Latency Measurement for Apple Devices with DSDS Capability for MVNO Carrier Deployment

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Abstract:
Modern smartphone devices support Dual SIM Dual Standby (DSDS), which allows multiple operator subscriptions to coexist on a single device while sharing a common radio hardware. This capability has become essential for Mobile Virtual Network Operator (MVNO) deployments that integrate nationwide coverage from a host Mobile Network Operator (MNO) with localized infrastructure operated by Multiple System Operators (MSOs) using shared spectrum such as the Citizens Broadband Radio Service (CBRS) band [1], [2]. The CBRS spectrum is mainly used for Data offload to reduce cost. In such hybrid deployments, any smartphone supporting DSDS mode can transition its primary data connectivity from the MNO eSIM to the MSO eSIM when entering MSO coverage areas. Although modern cellular systems support Always-On Packet Data Network (PDN) or Protocol Data Unit (PDU) sessions, which reduce session establishment overhead during mobility events [3], DSDS devices still experience service interruption due to radio resource switching and subscription activation constraints [4].

This paper presents a latency analysis framework for Apple devices operating in MVNO deployments that integrate host MNO networks with MSO private localized CBRS networks. In order to calculate latency assumption is made that Always-On PDN/PDU sessions are implemented to maintain uninterrupted data connectivity. This analysis is useful for comparing the device performance across different DSDS supporting models and different iOS versions to improve efficiency and performance of the devices.

The paper presents system architecture, signaling flows, latency component decomposition, and measurement methodology along with latency estimation tables. The proposed framework provides practical guidance for evaluating network performance in DSDS-enabled MVNO deployments using private 5G networks.

Keywords: DSDS, eSIM, MVNO, CBRS, Apple devices, handover latency, PDU session, mobile offload, subscription switching, 5G registration, PDU session, mobility latency, service interruption.

I. Introduction

Modern smartphones today often support more than one cellular subscription using Dual-SIM Dual-Standby (DSDS) technology. In this setup, the device stays connected to two different operator networks while using a single modem and RF system. On Apple devices, this is usually done through eSIM, which allows carrier profiles to be downloaded and managed remotely instead of using physical SIM cards [5].

The use of eSIM has made it easier for Mobile Virtual Network Operators (MVNOs) to build flexible network solutions. Many MVNOs now combine wide-area coverage from a primary Mobile Network Operator (MNO) with smaller, localized networks run by Multiple System Operators (MSOs). In the U.S., these MSO networks often use CBRS spectrum to provide LTE or 5G coverage in specific areas, helping to improve capacity and reduce reliance on the macro network [6]. In this type of setup, a device can move between the MNO and MSO networks based on signal quality, operator rules, or cost considerations. For instance, when a user enters a CBRS coverage area, the device may switch its data connection from the MNO eSIM to the MSO eSIM.

That said, DSDS devices have some limitations during this kind of switching. Since both subscriptions share the same RF hardware, only one can actively handle data at a time. When the device switches from one subscription to another, the modem must pause the current connection, retune the RF to a new frequency, and activate the second SIM profile. This introduces a short delay, which users may notice as a pause or disruption in services like video streaming, messaging, or video calls [7].

Modern networks try to reduce this delay by using Always-On PDN or PDU sessions, which keep the data session active even during mobility events. This avoids having to completely set up a new data session every time the device switches networks. Even with this improvement, the device still needs to go through RF switching, network access setup, authentication, and path updates before data starts flowing again.

Most traditional methods for measuring handover performance focus on signaling events, such as RRC messages or session setup procedures. While these are useful from a network perspective, they don't fully capture what the user *experiences*. In this paper, we take a different approach by looking at TCP traffic at the application level. We define handover latency as the time between the last application packet received over the MNO network and the first packet received over the MSO network. This provides a more direct and practical way to measure the real impact of handover on user experience in DSDS devices.

II. BACKGROUND AND PROBLEM STATEMENT

2.1 Evolution of MVNO Deployments with CBRS

Mobile Virtual Network Operators (MVNOs) typically deliver wireless services by utilizing the infrastructure of an established Mobile Network Operator (MNO). Most MVNOs does not own radio spectrum but they make use of the host network (host MNO) to provide nationwide coverage. Although this approach simplifies service deployment, it can limit the MVNO's ability to adjust network performance in specific locations such as indoor environments, dense urban areas, and enterprise campuses. Because they must depend on host MNO network policies and control to provide best experience to their users.

The introduction of the Citizens Broadband Radio Service (CBRS) in the 3.5 GHz band has created new opportunities for hybrid wireless deployments that combine macro cellular networks with localized private or shared radio infrastructure. This shared spectrum framework allows operators such as Multiple System Operators (MSOs) to provide localized cellular coverage in residential, enterprise, and venue environments. MVNOs can set up their own localized infrastructure to offload data from host MNO to their own network for cost optimization and improving network performance in highly populated areas such as downtown locations or sports arena etc.

2.2 Dual-SIM Dual-Standby (DSDS) Devices

Modern smartphones increasingly support Dual-SIM Dual-Standby (DSDS) capability, allowing users to maintain two active cellular subscriptions simultaneously. In traditional DSDS implementations, the device contains two SIM profiles—typically a combination of a physical SIM and an embedded SIM (eSIM) or two eSIM profiles—but both subscriptions share a single modem and radio transceiver. Because the radio hardware is shared, the device alternates between the two subscriptions using time-multiplexed radio access. User can select different sim for either for Voice/SMS/MMS or Data services and at a time only one sim will be used to Data service and user has option to select sim for Data.

In MVNO architectures that utilize CBRS, the traditional macro network provided by the MNO offers wide-area mobility and baseline connectivity, while the MSO-operated CBRS network provides localized coverage and additional capacity or Data offload for cost optimization. DSDS devices may use separate subscriptions for each access network. For example, the primary subscription may connect to the nationwide MNO network while the secondary subscription enables connectivity to a CBRS network deployed by the MSO. When the user enters an area covered by the CBRS network, the device switches the active data connection to the MSO network based on the switching logic. However, mobility between these heterogeneous networks introduces new challenges in maintaining session continuity and minimizing service interruption.

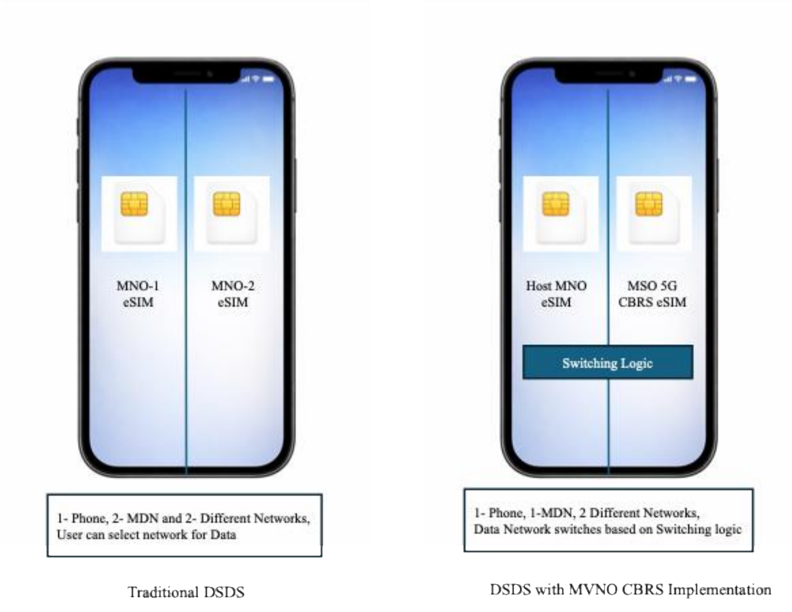

Figure 1: Traditional DSDS vs DSDS with MVNO CBRS Implementation

2.3 System Architecture for MNO–MSO CBRS MVNO Deployment

In this architecture, the primary subscription on the MNO network supports voice services using VoLTE or VoNR along with SMS signaling through the operator’s core network. The MNO network provides wide-area coverage and maintains control-plane connectivity for telephony services. At the same time, a second eSIM profile connected to the MSO private 5G network can be used primarily for data services. When the device enters the MSO coverage area, data sessions can transition from the MNO network to the MSO network to take advantage of localized high-capacity spectrum and enterprise network resources.

To enable seamless data continuity, the device can maintain an Always-ON PDU session anchored in the 5G core. When the device detects the MSO radio access network, the device’s switching logic or policy engine may initiate a data path transition from the MNO access network to the MSO access network while maintaining the application session. During this process, voice calls and SMS messaging continue to use the MNO subscription because telephony services remain anchored in the MNO core network.

This separation of services allows the device to leverage the strengths of both networks:

- MNO network: voice, SMS, wide-area reliability
- MSO private 5G network: high-throughput localized data connectivity

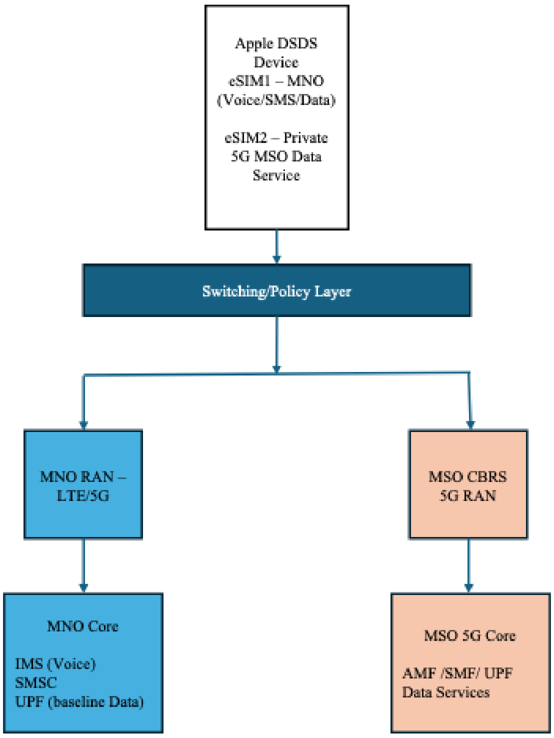

Figure 2: MNO-MSO CBRS – MVNO Deployment

2.4 Mobility and Service Continuity Challenges

Keeping services running smoothly during mobility is critical for today's mobile applications. Services like video calls, VoLTE, and multimedia messaging depend on stable and continuous connectivity to deliver a good user experience. Even a short break in data flow can lead to visible issues such as frozen video, audio glitches, or even dropped calls.

Within a single operator's network, mobility is usually handled through well-defined handover procedures. These allow the device to move from one cell to another without interrupting active sessions. The process is coordinated between base stations and the core network so that data sessions continue with minimal packet loss.

However, moving between an MNO macro network and an MSO CBRS network is more complex. In many cases, these networks may use different radio systems or core network setups. Because of this, the device often has to go through multiple steps during the transition, such as:

- Detection of coverage changes and policy-based network selection
- Switching the active subscription within the DSDS modem
- Establishing a new radio access connection with the target network
- Performing network registration or attach procedures
- Re-establishing the Always-ON PDU session or default bearer
- Re-registering with the IP Multimedia Subsystem (IMS) for voice and messaging services
- Each of these steps introduces additional delay that can impact application-level performance [8].

2.5 Always-ON PDU Session

In 5G Standalone (SA) networks, devices are expected to stay connected so that applications like video calls, messaging, and cloud services can work without interruption. The Always-ON PDU session helps achieve this by keeping a data session active between the device and the core network, even when the device is not actively sending or receiving data.

Since the session is already in place, the device does not need to set up a new connection every time data transfer starts. This reduces delay and improves responsiveness, especially during mobility events [2].

According to 3GPP specifications, a default PDU session can be created automatically when the device registers with the network. Once established, the session can remain active based on operator policies, allowing the device to quickly resume data transfer whenever needed [2][3]. This is particularly useful when devices move between different types of networks, such as public cellular networks and private 5G deployments using CBRS spectrum [1].

For DSDS devices, including modern smartphones, Always-ON PDU sessions help maintain continuity when switching between subscriptions. Because the IP session remains active in the core network, the device can resume data transfer more quickly after switching. This reduces service interruption and helps applications recover faster [2][9].

2.6 Problem Statement

In MVNO deployments that incorporate CBRS-based access networks, the mobility process is influenced by multiple factors including radio access procedures, DSDS modem scheduling constraints, core network signaling, and application-layer recovery mechanisms.

This paper addresses the problem of quantifying the end-to-end latency experienced during mobility events between MNO macro networks and MSO CBRS networks in DSDS-enabled devices operating in MVNO environments with Always-ON PDU session support.

The analysis focuses on four practical service scenarios that commonly occur in real-world deployments:

- Live data session (Live Streaming video or Video call) while moving from MNO macro coverage to MSO CBRS coverage.
- VoLTE call with simultaneous data usage while in MSO coverage area.
- Mobile-Originated (MO) and Mobile-Terminated (MT) SMS events occurring during an active Video call session while in MSO coverage area.
- Mobile-Originated (MO) and Mobile-Terminated (MT) MMS events occurring during an active Video call session while in MSO coverage area.

For each scenario, the study develops a latency calculation framework based on measurable device and network events. The analysis incorporates delays introduced by DSDS modem behavior, radio access procedures, core network signaling, Always-ON PDU session handling, and application-layer session recovery. By modeling these components, the paper aims to provide a systematic approach for estimating user-visible service interruption during mobility transitions in CBRS-enabled MVNO deployments.

III. Network Transition Flow

The user-visible “handover” from MNO data to MSO data is usually not a classic single-core make-before-break radio handover. In practice, it behaves more like a data-line switch plus access setup plus PDU session readiness on the MSO side, while voice/IMS can remain anchored on the host MNO line. That is consistent with Apple’s DSDS behavior and with 5GS session-management architecture, where registration, NAS session management, and PDU session establishment are separate procedures defined across TS 23.501, TS 23.502, and TS 24.501 [10]. Apple also documents geofence-based activation for private cellular networks and notes that geofence-triggered SIM switching can take a few minutes, so the geofence radius should be set slightly larger than the actual private-network coverage area. [11]

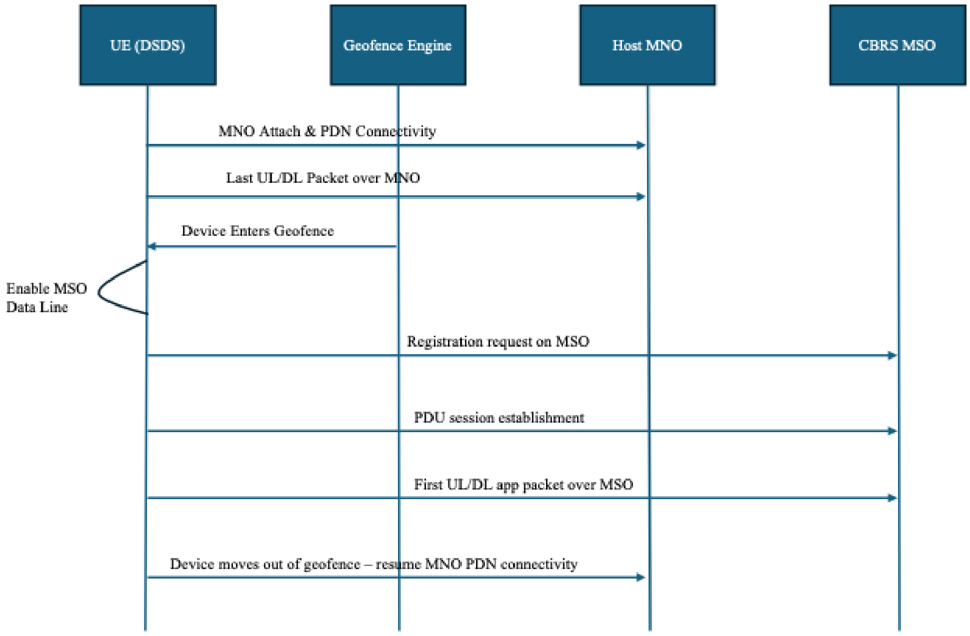

Figure 3: Network Transition flow with Always ON PDU [2][9]

IV. Use Cases for latency Calculation

4.1 Live Data Session while moving from MNO macro coverage to MSO coverage

A user is on Facetime video call while moving from MNO macro coverage area to MSO CBRS coverage. Always ON PDU is enabled but may require session re-establishment depending on architecture. Device is expected to select either MNO or MSO network for data offload on defined Hand in/out threshold under defined geofence. If device is moved to MSO CBRS coverage area, data will offload to MSO network, during this switch there should be minimal interruption.

Latency during mobility is defined as the user-visible service interruption time observed at the application layer. In this work, handover latency is defined using TCP packet timing. This metric represents the actual interruption observed by application layer. Run the multiple iterations of the scenarios based on requirement and calculate the final latency.

TCP based Latency definition –

$L_1 = t_{\text{MSO, first DL app pkt}} - t_{\text{MNO, last DL app pkt}}$

Test Run	Examples of Hand-out duration from MSO to MNO
1	0.5 seconds
2	0.4 seconds
3	0.4 seconds
4	0.2 seconds

Table1: Sample Test Runs for Hand-out Latency

Typical engineering budget
If the geofence has already fired early and the SIM/policy switch is done before RF edge entry, the network-side interruption can often be modeled in the hundreds of milliseconds to low seconds range. If the geofence fires late, Apple notes the SIM switch itself may take minutes, which dominates everything else.[11]

4.2 Voice call with live data session in MSO coverage

In this scenario, user initiates or receives Voice call when there is live data session on MSO data path. When call received or dialed, the voice and data both moves to MNO. When moving the data path to MNO, the live data session will get paused as the voice call is being set up. Once the call is connected user need to manually resume data session. After ending voice call the data path will switch back to MSO and auto resumed.

In this scenario there will be two latencies – Hand-out Latency (MSO to MNO) and Hand-in Latency (MNO to MSO). Run the multiple iterations of the scenarios based on requirement and calculate the final latency.

TCP based Latency definition

Hand-out Latency –
$L_{\text{Hand-out}} = t_{\text{MNO, first DL app pkt}} - t_{\text{MSO, last DL app pkt}}$

Hand-in Latency -
$L_{\text{Hand-In}} = t_{\text{MSO, first DL app pkt}} - t_{\text{MNO, last DL app pkt}}$

Test Run	Examples of Call Set up (Hand-out duration from MSO to MNO)	Examples of Call End (Hand-In duration from MNO to MSO)
1	0.5 seconds	0.3 seconds
2	0.4 seconds	0.2 seconds
3	0.4 seconds	0.4 seconds
4	0.2 seconds	0.3 seconds

Table 2: Sample Test Runs for Call based Hand-In and Hand-Out Latency

4.3 MO/MT SMS during video call in MSO coverage

In this scenario, user sends/receives SMS during the live facetime video call in MSO coverage area. But during the SMS is sent or received, data path should not switch to MNO. Also, when SMS is sent or received there should be minimal interruption in video call. Run the multiple iterations of the short SMS and long SMS based on requirement and calculate the final latency.

TCP based Latency definition

$$L_{\text{App Based Latency}} = t_{\text{MSO first restored DL packet after SMS sent/received}} - t_{\text{MSO last normal DL packet before SMS sent/received}}$$

Test Run	Examples of MO SMS (MSO data interruption)
1	0.1 seconds
2	0.2 seconds
3	0.1 seconds
4	0.1 seconds

Test Run	Examples of MT SMS (MSO data interruption)
1	0.2 seconds
2	0.1 seconds
3	0.2 seconds
4	0.2 seconds

Table 3: Sample Test Runs for SMS based MSO data interruption

4.4 MO/MT MMS during video call in MSO coverage

In this scenario, user sends/receives MMS during the live facetime video call in MSO coverage area. During the MMS is sent or received, data path should not switch to MNO. Also, there should be minimal interruption in video call. MMS is different from SMS because it is mainly a packet-data transaction involving messaging infrastructure and media upload/download, so it competes more directly with the ongoing video call session on the data path.

TCP based Latency definition

$$L_{\text{App Based Latency}} = t_{\text{MSO first restored DL packet after MMS burst}} - t_{\text{MSO last DL packet before MMS burst}}$$

Test Run	Examples of MO MMS (MSO data interruption)
1	0.3 seconds
2	0.4 seconds
3	0.2 seconds
4	0.4 seconds

Test Run	Examples of MT MMS (MSO data interruption)
1	0.3 seconds
2	0.2 seconds
3	0.4 seconds
4	0.5 seconds

Table 4: Sample Test Runs for MMS based MSO data interruption

V. SUMMARY TABLE

Following is summary table for all the scenarios and how it impacts the actual user experience using MVNO carriers with CBRS network deployment.

Scenario	Main Interruption Source	Suggested Latency Expression	Likely User visible impact
Live data MNO → MSO	Geofence + data-line switch + attach/registration + PDU setup	$L=t_{\text{first DL on MSO}}-t_{\text{last DL on MNO}}$	Data freeze, app stall, stream rebuffer
Voice call + live data in MSO area	Same as above + DSDS voice/data coordination	$L_{\text{Hand-out}}=t_{\text{MNO, first DL app pkt}}-t_{\text{MSO, last DL app pkt}}$ $L_{\text{Hand-In}}=t_{\text{MSO, first DL app pkt}}-t_{\text{MNO, last DL app pkt}}$	Voice OK, data app brief freeze, stops and sometime need to manually resume
SMS + Video in MSO area	SMS signaling + DSDS coordination	$L_{\text{video-gap}}=t_{\text{restore}}-t_{\text{pre-SMS last}}$	Small jitter spike / brief video call glitch
MMS + FaceTime in MSO area	Packet-data contention during media transfer	$L_{\text{video-gap}}=t_{\text{restore}}-t_{\text{pre-MMS last}}$	Bigger video call freeze than SMS

Table 5: Summary Table

VI. Experimental Measurement Method

6.1 Recommended measurement tools:

- **Wireshark**
- tcpdump
- Apple device diagnostic logs

6.2 Measurement points:

- TCP packet timestamps
- network registration events
- PDU session establishment logs

VII. CONCLUSION

This paper presented a latency analysis framework for Apple devices with DSDS capability operating in MVNO deployments utilizing private 5G CBRS networks. A TCP packet-based measurement model was proposed to quantify application interruption during network transitions.

The analysis covered four operational scenarios including live data handover, voice and data concurrency, SMS messaging, and MMS delivery. Latency estimation tables and architectural diagrams were provided to illustrate the performance characteristics of DSDS mobility.

The proposed methodology can be used by network operators and device vendors to evaluate the performance of MVNO deployments integrating macro cellular networks and private CBRS infrastructure. This methodology can be used to compare and evaluate the OS and Phone performance for each OS upgrade and across different CBRS supporting phone models.

Future work will include real-world field measurements and AI-based network optimization techniques for DSDS mobility.

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