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Multi-SIM support in 5G Evolution: Challenges and Opportunities

O. Vikhrova, S. Pizzi, A. Terzani, L. Araujo, A. Orsino, G. Araniti

Abstract—Devices with multiple Subscriber Identification Modules (SIM)s are expected to prevail over the conventional devices with only one SIM. Despite the growing demand for such devices, only proprietary solutions are available so far. To fill this gap, the Third Generation Partnership Project (3GPP) is aiming at the development of a unified cross-platform solutions for multi-SIM device coordination. This paper extends the technical discussion and investigation of the 3GPP solutions for improving Mobile Terminated (MT) service delivery to multi-SIM devices. Implementation trade-offs, impact on the Quality of Service (QoS), and possible future directions in 3GPP are outlined.

I. INTRODUCTION

As smartphones and services became more affordable, their users have tended to use different mobile subscriptions (i.e., SIM cards) for travel, business, and personal needs. For example, the total number of SIM connections worldwide has exceeded the global population while the number of unique subscriptions make only 60% of the population [1]. By that time, mobile devices that accommodate more than one SIM card, also known as dual-SIM devices, have gained popularity, especially in countries with uneven coverage and in-country roaming. With the advent of embedded SIM (eSIM) [2], managing multiple mobile subscriptions within a single device has become more agile and user-friendly. The eSIM technology allows customers to install many eSIM profiles and select between the subscriptions at will via a software menu, although only one profile can be active at any given time.

The introduction of eSIM facilitates the global adoption of multi-SIM devices [3]. The technology has been adopted by all leading smartphone manufacturers, including Apple, Samsung, and Huawei. Since the addition and change of Mobile Network Operator (MNO)s became easier and faster, mobile operators expect substantial revenue from providing eSIM and improving dual-SIM user's experience [4].

With multiple subscriptions, MT services, such as voice calls, Short Message Service (SMS), and emergency notifications from different networks risk to overlap and fail to reach the user. Therefore, service reception at multi-SIM devices may require specific software and protocol enhancement on User Equipment (UE) and network sides.

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So far, device manufacturers have been handling the case independently and in an implementation-specific manner without coordination and support from the 3GPP. This has led to various proprietary UE solutions and network functions implementations with potential network performance degradation and user experience deterioration.

To fill this gap, 3GPP has put effort into unifying cross-platform solutions to coordinate multi-SIM device operation. Specifically, it has defined use cases and solution requirements in the study item [5]. A consequent study [6] has discussed challenges to support multi-SIM functions and indicated possible solutions with the aim to ensure reliable and seamless UE operation in Fourth Generation (4G) and Fifth Generation (5G) systems. According to the 3GPP vision, all SIM registrations of a device should be treated as independent UEs from the network perspective. This clearly imposes challenges on the delivery of MT traffic over different SIMs and UE mobility management operations.

We aim to analyze the efficacy of solutions for multi-SIM management under investigation at 3GPP from the radio access and core network perspective. Signaling overhead, implementation cost, and corresponding service latency significantly depend on what solution is adopted in a certain network deployment. Our comparative analysis and considerations about the central 3GPP solutions contribute to the existing discussion across the industry and standardization bodies.

First, we introduce the main issues raised by multi-SIM operation and the motivations behind the 3GPP study. Next, we summarize the state-of-the-art of mobility management and MT traffic delivery in 4G and 5G systems and overview solutions for the efficient handling of multiple network registrations and service reception from different MNOs. In the end, we discuss the pros and cons of the envisaged system enhancements and outline future directions.

II. MULTI-SIM OPERATION ISSUES

Before the 3GPP study of the multi-SIM operation related issues in [5], Global System for Mobile Association (GSMA) defined a minimum set of requirements intended to ensure consistent behavior of multivendor multi-SIM devices and gave the definition of a multi-SIM device [2]. In the context of its technical specification, multi-SIM devices either have a single 3GPP network connection and a single International Mobile Equipment Identifier (IMEI) associated with a single selected SIM from several within the device, or have multiple simultaneous 3GPP network connections and multiple IMEIs, each of which is associated with a particular SIM. The former

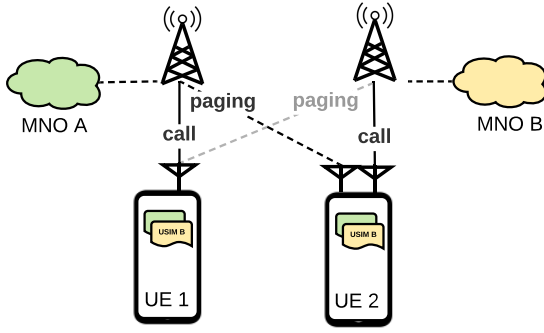


Fig. 1. Different configurations of Multi-SIM UEs.

means that both SIMs share the same cellular transceiver, while the latter assumes that each SIM uses a dedicated transceiver, as illustrated in Fig. 1.

The GSMA has defined Dual SIM Dual Standby (DSDS) and Dual SIM Dual Active (DSDA) operation modes for two different categories of multi-SIM devices.

- **DSDS device** (UE 1 in Fig. 1) maintains “idle” connections to the two networks through time multiplexing. When in-call on one of the SIM, the connection to the corresponding network moves to the “active” state and the UE becomes unavailable for paging (unreachable) on another network for the duration of the call.
- **DSDA device** (UE 2 in Fig. 1) can simultaneously maintain “active” and “idle” connections owing to the dedicated transceiver for each SIM.

To ensure the consistent behavior of different types of multi-SIM devices in cellular networks, the 3GPP has defined four issues caused by the lack of unified solutions for multi-SIM operation.

- **Ongoing service interruption.** While having ongoing service over one SIM, a UE may need to reply to paging message or update its location in the other network. Any transmission associated with one SIM may cause an ongoing service interruption over the other SIM.
- **Unwanted resource wastage.** If a UE becomes unavailable for paging in one system due to an active communication in the other one without appropriate network notification, resources allocated for paging will be unused. Moreover, when network fails to reach UE in the expected cell, it escalates paging to a wider area, which requires extra resources.
- **Misleading assumption of reachability.** If a UE can not reply to the paging message or the ongoing connection gets disrupted, the system may assume that the UE, e.g., has moved to a new Radio Access Network (RAN) area or experiences low link quality. The wrong assumption leads to statistics distortion misguiding algorithms that rely on them.
- **Collision of paging occasions.** Paging occasions of a UE for different SIM profiles may overlap either occasionally or systematically. Paging collision can be resolved on different levels of paging management. However, any unresolved collisions will cause service disruption or

loss, resource wastage, and incorrect assumption of UE reachability for paging.

Privacy implication issues are currently not in the 3GPP agenda. However, preliminary ideas on secure communication of multi-SIMs related information can be found in [7].

To deal with the above challenges, the 3GPP has defined 28 candidate solutions for improved multi-SIM operation in [6]. These solutions specify methods or necessary changes to the existing procedures to account for the different aspects of the multi-SIM UE configuration, connections onto the networks and user preferences regarding the handling the arriving services when busy with a call over another SIM. The solutions under 3GPP discussion have been grouped into different categories summarized in Table I. Thus, some solutions are applicable only if connections for all SIMs are maintained in 5G systems, while others allow a connection on 4G networks.

TABLE I
CLASSIFICATION OF MULTI-SIM SUPPORT CHALLENGES.

Focus	Categories
CN connection	<ul style="list-style-type: none"> • UE connects with 5G on both SIMs • UE connects with 5G and EPS • UE connects with EPS on both SIMs
UE configuration	<ul style="list-style-type: none"> • single Rx and single Tx • double Rx and single Tx antenna
MNO configuration	<ul style="list-style-type: none"> • both SIMs are owned by the same MNO • SIMs belong to different MNOS
Cell camping	<ul style="list-style-type: none"> • Multi-SIM UE camps on the same network • Multi-SIM UE camps on different networks
Services	<ul style="list-style-type: none"> • support for 3GPP services only • support for 3GPP and non-3GPP services • support for emergency calls

III. MOBILE-TERMINATED TRAFFIC DELIVERY

Multi-SIM operation concerns Mobility Management (MM) procedures such as UE registration in a Public Land Mobile Network (PLMN) and its subsequent tracking within the network for the MT traffic delivery [8]. In 4G, a Mobility Management Entity (MME) is responsible for the MM functions including cell and network selection, UE registration, paging, connection establishment and handover. In 5G, the MM is controlled by two separate functions, namely Access and Mobility Management Function (AMF) and Session Management Function (SMF). The former is in charge of managing UE authentication, authorization, and mobility control, while the latter mainly provides session management and Internet Protocol (IP) address allocation [9].

After the SIM activation, a UE selects a RAN and camps on a PLMN during the attach procedure. Upon registration, UE can be either in IDLE or CONNECTED state from the CN and RAN point of view. At the end of the data transmission, registered UE is moved to the IDLE state within the CN and RAN having logical connection with the CN over Non-access Stratum (NAS). At this stage, the UE can only receive signaling messages, while its location at the cell level is unknown.

When a connection between a UE and RAN is established, the UE moves to the CONNECTED state in both network

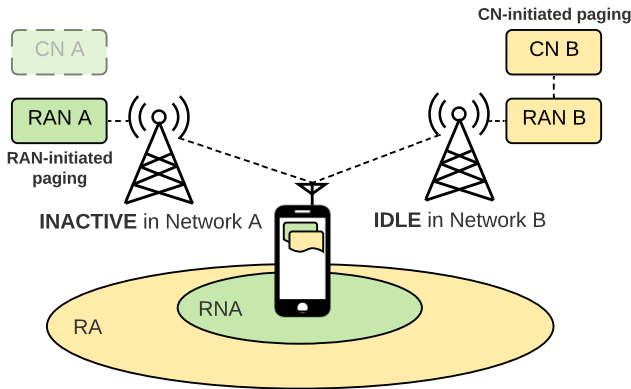


Fig. 2. RAN-initiated and CN-initiated paging.

segments and can be explicitly tracked by the network. In 5G, besides CONNECTED and IDLE states, a UE can be moved to an INACTIVE state, which allows the network to preserve “active” connection with CN, while the connection within the RAN is “idle”. When a UE is in the INACTIVE state, it can be searched for in a narrower RAN area. Position of an IDLE UE in 4G and 5G is tracked within the dedicated Tracking Area (TA) and Registration Area (RA), respectively. The TA/RA consists of the list of cell IDs used for the UE search. The RA includes several TAs allowing for steering UE search and access in 5G systems. Every time a UE moves outside the TA/RA, it should update the corresponding MME/AMF about its new location through the Tracking Area Update (TAU) or Registration Area Update (RAU) (5G only) procedure. Paging is a prerequisite procedure for any network-originated communication as it helps to determine the UE location in the RAN and subsequently reroute MT traffic if the UE is in the IDLE state. Unlike the paging procedure in 4G, which is always triggered by the CN, 5G discerns between CN-originated and RAN-originated paging, as illustrated in Fig. 2 and explained in what follows [10].

- **CN-originated paging.** To identify the UE’s location, MME/AMF cascades a paging message in all cells from the UE’s TA/RA list. Each base station then tries to reach the UE at a specific Paging Frame (PF) and Paging Opportunity (PO) inside the frame. The UE listens to the paging indication in the downlink at a given PO. When the page is received, the UE usually replies, so the CN can locate the UE on the cell level and forward MT traffic to the serving base station.
- **RAN-originated paging.** If a UE is in the INACTIVE state, its location is tracked at the level of Registration Network Area (RNA). When MT traffic arrives, it is immediately rerouted to the last RAN used by the UE. Then, the RAN initiates the paging procedure to notify the UE about the upcoming downlink transmission.

By default, the PF and PO of the RAN-originated and CN-originated paging coincide. To randomize UE paging instances in 4G, the PF and PO values are calculated by an algorithm based on the International Mobile Subscriber Identifier (IMSI),

which is allocated by the MNO. For paging UEs in the CONNECTED state, the MME allocates a temporally unique ID upon the successful random access attempt. To protect UEs against the IMSI catchers and ensure secure paging in 5G, 3GPP has replaced IMSI with a secure analogue, known as Subscription Concealed Identifier (SUCI). For paging transmission protection, new temporal IDs for CN-based and RAN-based paging have been introduced, which are also used to obtain the UE specific PF and PO. It is compulsory to periodically refresh temporal IDs to make it more difficult for an attacker to track a device during paging [11].

IV. 3GPP SOLUTIONS FOR MULTI-SIM DEVICE SUPPORT

The ability of a UE with multiple active SIMs to properly receive paging notifications from different networks and reply to them in time greatly depends on the UE configuration. The two most challenging scenarios are when the UE can use one Tx and one or multiple Rx antennas. These scenarios are in focus of the 3GPP study [6].

In this section we provide an overview of solutions for the multi-SIM support in cellular networks discussed in the 3GPP SA2 and RAN2 working groups. Solutions outlined as *general methods* are aimed at handling MT service, coordinating leaving for another call when only one Tx antenna and any number of Rx antennas are available to a UE. These solutions deal with the problem that the UE can reply only to one network at a time. Solutions of the second group cover the case when the number of available *Rx antennas* is limited to *one* and UEs can not receive paging messages from both networks. The last group is dedicated only to *paging collision avoidance*. These methods can be applied together with the solutions from the other groups to improve the quality of MT services.

The scenario under consideration is a UE with two active SIMs connected to 4G and/or 5G network. The information about the support of the following solutions in these two generations of cellular networks is summarized in Table II. A user would typically choose one network as a primary for more important or frequent calls and assume the other network(s) as secondary. In Fig. 3 we give an example of the message flow between two networks when a UE has an ongoing call in one network and receives paging from the other one applying several solutions introduced below.

A. General methods

Paging Cause. Rules for handling of MT service at the multi-SIM device can be pre-defined by a user or follow some built-in logic. For example, a rule may instruct a device whether it should present a notification about a new voice call to the user if the latter is engaged in another voice call. Similar rules can be defined for the handling MT user plane (voice call) and control plane (SMS or emergency notification) traffic at the network side. A *Paging Cause* can indicate the type of arriving service to assist the UE and network with choosing an appropriate strategy for handling the MT traffic. It is proposed to include information about the paging cause into the paging message as a new field. In case of the voice call arrival, paging

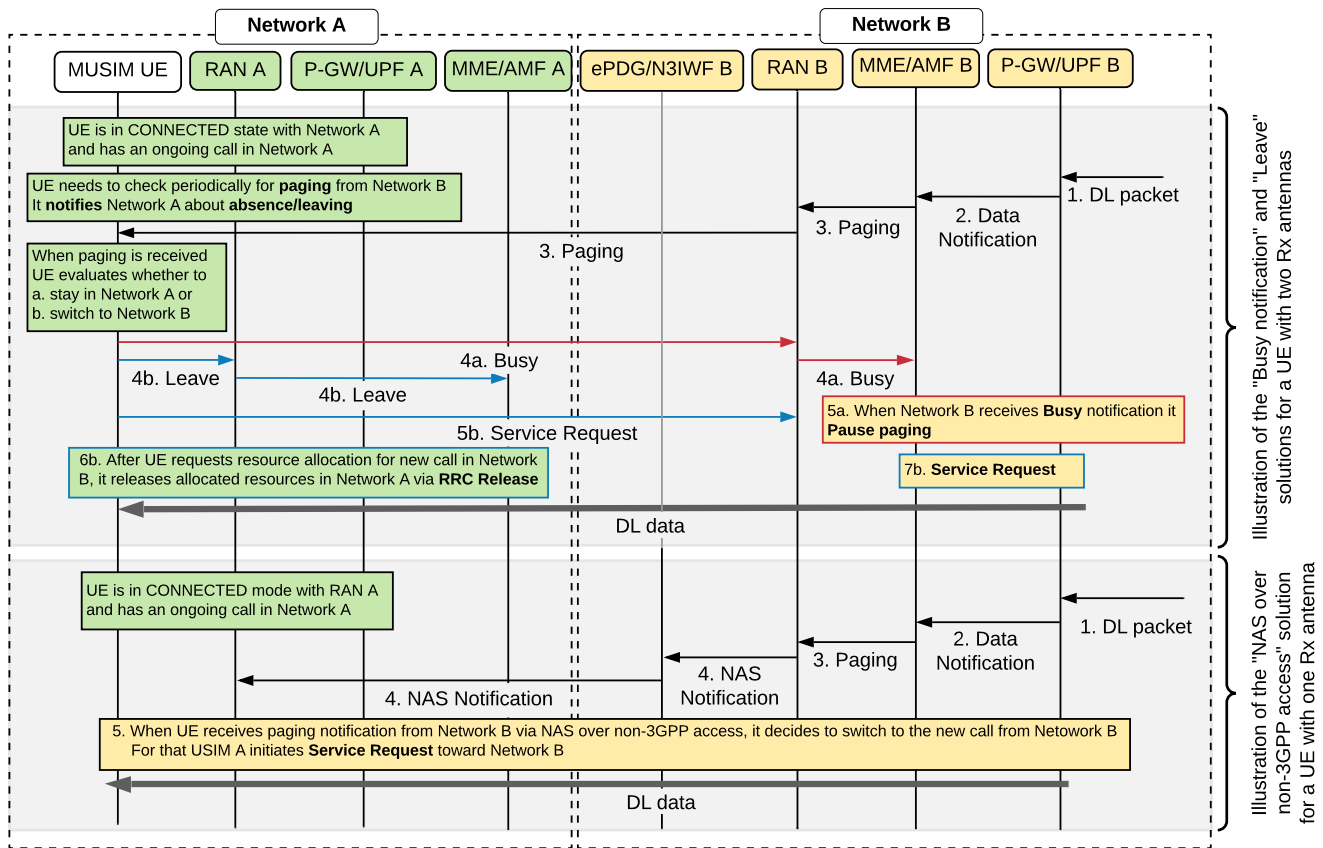


Fig. 3. Flow diagram for the Multi-SIM UE coordination over 3GPP accesses and with a non-3GPP access option.

cause should also be included into the Network Triggered Service Request (Downlink Data Notification) initiated by the User Plane Function (Serving Gateway) to inform AMF (MME) about the user plane traffic arrival in 5G (4G). The solution requires modifications of the paging message and has RAN and CN impacts since the involved nodes should process the new field. This solution alone lacks feedback when a user receives the page but decides not to respond, which leads to a significant waste of resources, because of the paging escalation. Furthermore, the AMF (MME) may come to an incorrect conclusion about the reason for the paging failure.

Notification about short absence period. If a user needs to leave an ongoing call in the primary network for a short time to reply to the page or perform RAU/TAU in the secondary one, it can send notification of a short absence to the primary network and communicate with the secondary network without losing allocated resources in the primary one. During the absence, the traffic at the primary network can be delayed, buffered, or discarded according the QoS requirements. The UE does not need to request Radio Resource Control (RRC) connection release in the primary network for a period of absence. This solution aims at avoiding ongoing service interruption and saving network resources and can be applied in 4G and 5G networks. How to inform the secondary network about the UE comeback to the primary network is not specified yet. Furthermore, the solution does not provide any means to leave the primary network when needed.

Busy indication. When a UE receives a paging message in the secondary network, it can reply with a *busy* notification if the connection with the primary network is preferable. Then the AMF stops paging and replies to the node initiated paging that the UE is reachable, but it has denied the service. This solution excludes paging escalation and prevents the secondary network from misleading assumptions about the UE availability. This new feature can be supported in 5G Core (5GC) and EPS. However, whether it should be used when UE is in the INACTIVE state is not decided yet.

Local leaving. When a UE decides to leave the primary network, it should properly release allocated radio resources. To minimize signaling overhead and latency, the UE can trigger *local leaving* by sending the notification to the CN over the Access Stratum (AS). Once the notification is sent, the UE can immediately switch to the secondary network, and the CN takes responsibility for releasing RRC in the primary RAN and terminating the service. This solution can be implemented both in 5G and 4G systems. To make the solution more efficient, the UE should negotiate local leaving configuration with the RAN. Then the latter can instruct the UE whether it should send a release or suspend request (only in 5G) when leaving the network.

Scheduling gap. When only paging detection in the secondary network is required, the UE may request a *scheduling gap* to tune away from the primary network for the page reception. The RAN decides whether the scheduling gap

Illustration of the "Busy notification" and "Leave" solutions for a UE with two Rx antennas

Illustration of the "NAS over non-3GPP access" solution for a UE with one Rx antenna

requested through the AS signaling can be used. The solution can be used when UE is in the CONNECTED state in one of the networks. It can not be applied for multi-SIM UE with 4G only registrations. It does not involve CN interaction but could be reasonably used in combination with a busy indication as a reply to the received paging message in the secondary network.

Graceful leaving and resumption. The solution allows a UE to leave the primary network and notify it about the return. As for the local leaving, the UE can inform the CN over the NAS including additional information such as expected period of absence and policy for handling MT traffic. The former helps the RAN to decide whether to move UE to the IDLE or INACTIVE state (applicable only in 5G). If UE is in the CONNECTED state, it uses AS communication to notify the network about leaving and return. The solution is aimed at reducing signaling overhead and minimizing the risk of service interruption. It can be enabled in 4G and 5G impacting RAN and CN segments.

Leave and return. Another way to avoid uncoordinated leaving from the primary network is to indicate over AS a user's intention to abandon the ongoing service. Once confirmed, the RAN replies back with the RRC Release message and moves the UE to the IDLE state. The CN holds paging for a network-configured time interval and evokes MT traffic buffering. At the end of the interval, the CN sends the page to the UE to re-establish the connection and deliver the buffered traffic. If it does not receive a reply, the paging is considered failed. If RAN-originated paging fails, the buffered data is discarded, and all relevant nodes are informed that the UE is unavailable.

B. Solutions for Multi-SIM UE with single Tx/Rx antenna

Push notification. A UE with limited hardware capabilities may indicate to the network A its intention to register for paging events since it can not monitor the paging channel while communicating with the network B. If the CN acknowledges the request, it provides the IP address of a network function or a node referred to as *Paging Server*. When network B wants to page a UE, it initiates the direct paging and sends *Push Notification* via Paging Server B. If UE is unavailable for the direct paging in network B, it will receive the *Push Notification*. If UE is in the IDLE state in both networks, the UE will be paged sequentially: first with the direct paging in network B and with the Push Notification in network A after some delay. The arrival of downlink traffic in network A triggers the direct paging in network A. Therefore, the UE will be reached in network A if it is not available in network B. These two paging processes are independent. If both successful, the push message will be ignored. This solution is available in 4G and 5G networks.

Notification via non-3GPP Access. Notification of the MT traffic arrival in the secondary network can be delivered in the primary network via the Non-3GPP Interworking Function (N3IWF). The UE should indicate in the registration request to be reachable for paging through the N3IWF. When MT traffic arrives in the secondary network, the AMF reroutes it to the proper N3IWF. The notification from the secondary

network will be delivered over the user plane in the primary network to avoid UE paging in the secondary network. Thus, the UE does not need to switch between networks and deal with any uncoordinated leaving and paging losses. However, the solution requires an initial configuration of the non-3GPP access, connection establishment. It is supported only in 5G.

Push notification via SMS. The solution is similar to the Push notification and supported by 5GC and EPS, but the notification is delivered via SMS. A UE has to indicate to the CN of the primary PLMN that it wants to register for paging events and receive notification via SMS. This solution does not require any business relationship between the two PLMNs because the user ID explicitly indicates the identity of the secondary PLMN to the primary one and vice versa.

C. Solutions for avoiding paging collisions

NAS parameters change. Overlapping POs cause paging loss and system performance degradation. For multi-SIM UE in 4G-only networks, such collision leads to a systematic paging loss, because the POs are calculated based on the long-term IMSIs. If UE detects POs conflict during the registration at the 5G system, it should request a new 5G Globally Unique Temporary Identifier (5G-GUTI) through the mobility update procedure indicating suitable values. If AMF can not allocate a 5G-GUTI that fits the assistance information, it may assign new POs by updating parameters for the paging mechanism, e.g., indicating a new paging offset. The natural extension of the previous solution that can be used in any systems is to request an **alternative UE_ID** from the MME or AMF. In case of RAN-based paging, the network accepts the proposed UE_ID only for calculating a new timing for paging. For the CN-based paging, the new UE_ID can be enforced only after the network confirmation. The new PO can be used until the UE revokes it. Paging collisions could be dynamic because the UE-Identity (ID) in 5GC is periodically updated.

Paging offset. If two or more SIM registrations in EPS result in paging collision, a *multi-SIM offset* can help to resolve the PO overlapping when UE-ID can not be changed. The offset value should not lead to even a partial PO overlapping. Therefore, it should be assigned taking into account the number of active registrations and offset values for all other SIMs. The solution can also be used in 5G.

Paging on consecutive POs. To eliminate the risk of PO collision when UE receives all paging notifications over the primary network, the POs of both networks should be consecutive in time. The solution proposes to extend the legacy paging with a counter of paging attempts giving a chance to reach the UE at the next PO following the collided one.

V. QUALITATIVE ANALYSIS AND OPEN ISSUES

As the above solutions have different impact on RAN, CN, UE, in this section we analyze their drawbacks, cost of implementation, and discuss possible improvements. We present our qualitative evaluation based on the available 3GPP documents and discussions in SA2 and RAN2 groups, and do not intend to give a definitive conclusion on what solutions shall be applied. With this analysis we aim to give a holistic

TABLE II
OVERVIEW OF THE 3GPP SOLUTIONS FOR MULTI-SIM COORDINATION.

Solutions	RAN-based	CN-based	5G	4G
1. Paging Cause	✓	✓	✓	✓
2. Short absence	✓		✓	✓
3. Busy	✓	✓	✓	
4. Local leaving	✓	✓	✓	✓
5. Graceful leaving	✓	✓	✓	✓
6. Leave and return		✓	✓	✓
7. Scheduling gap	✓	✓	✓	
8. Push notification		✓	✓	
9. Notification over non-3GPP access		✓	✓	✓
10. Notification via SMS		✓	✓	✓
11. NAS parameters change		✓	✓	
12. Alternative UE_ID		✓	✓	
13. Paging offset	✓	✓	✓	✓
14. Consecutive POs paging	✓	✓	✓	✓

perspective on the topic as well as to help readers to put discussed solutions into a broader context.

A. Pros and cons of the solutions for multi-SIM support

Among the discussed solutions, a new *Paging cause* field helps avoid inquiry to identify why the UE was paged, minimizing any impact on the ongoing service on the other SIM. However, if UE does not respond to the page, the paging request will be escalated, wasting radio resources within the large registration area. The solution enabling an on-off period of absence with the primary network prevents unnecessary interruptions of the ongoing service and paging escalation in the secondary network. However, no user control of the solution is described. While being away from the primary network for a short period, e.g., for sending busy notification, some service interruption in the primary network may occur.

Solutions in subsection IV-B can be thought of as a notification type and fit all types of multi-SIM devices, even the most constrained ones. However, *push notification* requires the implementation of a paging server, while *SMS-based solution* may suffer from uncontrolled and long delays. Importantly, even if a UE is paged by two methods in parallel, the solution can not guarantee that either of them will be successful. The interactions between two PLMNs and traffic forwarding from one PLMN to another one in several solutions for UEs with a single Rx and Tx antenna raise also charging issues. The straightforward solution is to address these issues to the MNOs and settle it based on the Service Level Agreement (SLA) agreements between the involved MNOs.

Paging collisions could be solved in many ways, as explained in section IV-C. A group of solutions based on changing PO every time a collision risk is detected requires extra signaling and, as a consequence, extra resources utilization and latency increase. Changing the paging strategy also helps to deal with overlapping POs. However, the gain of such approaches is questionable due to the need for keeping the strategy up-to-date and to the difficulty of designing a paging strategy that can adapt for a general multi-SIM scenario.

Some solutions, including the one based on the *UE assistance information*, are foreseen to increase signaling and device energy consumption since the UE is responsible for

detecting PO collisions, providing support information for leaving, and informing network about the current UE capabilities and configuration.

Solutions that tackle resource waste and misleading assumption of reachability belong to a group of a *coordinated leaving* approaches, which in turn can be divided into: (i) NAS triggered leaving, (ii) AS triggered leaving, with and without release assistant information, and (iii) leaving for a given interval. UE requests to leave or resume a connection via NAS signaling can be communicated only within the RAN (if INACTIVE state is supported) or reach the CN. Corresponding *graceful leaving* and *local leaving* solutions aim to minimize the overhead needed for coordinated leave and return and minimize service interruption in the primary network. For a short leave, it is more beneficial to move UE to the INACTIVE state than to the IDLE state due to the lower latency and signaling cost.

AS-level solutions are applied when a UE wants to leave ongoing communication in the primary network because the secondary network's upcoming service has higher priority. The fastest way to tune away from the primary network and start receiving service over another is to use local leaving, which does not require network acknowledgment for the RRC release. These resource-efficient solutions for coordinated leaving also raise significant concerns about the further actions aligning between UE and network.

To date (August 2021) SA2 and RAN2 groups have not come to the conclusion on which of the discussed solutions to pursue in addressing the issues defined in the study item [6]. Nevertheless, according to the current discussions in 3GPP, the industry have given preference to the "local leaving", "paging cause", and "paging offset" solutions. However, the official updated version of the 3GPP study item will be available only in Q1 2022.

B. CN-based vs RAN-based solutions and steps ahead

The central discussion of the candidate solutions for the multi-SIM support in Release 17 comes to the question whether the overhead related to handling paging collision and connectivity interruption should be on the CN or RAN side. In this section, we provide a concise technical analysis of the RAN-based and CN-based solutions together with the future research directions. Due to the complexity of the system to be modeled and lack of information on how the different solutions are implemented in reality, a system level simulation was not an appropriate methodology. For this reason, we have modeled each solution according to our assumptions on, e.g., what messages are exchanged between network and multi-SIM UE, what signaling latency is involved. We have drawn conclusions in a form of key performance metrics defined below for the RAN-based and CN-based solutions and summarized them in Figure 4:

- **Complexity:** to demonstrate at what extent a solution impacts UE, RAN, or CN;
- **Overhead:** to show how much signaling overhead the solution brings;
- **Scalability:** to indicate whether the solution is applicable for a large number of UEs and/or RAN nodes;

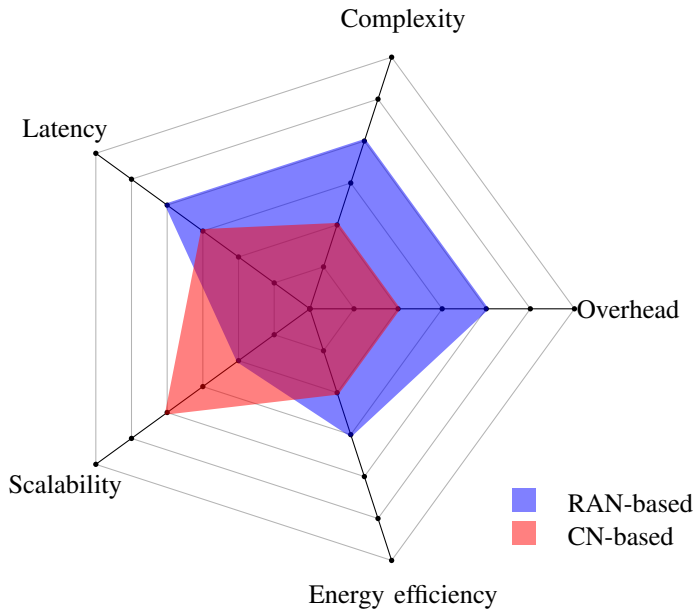


Fig. 4. Comparison of the solutions for multi-SIM coordination.

- **Latency:** to compare how long it takes for the solution to take effect;
- **Energy efficiency:** to demonstrate whether a solution can increase energy consumption.

The advantage of RAN-deployed solutions is the low latency since the signaling happens between two different RANs or between UE and RAN. However, this benefit comes with the assumption that the UE is capable of keeping active RRC connections with both RANs simultaneously. The drawback of the RAN-based solution is the requirement to perform MM procedures in two RANs at the same time. It will be particularly challenging for these RANs to avoid PO collisions because of the network dis-synchronization and the frame structure misalignment (i.e., when the time instants of the frames start and the frames end are different).

CN-based solutions instead have no impact on the RAN as all the management is done in the CN. A UE can be connected to only one RAN at a time. The complexity and implementation cost of the CN-based solutions are lowest. Furthermore, the UE will be able to save battery since it has to listen to the paging only in one RAN. However, the main drawback of the CN-based solutions is an increased latency for the overall procedure with respect to a RAN-based solution.

Currently, 3GPP is analyzing both solution categories to identify the best one for providing necessary functions for the multi-SIM support that introduce lower overhead and system impact. The overall picture and 3GPP standardization dynamics lead to the conclusion that CN-based solutions are seemed to be the most suitable as a way forward. Nevertheless, since the evaluation of all the solutions is still ongoing in 3GPP, a clear understanding of what approaches will be adopted becomes available only in the first quarter of 2022.

VI. CONCLUSIONS

In this paper, we have highlighted the challenges raised by the global adoption of devices with multiple SIMs and presented approaches for the multi-SIM device coordination investigated by the 3GPP. In particular, we have analyzed the candidate solutions for Rel-17 classified as (i) general methods that build the basis for multi-SIM UE support, (ii) solutions for constrained UEs with latency and reliability limitations, and (iii) different solutions for avoiding paging collisions. We have discussed their benefits, drawbacks and impact to support the ongoing work in the 3GPP towards the adoption of CN-based solutions.

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