option described is also applicable to Option 4*

Figure 9: Voice Architecture Option C for Single SIM Devices

One drawback of anchoring IMS APN in the MNO's PGW is that if the MNO has deployed 4G EPC core only, then the dedicated core needs to incorporate an interworking function to translate HTTP interface based 5G session control signaling messages received from the H-MVNO AMF into GTP-C based 4G EPC signaling messages to successfully set up the MNO's PGW as the anchor. To circumvent the need for this new interworking function, a dedicated UPF for voice could be deployed as part of the dedicated core.

In this architecture, the SMSC will still have to interact with the H-MVNO's UDM+HSS to determine the SMS serving node(s) (SMSF or IP-SM-GW). In addition, the GMLC provider will still have to interact with the H-MVNO's UDM+HSS to query the serving node (AMF/MME) to retrieve the location of the user device during text to 911 sessions while the UE is connected via the H-MVNO's RAN. Like option B, H-MVNO will have to deploy the LMF in its core to determine user location during text to 911.

Table 3 below summarizes the pros and cons for the above voice architecture options.

Table 3: Benefits and Impacts of Various Voice Architecture Options

Voice Options	Benefits	Impacts
Option A	• No coordination required with the MNO	• Requires H-MVNO to deploy IMS, TAS and SMSC (or partner with a voice/SMS service provider). • H-MVNO (or its voice partner) will have to support MNP, interconnectivity with PSTN, emergency calling, and associated location requirements. • H-MVNO (or its voice partner) needs to enable interconnection with PSTN and for outbound roamers.
Option B	• H-MVNO does not have to deploy voice and SMS platforms—IMS, TAS, IP-SM-GW, and SMSC. (SMSF may be required to facilitate delivery of SMSs when IP-SM-GW is unavailable.)	• Coordination is required with the MNO to enable interfaces between MNOs' IMS and SMS platforms and H-MVNOs' 5G core systems. • H-MVNO will still have to deploy location management function (LMF) (i.e., location server) to deliver location for text to 911 initiated by the user over H-MVNO's network. • MNO needs to enable forwarding/redirection of queries from GMLC provider to the appropriate function in the H-MVNO network and the dedicated core network.
Option C	• H-MVNO does not have to deploy voice and SMS platforms—IMS, TAS, IP-SM-GW, and SMSC • Fewer interfaces required between the MNO and H-MVNO networks compared to option B	• Dual provisioning required (USIM to be provisioned in H-MVNO network, while ISIM to be provisioned in MNO network). • If MNO has not deployed a combined 4G/5G core, an interworking function is required to translate session management messages. • Interface between SMSC and HSS+UDM will still be required to retrieve the serving SMSF if it is deployed in the H-MVNO network and not statically configured. • H-MVNO will still have to deploy LMF (i.e., location server) to deliver location for text to 911 initiated by the user over H-MVNO's network. • MNO needs to enable forwarding/redirection of queries from GMLC provider to the appropriate function in the H-MVNO network and the dedicated core network.

4. Conclusion

CableLabs recognizes the evolving mobile industry landscape driven by the introduction of 5G and the availability of new and innovative spectrum options. Many of our members are either MNOs supporting MVNOs or MVNOs looking to deploy their mobile networks. Globally, MVNOs have been around for some time, with varying degrees of control being made available to them. As regulators are also looking to facilitate increased competition, MVNOs are expected to play an integral part in that effort.

In a data-centric connectivity environment, because of continually growing usage and a lack of control over subscribers, MVNO arrangements have typically constrained the MVNOs' mobile service plans. As the data usage continues to grow, it is generally recognized within the industry that data offloading onto Wi-Fi and/or own mobile network is necessary for the success of an MVNO.

This paper presents evolutionary converged MVNO architectural blueprints that will allow CableLabs members who are MVNOs or are considering becoming one to converge their wireless connectivity service and maximize the offload onto their own mobile and Wi-Fi deployments while improving MVNO user experience. They will also allow an MNO member to differentiate itself from its competitor by offering greater flexibility to its MVNO customers and creating a win-win strategy for itself and its wholesale partners (MVNO). **Error! Not a valid bookmark self-reference.** and Table 5 summarize a comparative assessment of the different architecture options.

Table 4: Comparative Assessment of Architecture Options

Attributes	Dual SIM Architectures			Single SIM Architectures	
	DSDS	Evolved DSDS		Inter-Network HO	Dedicated Core
	Option 1	Option 2	Option 3	Option 4	Option 5
Support for dual SIM devices	✓	✓	✓	✓	✓
Support for single SIM devices	✗	✗	✗	✓	✓
No need for customization on the device to manage network transition	✗	✗	✗	✓	✓
Enhanced user experience through full data visibility, uniform policy, and subscription management	✗	✓	✓	✓	✓
Maximized use of H-MVNO access network when available without a connection manager client in the device	✗	✓	✓	✓	✓
Seamless low-latency mobility	✗	✗	✗	✓	✓
No interfaces needed between the two networks	✓	✗	✗	✗	✗
Minimizes signaling traffic impact on MNO core serving MNO subscribers due to handovers	✓	✓	✓	✗	✓
Use of standardized ATSSS solution for improved session continuity across all accesses	✗	✗	✓	✓	✓
No custom configuration of mobility related parameters in MNO's access network	✓	✓	✓	✗	✗

Table 5: Comparative Assessment of Single SIM Architecture Voice Options

Attributes	H-MVNO Single SIM Architectures (Voice)		
	Option A	Option B	Option C
No coordination required for enabling interfaces between MNO IMS and H-MVNO network	✓	×	×
No need for H-MVNO to host voice and SMS platforms	×	✓	✓
No need for additional interface to authenticate H-MVNO subscribers	✓	×	✓
No need for dual provisioning (USIM and ISIM separately provisioned across the two networks)	✓	✓	×

The blueprints presented in this paper are standards based and evolutionary in nature. Members could start with the evolved DSDS option, then evolve to implement full mobility between their and MNO deployments by using the dedicated core option. The dedicated core architecture allows MNOs to isolate their infrastructure and customers from any excessive MVNO-related signaling or user traffic resulting from mobility between the MNO and MVNO access networks.

For dual SIM architecture options, voice is always carried over the MNO SIM utilizing the MNO network. This dual SIM approach can also be considered as an alternative to voice options A-C for architecture options 4 and 5 whereby N26 is used to enable low-latency data-centric applications (e.g., VR/AR applications) while the voice/SMS is supported using the second SIM via the MNO network. For single SIM devices requiring voice/SMS support, one of the voice architecture options will have to be considered.

Members could leverage the architecture options discussed in the paper to converge policy and subscription infrastructure across all access networks (MNO, MVNO, Wi-Fi) and enable a seamless user experience to their customers irrespective of the underlying wireless access technology.

Abbreviations

3GPP	3rd Generation Partnership Project
AMF	access and mobility management function
APN	access point name
AS	access stratum
ATSSS	access traffic steering, switching, and splitting
DCN-ID	dedicated core network identity
DECOR	dedicated core
DNS	domain name server
DSDA	dual SIM dual active
DSDS	dual SIM dual standby
eDECOR	enhanced dedicated core
EPC	evolved packet core
eSIM	embedded SIM
GMLC	gateway mobile location center
GTP-C	general packet radio service tunnelling protocol control plane
GTP-U	general packet radio service tunnelling protocol user plane
GW	gateway
H-MVNO	hybrid mobile virtual network operator
HR	home routed
HSS	home subscriber server
IMS	Internet protocol multimedia subsystem
IMSI	international mobile subscriber identity
IP-SM-GW	internet protocol-short message-gateway
KPI	key performance indicator
LMF	location management function
MCC	mobile country code
MME	mobility management entity
MNC	mobile network code
MNO	mobile network operator
MNP	mobile number portability
MOCN	multi-operator core network
MVNO	mobile virtual network operator
NAS	non-access stratum
NSA	non-standalone
OTT	over-the-top
PGW-C	packet gateway control plane
PGW-U	packet gateway user plane
PLMN	public land mobile network
PSAP	public safety answering point

PSTN	public switched telephone network
RAN	radio access network
RAT	radio access technology
RFSP	radio access technology/frequency selection priority
RRM	radio resource management
SA	standalone
SCTE	Society of Cable Telecommunications Engineers
SIM	subscriber identity module
SMF	session management function
SMS	short message service
SMSC	short message service center
SMSF	short message service function
SPID	selection priority identity
TAC	tracking area code
TCC	text control center
UDM	unified data management
UE	user equipment
UPF	user plane function

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