Cross-Working Group Work Item Network Reselection Improvements (NRI)

5GAA Automotive Association

Technical Report

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Contents

Foreword

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(1) This numbering system has six logical elements:
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  A (System Architecture and Solution Development)
  P (Evaluation, Testbed and Pilots)
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1. Scope

The scope of this Technical Report (TR) is to describe how to use existing 3GPP methods to decrease service interruptions due to network reselection, and to describe the related mobile network operator (MNO) impacts in order to improve the process. The TR provides the original equipment manufacturer (OEM) view on current and desired network reselection. Some additional information on how to minimise impact on UCs due to network reselection is also provided.

2. References

[1]	5GAA, Cross-working Group Work Item Description for V2X Network Reselection Improvements
[2]	Across Borders: Keeping Vehicles Connected
[3]	https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/bkgd
[4]	https://5gaa.org/news/5gaa-releases-white-paper-on-making-5g-proactive-and-predictive-for-the-automotive-industry/
[5]	5GMED: https://cordis.europa.eu/project/id/951947
[6]	5GCroCo: https://5gcroco.eu/
[7]	5G-CARMEN: https://www.5gcarmen.eu/
[8]	5G-MOBIX: https://www.5g-mobix.com/
[9]	5G-Routes, 5G-Blueprint: https://ec.europa.eu/digital-single-market/en/news/eu-boosts-investment-5g-hardware-innovation-and-trialling-5g-based-connected-and-automated

3. Abbreviations

Only 3GPP abbreviations and common abbreviations used in this report.

4. Problem description

When user equipment (UE) changes its serving mobile network (e.g. when crossing country borders, entering an area in a country without coverage from a so-called home public land mobile network, HPLMN), an interruption in connectivity (normally) occurs since the UE needs to connect to a new network which takes some time, i.e. scanning the spectrum to find a public land mobile network that it can attempt to use or 'visit' (hence VPLMN).

These interruptions can often result in disconnected phone calls and/or blackout periods for connected vehicle services lasting up to several minutes. This could be seen as a major drawback for the use of cellular networks, especially when alternative solutions may be applied.

4.1 Modem considerations

To a certain extent, the interruption time depends on the modem and UE implementations e.g. some modems 'remember' information and can thus select a network faster. Another influencing factor is the scanning algorithm implemented, e.g. if many bands and radio technologies are supported it depends on where to start scanning the spectrum and where a new carrier frequency is found with an allowed PLMN.

Additionally, information provided on the SIM card can impact network reselection, e.g. if preferred roaming partners are provided, selection latency (or delays) will be improved by skipping PLMNs that are 'not allowed'.

4.2 OEM considerations

In most cases, an OEM would prefer to just sign up with one selected MNO and rely on that operator and its roaming partners to provide service continuity. It can be difficult and costly for an OEM to know and understand the relations between MNOs.

The OEM offers its customers seamless voice and data services, which means there are no interruptions during the handover between VPLMNs, e.g. during autonomous driving mode.

For services such as autonomous driving and tele-operated driving, continuity is a high priority and this is only possible when the handover between MNOs is smooth. With the home routing roaming method, as generally used by MNOs, the device loses connectivity for some time which disturbs the autonomous/tele-operated driving.

An interruption of several minutes cannot be considered as a state-of-the-art solution under 5G conditions; OEMs expect more in terms of throughput, latency, reliability and quality of service.

Since OEM M2M SIM cards are operated within one MNO mobile-to-mobile (M2M) network, and most of the services – voice (VoLTE), data and SMS – are routed to this home network, also known as ‘home routed’, seamless handover is orchestrated from the network end, not from the device. This avoids any service interruption with the new registration initiated from the device. With a network-orchestrated handover like this, the device IP address can remain unchanged.

Current and future OEM service offers rely on data-based services, also known as ‘digitalisation’. To mitigate interruptions in cross-border scenarios, the OEMs therefore require full implementation on the MNO side.

4.3 MNO considerations

The principle of home routing for roaming subscribers is commonly used today, meaning that the subscriber’s user plane is routed back to the home network from the visited network. The architecture for 4G and home routing is shown in Figure 1 below, while the equivalent 5G architecture is shown in Figure 2. (Older 3GPP technologies and the circuit-switched domain are not expanded on here.)

Home routing with substantial user-plane interruption is still widely used because MNOs generally have little incentive to cooperate and optimise their cross-border network setups. Further discussion is needed to explore ways to improve this situation. This topic is outlined in Chapter 7.

5. Solutions possible with current 3GPP standards

In this chapter, potential improvements in network reselection using existing 3GPP functionality are outlined from a technical perspective.

5.1 4G

This section provides a technical description on an abstracted level. Further details from extracted 3GPP specifications (TS 23.401), including signalling sequences are available in Annex A: 4G

It should be noted that for Non-Stand Alone (NSA) 5G deployments, the 4G procedures detailed here are applicable since 4G with LTE is the anchor technology, 5G New Radio (NR) being used with dual connectivity when NR coverage exists. This means that network reselection occurs on 4G LTE, and NR connectivity is re-established subsequentially.

5.1.1 UE roaming with new registration

Home routing for 4G architecture is illustrated below. Note that not all functional entities are shown; only those that are relevant to network reselection.

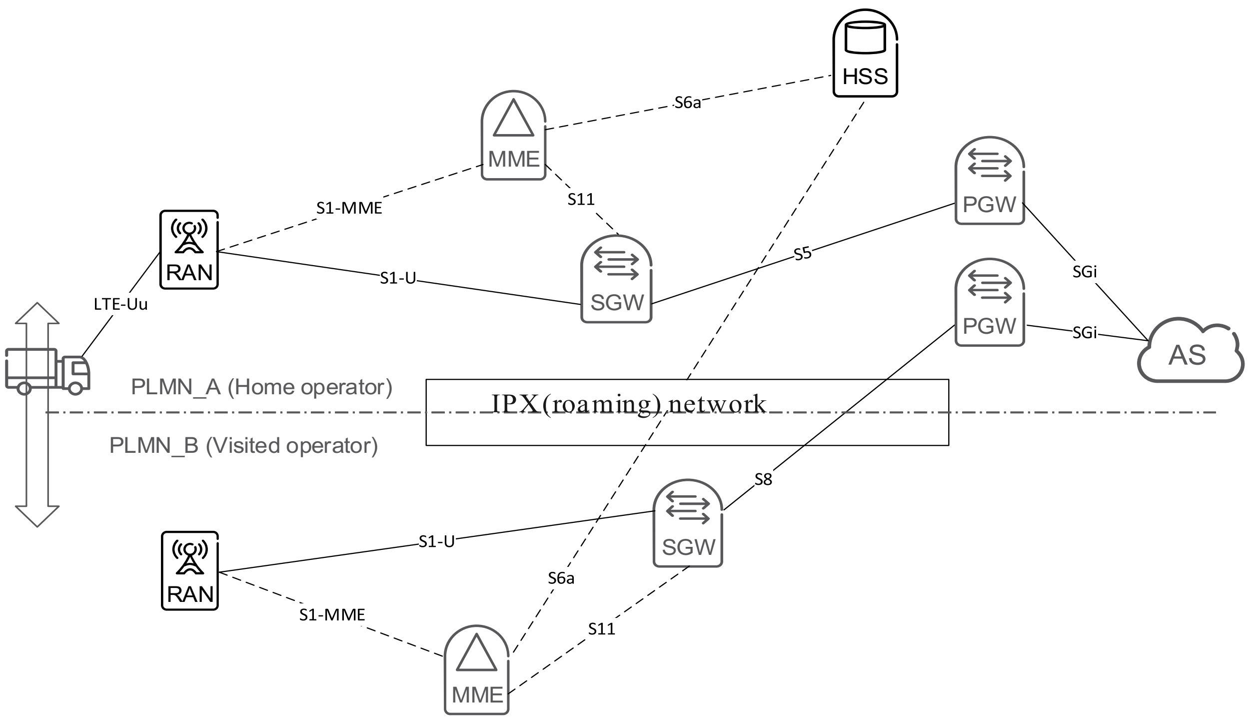

Figure 1: 4G Architecture for 'home routing' when roaming

In this setup, the MME in the visited network contacts the home subscriber system (HSS) in the subscribers' home network to obtain subscriber data. When the subscriber is accepted by the visited network, the user plane to the packet data gateway (PGW) is established in the home network where the subscriber's IP address is anchored, and 'internet' access provided, as illustrated with the cloud named application services (AS). The connectivity between the mobile networks use an intermediate network, the IPX network.

This (baseline) setup has several 'contributors' to network reselection time.

1. The home/serving network holds on to the subscriber until connection is lost.
2. The UE must scan the spectrum to find a carrier and connect.
3. The UE attempts to 'attach' when it has found a carrier, i.e. this could fail if the UE is not allowed to use the network, requiring a new attempt from the UE on another PLMN.
4. A successful attachment, creating a user context in the visiting network, takes some time thanks to the required registration/authentication.
5. The user plane needs to be re-established on the new network.

Some of the above potential causes of interrupted connections can be improved depending on the spectrum used and UE scan algorithms, or thanks to the UE's ability to 'remember' information from previous connections/interactions. Another possible improvement could be achieved in the way the MNO configures information on the SIM card. However, configuration of SIM cards requires additional effort for each subscriber, so this is seldom done.

For a mobile network operator, this baseline roaming case is a well-established process. It does not require too much interaction or coordination with other MNOs; a fairly simple roaming agreement is needed between the MNOs and interconnection between MNOs is then facilitated by the IPX network.

A 'baseline' setup in most cases would result in a user plane (connection) interruption of several minutes, e.g. see Reference [2] Across Borders: Keeping Vehicles Connected.

5.1.2 UE roaming with MME relocation (idle mode mobility)

The term 'idle mode mobility' is used because the UE is released and then the connection is re-established in the new network.

The home routing scenario can be improved by applying some existing 3GPP features and an additional roaming interface, as indicated in 3GPP TS 23.401 (see Figure 2).

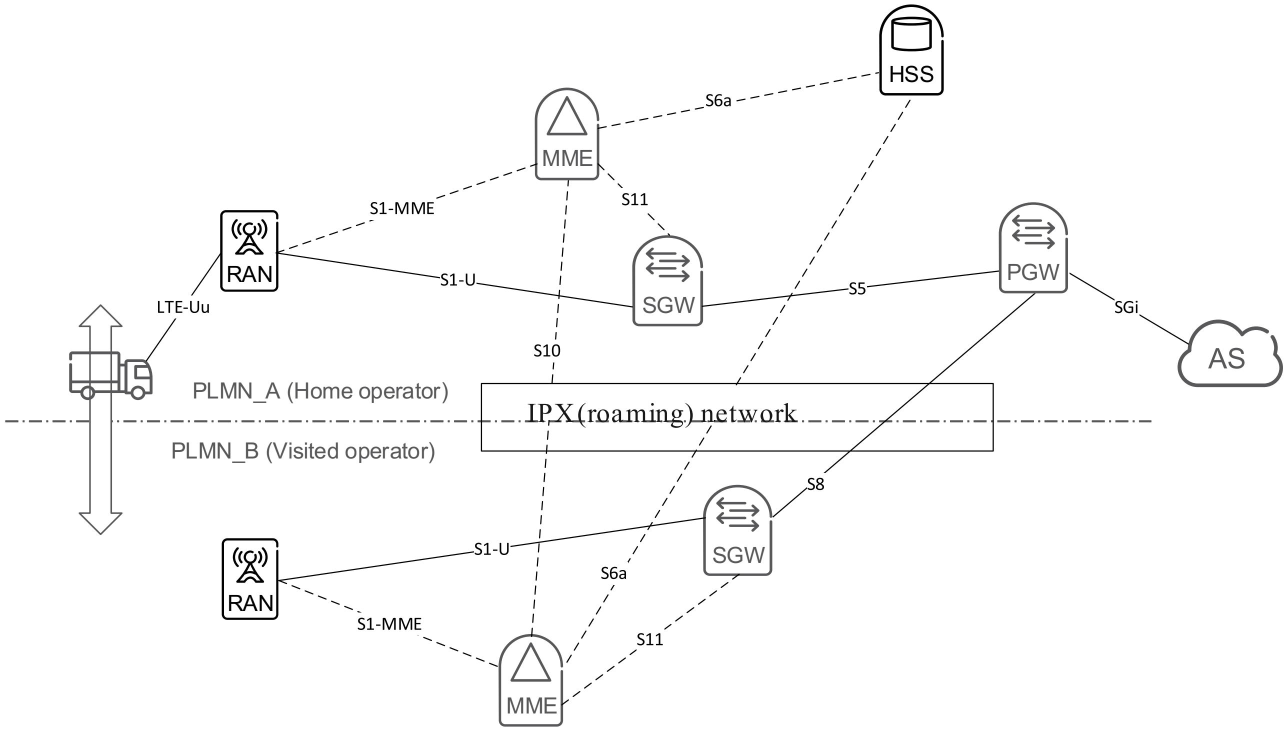

Figure 2: 4G roaming architecture with S10 interface

The additional features activated in this scenario are explained below and mapped to the various contributors to network reselection time described in the baseline setup.

1. The home/serving network holds on to the subscriber until connection is lost.
   ▸ Addressed by the controlling radio access network (RAN), which is configured with a threshold for when a UE should be released, i.e. while decent connection/performance still exists.
2. The UE must scan the spectrum to find a carrier and connect.
   ▸ Addressed by including redirect information in the release message, i.e. the controlling RAN is configured to inform the UE (as part of the release) about available target frequency bands to allow the UE to immediately tune into a new carrier (without having to scan the spectrum).
3. The UE needs to attempt to attach when it has found a carrier, i.e. this could fail if the UE is not allowed to use the network, requiring a new attempt from the UE on another PLMN.
   ▸ Addressed by the packet core function 'equivalent PLMN'; the UE is informed about PLMNs it is allowed to use, eliminating the need for blind attachment attempts.

4. A successful 'user context' attachment in the visiting network takes longer due to the registration/authentication time.
   ▸ Addressed by the additional roaming interface between MMEs (S10), which allows the MME in the VPLMN to fetch the UE context from the source MME.

5. The user plane needs to be re-established on the new network.
   ▸ Also addressed by the additional roaming interface between MMEs (S10), since the new network is made aware of the PGW and UE IP address used, and the user plane is re-established as part of the tracking area update in the new network.

The network setup for idle mode mobility reduces the user plane (connection) interruption to ~1 second, e.g. see Reference [2] Across Borders: Keeping Vehicles Connected.

MNO impacts

The setup for the idle mode mobility scenario does, however, require additional configuration by MNOs and cooperation between MNOs, as outlined below:

1. An MNO needs to ensure the availability of required functionality from infrastructure vendors – meaning MNOs need to test prior to implementation and post-implementation, as applicable.
2. Roaming agreements between MNOs need to be enhanced to deliver such functionality.
3. The MNOs would have to configure their networks as equivalent PLMNs; if only applied to country borders this can be done as a general network configuration, but if applicable within a country, this can be done on a 'tracking area' basis.
4. The MNOs would have to make the S10 interface available for roaming, i.e. MMEs need to be addressable using the IPX roaming network (alternatively, this could be made through bilateral agreements/connections between trusted partners).
5. The MNOs need to know the frequency bands of the adjacent networks; this is a fairly static knowledge (e.g. new frequency bands are not acquired that often but this needs to be monitored and occasional changes applied).
6. The equipment in radio cells, where an MNO change should occur, needs to be configured to release the UE at a threshold when cell performance is deteriorating, and no suitable target cell exists in the serving network. The serving network also needs to include redirection information (i.e. about frequency band(s) in the new MNO network target cell) in the release message.
7. The correct thresholds for sending the release message with redirection information need to be obtained; this implies that drive tests are needed.

UE impacts

The UE needs to use the frequency band advice provided by the serving network to improve the scanning procedure; however, the roaming would be successful anyway. How the frequency band advice is used in UE scanning algorithms is implementation dependant.

5.1.3 Handover

An additional improvement step would be to support the handover, as defined by 3GPP, between the networks. These would use a core network type of handover, not using X2 between base stations (eNBs), because X2 is not normally used between networks. In such a scenario, the architecture would be the same as in Figure 2 but in this case also the handover functions should be configured. In short, handover implies that the source (controlling) network gets information from the UE about potential handover candidates in the target network, the source network contacts the potential target network and asks for resources in the target network, and if granted the source network sends a 'handover command' to the UE with information about the target network. The UE then tunes into and connects to the new network.

The network setup for handovers reduces the user plane (connection) interruption to ~0.1 second, e.g. see Reference [2] Across Borders: Keeping Vehicles Connected.

MNO impacts

Again, the setup for the idle mode mobility scenario requires additional configuration by MNOs and cooperation between MNOs, as outlined below:

1. An MNO needs to ensure availability of required functionality from infrastructure vendors – requirement for MNOs to test prior to implementation and post implementation as applicable
2. Roaming agreements between MNOs needs to be enhanced to include this functionality.
3. The MNOs would have to configure their networks as Equivalent PLMNs, if only applicable for country borders this can be done as a general network configuration, if applicable within a country, this can be done on a per tracking area basis. ► Same as for Idle mode mobility.
4. The MNOs would have to make the S10 interface available for roaming, i.e. MMEs needs to be addressable using the IPX roaming network (alternatively this could potentially be made on bilateral agreements/connections between trusted partners). ► Same as for Idle mode mobility.
5. The MNOs needs to know the frequency bands of the adjacent networks, this is a fairly static knowledge, e.g. new frequency bands are not acquired that often.
6. For handover, the MNOs needs to know more than the frequency bands of the adjacent networks, the MNOs also need to know the radio nodes identities of the nodes in the adjacent networks, this is a fairly dynamic knowledge, e.g. new radio sites are deployed, radio cells are split to increase capacity etc. In radio cells where an MNO change should occur, the radio equipment needs to be configured with information about the adjacent network.
7. The correct thresholds for the handover function need to be obtained, this may imply that drive tests need to be performed.

UE impacts

Mandatory 3GPP functionality for handover is used, i.e. the UE receives instructions from the network.

5.2 5G

This section provides a description on an abstracted level, details are extracted from 3GPP TS 23.501/502 (including signalling sequences) available in Annex B: 5G

5.2.1 UE roaming with new registration

The home routing for the 5G SA (stand-alone) architecture is illustrated below. Note that not all functional entities are show for clarity.

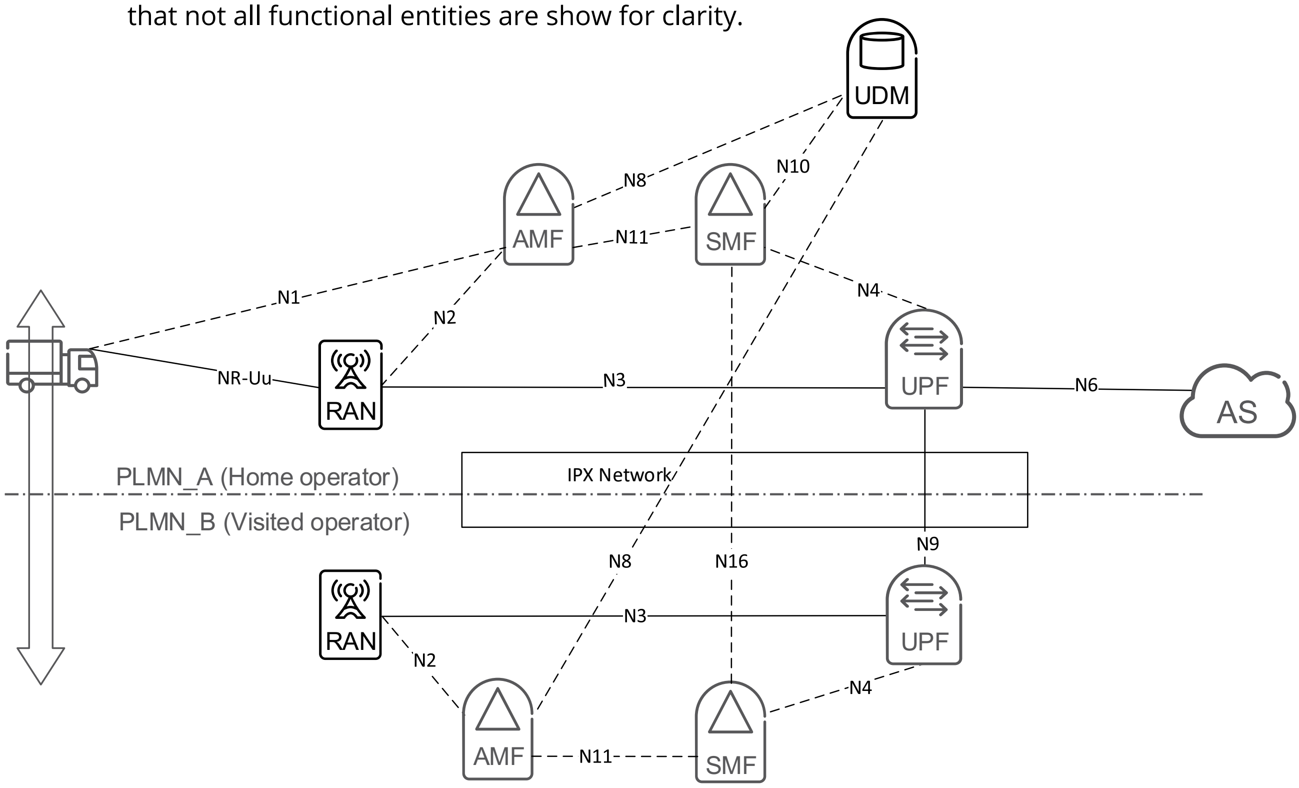

Figure 3: 5G architecture for home routing when roaming

The 5G case applies the same broad principles as those for 4G home routing. The control and user plane split makes the N16 interface between session management functions (SMFs) in different PLMNs necessary. (For 4G, session management is handled by the S8 interface which carries both the control and user plane.)

The same contributors to network reselection time are noted for both 4G and 5G:

1. The home/serving network holds on to the subscriber until connection is lost.
2. The UE must scan the spectrum to find a carrier and connect.
3. The UE attempts to 'attach' when it has found a carrier, i.e. this could fail if the UE is not allowed to use the network, requiring a new attempt from the UE on another PLMN.
4. A successful attachment, creating a user context in the visiting network, takes some time thanks to the required registration/authentication.

5. The user plane needs to be re-established on the new network.
Similar interruption time as for 4G are expected, i.e. the 5G "baseline" setup in most cases would result in a user plane (connection) interruption of several minutes.

5.2.2 UE roaming with AMF relocation (idle mode mobility)

As previously pointed out, the term idle mode mobility is used when the UE is released and the connection needs to be re-established in the new network.

Similarly to the 4G example, the home routing scenario for 5G can be improved through some existing 3GPP features and by deploying N14 between the operators, as illustrated in Figure 4.

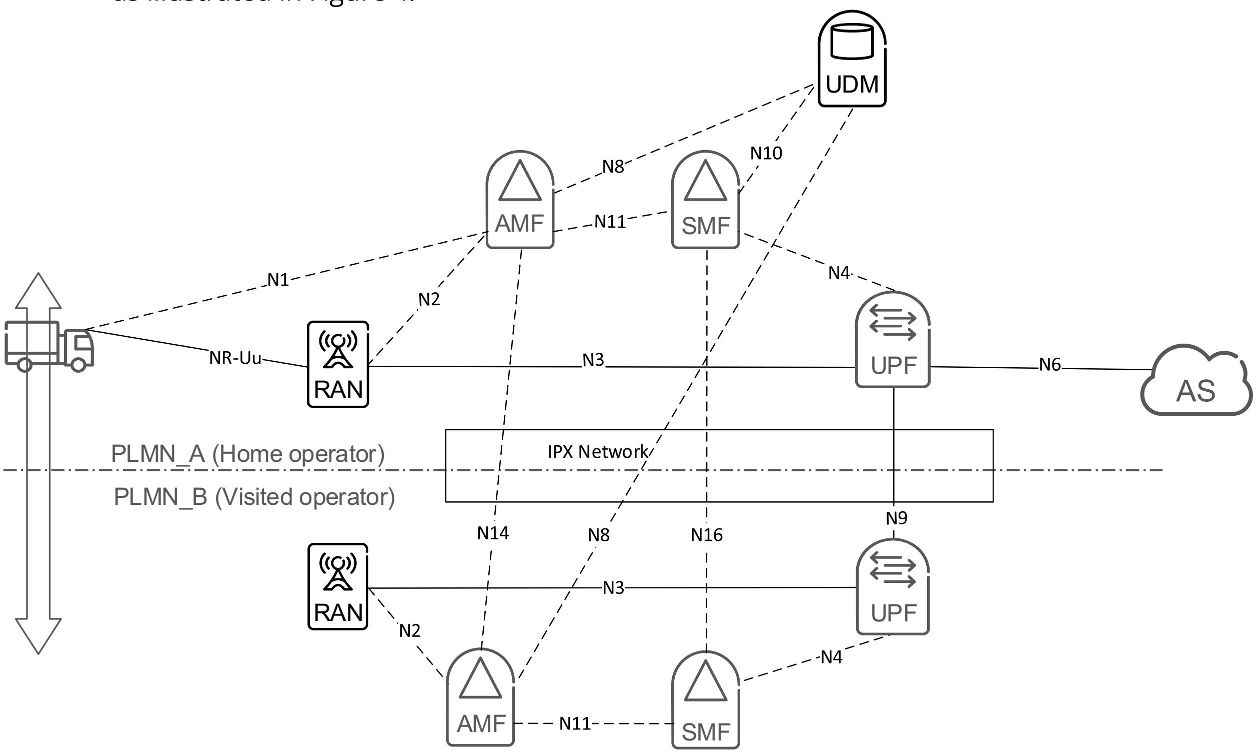

Figure 4: 5G Roaming architecture with N14 interface

To support this scenario, the N14 interface needs to be deployed between PLMNs, i.e. as a roaming interface between access and mobility functions (AMF). This corresponds to the S10 interface in 4G.

The same or equivalent features elaborated on in the 4G example are activated in the 5G system described in this scenario. For clarity's sake, they are explained again below and mapped to the various contributors to network reselection time described in the baseline setup:

1. The home/serving network holds on to the subscriber until connection is lost.
   - Addressed by the controlling RAN, which is configured with a threshold for when a UE should be released, i.e. while decent connection/performance still exists.

2. The UE must scan the spectrum to find a carrier and connect.
   ▸ Addressed by including redirect information in the release message, i.e. the controlling RAN is configured to inform the UE (as part of the release) about available target frequency bands to allow the UE to immediately tune into a new carrier (without having to scan the spectrum).
3. The UE needs to attempt to attach when it has found a carrier, i.e. this could fail if the UE is not allowed to use the network, requiring a new attempt from the UE on another PLMN.
   ▸ Addressed by the packet core function 'equivalent PLMN'; the UE is informed about PLMNs it is allowed to use, eliminating the need for blind attachment attempts.
4. A successful attachment, creating a user context in the visiting network, takes longer due to registration/authentication time.
   ▸ This is addressed with the additional roaming interface between AMFs (N14); this interface allows the AMF in the VPLMN to fetch the UE context from the source AMF.
5. The user plane needs to be re-established on the new network.
   ▸ Also addressed with the additional roaming interface between AMFs (N14), since the new network is made aware of used UPF and UE IP address, and the user plane is re-established as part of the tracking area update in the new network.

It is assumed that this network setup for idle mode mobility reduces the user plane (connection) interruption to similar levels as for 4G, i.e. ~1 second.

MNO impacts

This idle mode mobility scenario also requires additional configuration by MNOs and cooperation between MNOs, as outlined below:

1. An MNO needs to ensure the availability of required functionality from infrastructure vendors – meaning MNOs need to test prior to implementation and post-implementation, as applicable.
2. Roaming agreements between MNOs need to be enhanced to deliver such functionality.
3. The MNOs would have to configure their networks as equivalent PLMNs; if only applied to country borders this can be done as a general network configuration, but if applicable within a country, this can be done on a 'tracking area' basis.
4. The MNOs would have to make the N14 interface available for roaming, i.e. AMFs needs to be addressable using the IPX roaming network (alternatively, this could be made through bilateral agreements/connections between trusted partners).
5. The MNOs need to know the frequency bands of the adjacent networks. This is a fairly static knowledge, e.g. new frequency bands are not acquired that often.
6. The equipment in radio cells, where an MNO change should occur, needs to be configured to release the UE at a threshold when cell performance is deteriorating, and no suitable target cell exists in the serving network. The serving network also needs to include redirection information (i.e. about frequency band(s) in the new MNO network target cell) in the release message.
7. The correct thresholds for sending the release message with redirection information need to be obtained; this implies that drive tests are needed.

UE impacts

The UE needs to use the frequency band advice provided by the serving network to improve the scanning procedure, however roaming would be successful anyway. How the frequency band advice is used in UE scanning algorithms is implementation dependant.

5.2.3 Handover

To support this scenario, the N14 interface needs to be deployed between PLMNs, i.e. as a roaming interface between AMFs (this corresponds to the S10 interface in 4G).

An additional step to improve roaming would be to support handover, as defined by 3GPP between the networks. In this case, it would involve a core network type of handover, not using Xn between base stations (gNBs) because they are not normally used between networks. In this scenario, the architecture would be the same as in Figure 4 (5G roaming architecture with N14 interface), but also configure or factor in the handover functions. In short, the source (controlling) network gets information from the UE about potential handover candidates in the target network, the source network contacts the potential target network and asks for resources. If granted, the source network sends a 'handover command' to the UE with information about the target network, the UE then tunes into and connects to the new network.

Similar to 4G, it is assumed that with additional effort the networks can be configured for handover to reduce the interruption time. It is assumed that the 5G scenario can anticipate similar interruption times to 4G, i.e. around 100 ms.

MNO impacts

Again, handover scenario anticipates additional configuration by MNOs and cooperation between MNOs, as outlined below:

1. An MNO needs to ensure availability of required functionality from infrastructure vendors – requirement for MNOs to test prior to implementation and post implementation as applicable
2. Roaming agreements between MNOs needs to be enhanced to comprise this functionality.
3. the MNOs would have to configure their networks as Equivalent PLMNs, if only applicable for country borders this can be done as a general network configuration, if applicable within a country, this can be done on a per tracking area basis. ▸ Same as for Idle mode mobility.
4. The MNOs would have to make the N14 interface available for roaming, i.e. AMFs needs to be addressable using the IPX roaming network (alternatively this could potentially be made on bilateral agreements/connections between trusted partners). ▸ Same as for Idle mode mobility.
5. For handover, the MNOs needs to know more than the frequency bands of the

adjacent networks, the MNOs also need to know the radio nodes identities of the nodes in the adjacent networks, this is a fairly dynamic knowledge, e.g. new radio sites are deployed, radio cells are split to increase capacity etc. In radio cells where an MNO change should occur, the radio equipment needs to be configured with information about the adjacent network.

6. The correct thresholds for the handover function need to be obtained, this may imply that drive tests need to be performed.

UE impacts

Mandatory 3GPP functionality for handover is used, i.e. the UE receives instructions from the network.

6 Use case 'interruption' sensitivity

Further studies are required to evaluate use case (UC) sensitivity to connection interruption. For example, considering the likelihood that PLMN/MNO change would occur during the UC execution, what would be the potential implications for a user plane interruption, can a UC be restricted to one MNO (i.e. the UC would only be executed within one MNO's coverage)?

Potential mitigations could also be considered, such as making the application aware of the upcoming interruption and dealing with it in advance. For example, industry has discussed (Ref. [4]) the use of coverage maps and prediction features, such as NESQO & eNESQO. Furthermore, the point at which network change occurs can be adjusted with network configuration, e.g. to avoid a network change at an intersection or other potentially risky or inconvenient times. Another mitigation step for self-driving is to flag certain areas, roads or sections of a route as 'allowed routes', where connectivity is known to be in place and no driving problems can be expected, e.g. no accidents are detected on the road stretch ahead, but when vehicles leave these areas control is handed back to the driver.

Also, the use of mobile network quality of service (QoS) approaches are worth considering to ensure that enough capacity is available if, for example, tele-operated driving/support is deemed necessary.

Some initial thoughts on how to analyse UC sensitivity and mitigations are elaborated in Annex C.

7 For further study

The following technical items need further study:

1. Synchronisation if time division duplexing (TDD) bands are used.
2. Practicality of keeping cross-MNO data up to date, including the periodicity/frequency of updates and multiple PLMN changes.
3. 5G-CARMEN [7] considered two solutions for improved network reselection:
   a. One solution aims for a simplified variant from an MNO point of view of what is described in Chapter 5.1.2. Such a solution would also apply the equivalent PLMN and release with redirect methods, but would not require the S10 interface between MMEs. It could also speed up the network reselection (by how much would need to be quantified). The UE IP address would in most cases change with this solution.
   b. An alternative solution that was considered but not investigated in the project was based on a permanent roaming situation for each vehicle crossing the border (i.e. the vehicle is always in roaming regardless of the serving PLMN). This leverages multiple transmission/reception chains on the vehicle side as well as the availability of MEC platforms deployed on each side of the border (communicating via an inter-MEC interface which is used to coordinate in a V2X retrieval/transfer context and for triggering transmission/reception chains, i.e. 'switch on/off'), along with local breakout mechanisms enabled in all involved PLMNs. Permanent roaming can be achieved by equipping vehicles with UMTS subscriber identify modules (USIMs) provided by a supranational body, which is also responsible for charging, lawful interception etc. Each transmission/reception chain is thus linked to a certain USIM. Main drawbacks to this approach could be the likelihood of ping-pong effects, the need to support multiple transmission/reception chains at the vehicle side, and the need for radio coverage overlapping between two adjacent PLMNs.
   c. The 5G-CARMEN approach and results should be followed up.
4. Knowledge of any improvements being implemented in 5GCroCo [6] and 5G-MOBIX [8], and the results.
5. Knowledge of any improvements being implemented in upcoming 5GMED [5], 5G-Routes and 5G-Blueprint projects [9] and related results.

The following business considerations need further study:

1. Roaming agreements.
2. Organisation setup to cooperate.
3. Cost to reconfigure and test networks.
4. Sensitivity to sharing information regarding radio network configuration (radio cell/node identity).
5. Potential anti-competitive aspects if not all MNOs are included/involved.
6. The business value of improving network reselection times for the different actors.

8 Additional information

No legal/regulatory implications have been identified so far, i.e. an MNO can make roaming agreements with its preferred partners without legal , so it is assumed that NRIs agreed between MNOs should be similar.

9 Conclusions

Based on the findings from this initial investigation, use of existing 3GPP standards can bring the user plane interruption down from what can be several minutes to around 100 ms. However, further work is required to fully analyse the impact of doing so, and the business requirements/drivers based on use cases outlined in Chapter 10 (next steps).

10 Next steps

- 5GAA members participating in the 5G-CARMEN project [7] are expected to provide 5GAA updates on the project's progress in what pertains to the activities of the NRI XWI.
- The NRI XWI supporters will continue engaging with EU cross-border projects 5G-MOBIX [8] and 5GCroCo [6] to obtain details of their implementations and findings.
- Similarly, the NRI XWI supporters will approach the upcoming EU cross-border projects 5GMED [5], 5G-Routes and 5G-Blueprint projects [9] to obtain details of their implementations and findings.
- Profiting from the well-established relationship between 5GAA and GSMA, the NRI XWI supporters will work closely with GSMA towards a establishing a proof of concept for NRI with MNOs in three different regions (North America, Europe, Asia).
- Support from WG5 will be sought by NRI XWI supporters to investigate the business aspects of network reselection improvements, including but not limited to the following points:
    - Business case, business models, potential revenue, maintaining networks for network reselection, applicability to non-connected vehicle-customer segments, potential bundling of service packages (e.g. international data plans).
    - Given the current momentum in the industry, such a study should be prioritised, if possible.
    - Applicability to different regions of the world (potentially a WG5/WG3 XWI).
- The WG5 investigations are expected to represent an indispensable condition for the continuation of the needed further studies in Section 7.

Annex A: 4G

Input from 3GPP TS 23.401

A.1.1 UE roaming with new registration

When a UE loses the connectivity to a serving operator, the roaming procedure will take place. In particular, as described in [TS23.122], the UE will perform PLMN selection and identify the most suitable PLMN (according to its configuration).

The registration procedure is described in [TS23.401] and is shown in Figure 1. The following steps are needed in the inter-PLMN case:

i) Since the UE is unknown to the new (VPLMN) MME, it sends an Identity Request to the UE for the international mobile subscriber identity (IMSI).

ii) Authentication and Non Access Stratum (NAS) security setup are required to activate integrity protection and NAS cyphering.

iii) The (VPLMN) MME needs to contact the HPLMN HSS in order to perform a location update.

iv) The (VPLMN) MME sets up the bearers.

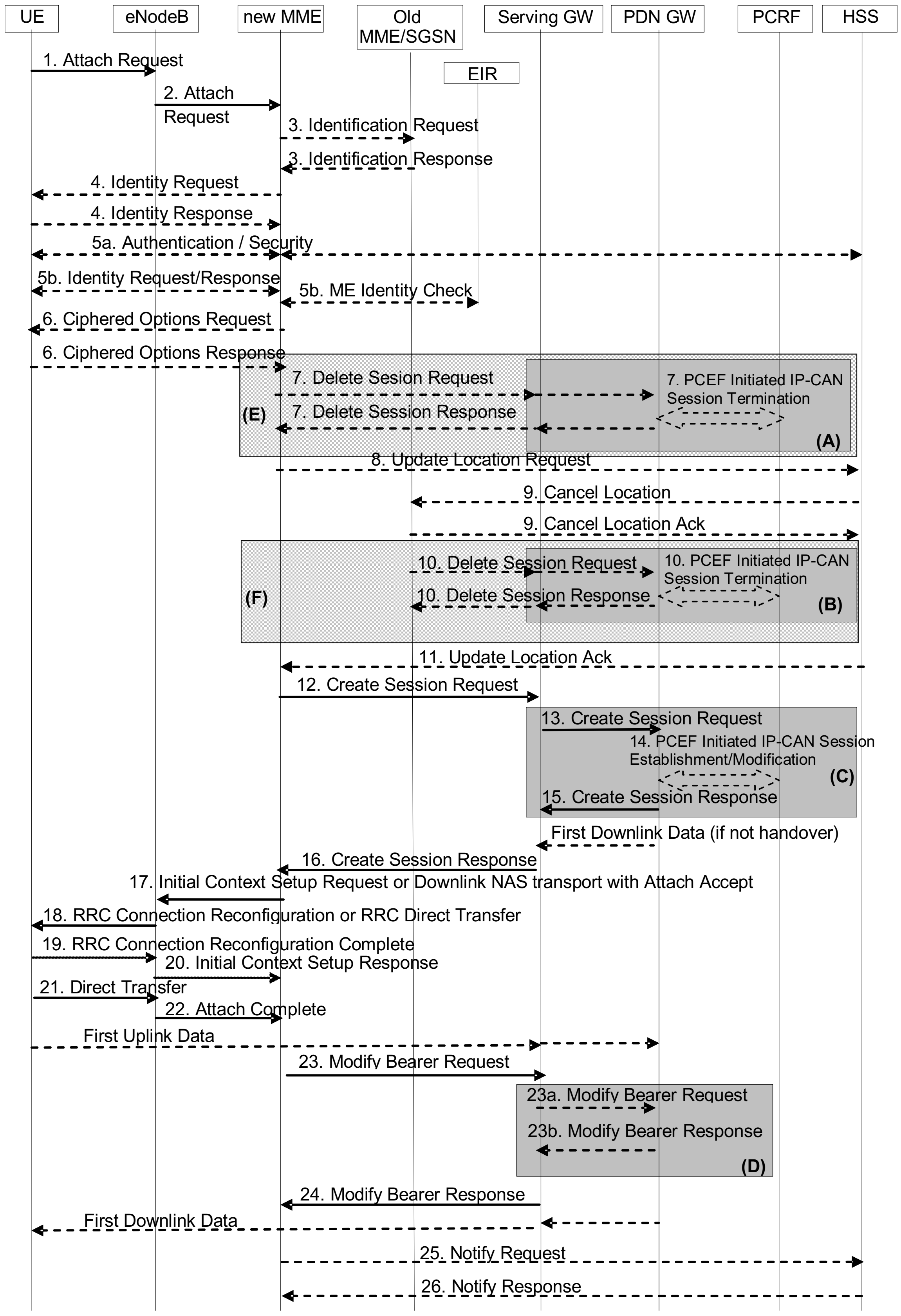

Figure I: New registration

A.1.2 Handover

An additional step would be to support handover, as defined by 3GPP, between the networks, i.e. as it works today within a network. In such a scenario, the architecture would be the same as in Error! Reference source not found, but also configure the handover functions. In this case, handover implies that the source or 'controlling' network obtains information from the UE about candidates by contacting the potential target network and asking it for resources; if granted, the source network sends a 'handover command' to the UE with information about the target network, and the UE then tunes into and connects to the new network.

The handover procedure is an elaboration of the steps related to inter-PLMN aspects:

- Once the UE identifies suitable handover candidates, it provides them to the serving eNB. The latter then examines if it has X2 connectivity with the target eNB. If not, it informs the source MME via a Handover Required message which includes: Direct Forwarding Path Availability (DFPA), Source- to-Target transparent container, target eNodeB Identity, CSG ID, CSG Access Mode, target TAI, and S1AP Cause. The DFPA indicates whether direct forwarding is available from the source eNB to the target eNB – which thanks to the multi-MNO environment is not available in this case.
- The source MME selects the target MME and provides the Forward Relocation Request message to the target MME. This includes: MME UE context, Source-to-Target transparent container, RAN Cause, target eNodeB Identity, CSG ID, CSG Membership Indication, target TAI, MS Info Change Reporting Action (if available), CSG Information Reporting Action (if available), UE Time Zone, Direct Forwarding Flag, Serving Network, Local Home Network ID, LTE-M UE Indication.
- The target MME of the VPLMN should select a new Serving GW and send it a Create Session Request.
- The source eNodeB should start forwarding downlink data from the source eNodeB towards the target eNodeB for bearers subject to data forwarding. This implies that the Source Serving Gateway should be configured accordingly in order to provide the data to the Target Serving Gateway.

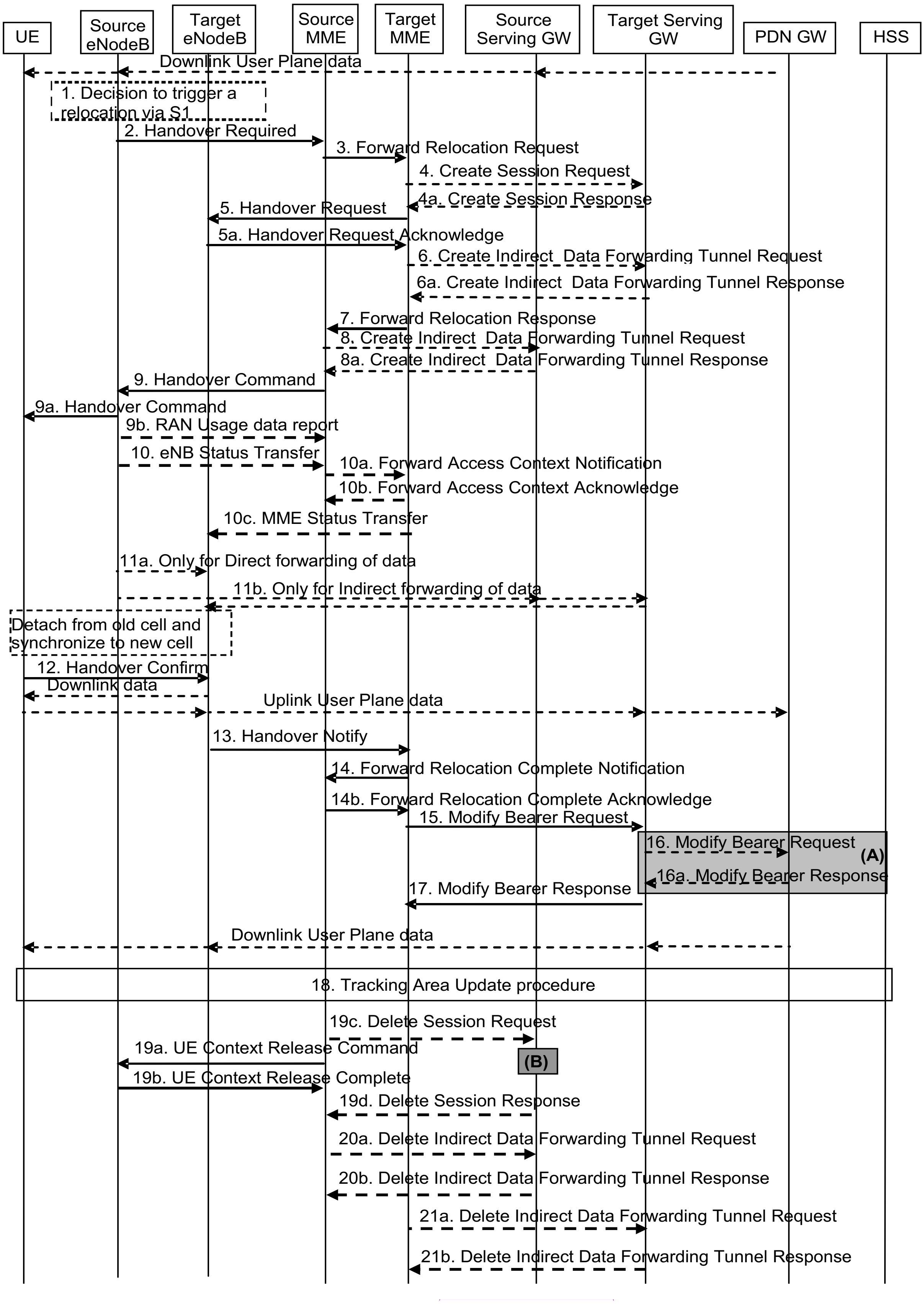

Figure II: Handover procedure

Annex B: 5G

Input from 3GPP TS 23.401

B.1.1 UE roaming with new registration

Once a UE loses connection with a serving operator, the roaming procedure will take place. In particular, as described in [TS23.122], the UE will perform PLMN selection and identify the most suitable PLMN (according to its configuration).

The registration procedure is described in [TS23.502] and is shown in Figure X. The UE shall indicate its UE identity in the Registration Request message as follows, listed in decreasing order of preference:

i) a 5G-GUTI mapped from an EPS GUTI, if the UE has a valid EPS GUTI.

ii) a native 5G-GUTI assigned by the PLMN to which the UE is attempting to register, if available;

iii) a native 5G-GUTI assigned by an equivalent PLMN to the PLMN to which the UE is attempting to register, if available;

iv) a native 5G-GUTI assigned by any other PLMN, if available.

The procedures related to the roaming case are described in [TS23.122] and relate to the context retrieval of the UE from the HPLMN UDM.

In particular (as shown in Figure Y) the VPLMN AMF invokes Nudm_SDM_Get service operation message to the HPLMN UDM to get amongst other information the Access and Mobility Subscription data for the UE (see 3GPP TS 23.502).

In any case, the delay to attach to a VPLMN is 100 seconds on average because of the sequential process and the context transfer procedure [MBTW18]. In the case of the HPLMN the registration requires significant time as well – in the range of 9 seconds according to the same measurements' analysis.

This solution is implemented using the N8 interface among the operators and does not require deployment of N14.

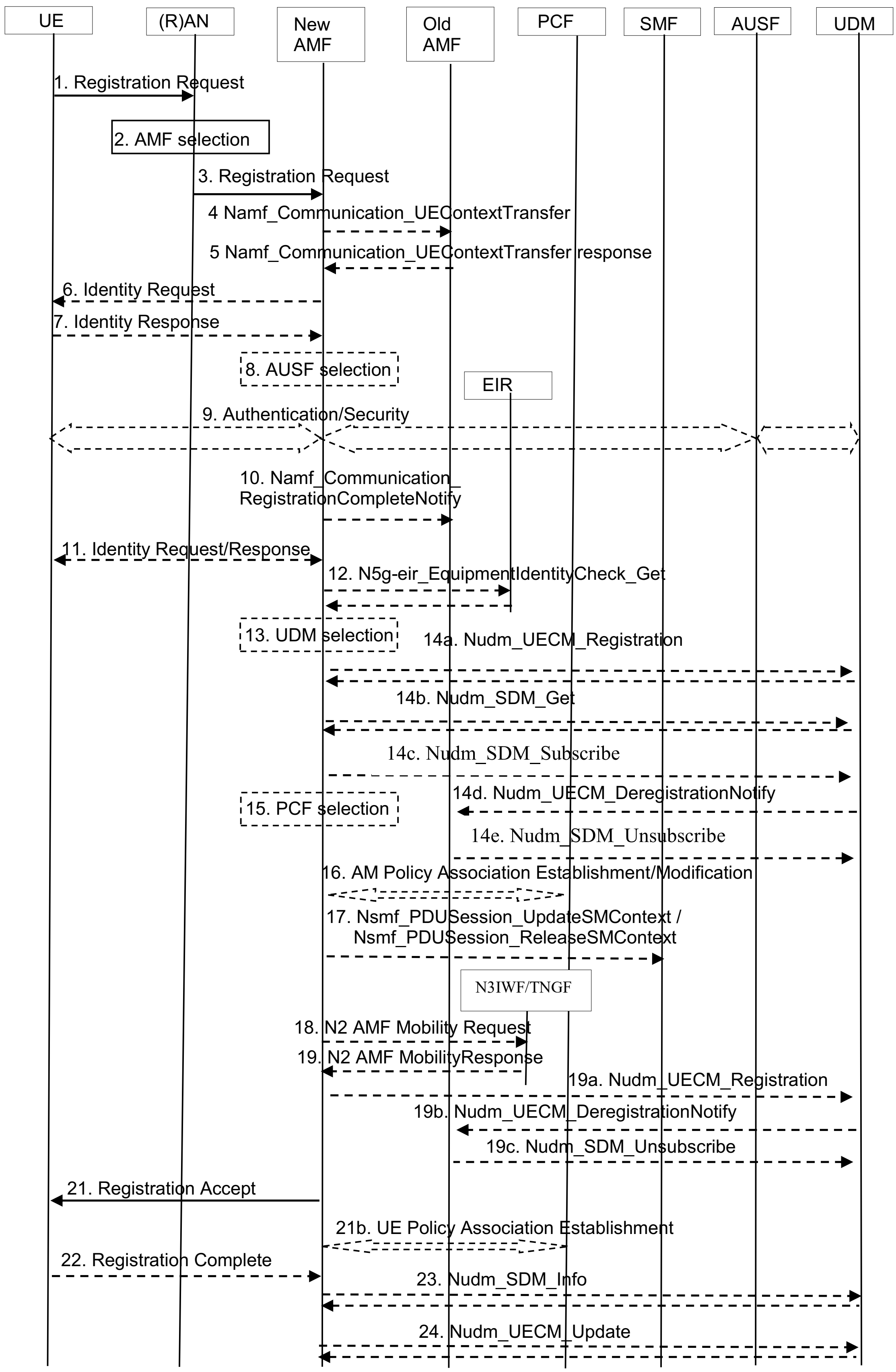

Figure III: Registration procedure

B.1.2 Handover

Inter-MNO handover for 5G systems has been described in detail in [23502]. The solution is an elaborated version of the N2-based handover and requires N14 deployment between the operators.

The procedure consists of two phases, the preparation and the execution phase, presented in Figures X and Y respectively.

- Preparation phase (elaboration of the steps related to inter-PLMN aspects):
    - Once the UE identifies potential gNBs that are suitable for it to be handed over it provides them to the serving gNB. The latter examines if it has Xn connectivity with the target gNB. If not, it informs the serving AMF (S-AMF) through a Handover Required message, which includes: the Target ID, Source-to-Target transparent container, SM N2 information list, PDU Session IDs, Intra-system Handover Indication. Then, the S-AMF selects the T-AMF by following the AMF discovery and selection procedure, querying the target PLMN-level NRF via the source PLMN-level NRF with target PLMN ID. The target PLMN-level NRF returns an AMF Instance address based on the Target Operator configuration.
    - Then the S-AMF provides to the T-AMF the Namf_Communication_CreateUEContext Request, including the target cell ID, UE information, and slicing information.
    - The SMF of the VPLMN should select a new UPF to act as an intermediate for the PDU Session, and the different CN Tunnel Information that needs to be used. Thus, the SMF sends an N4 Session Modification Request message to the UPF (PSA). The SMF provides the CN Tunnel Information (on N9); if this information is allocated by the SMF, the UL Packet detection rules associate the CN Tunnel Information (on N9) to be installed on the UPF (PSA). The UPF (PSA) responds accordingly and the SMF sets up the session using the T-UPF.
    - Afterwards the T-AMF communicates with the T-RAN according to the standard N2-based handover with AMF relocation, and then the T-AMF informs the S-AMF about the handover procedure's progress.

- Execution phase (elaboration of the steps related to inter-PLMN aspects):
    - As shown in the figure, uplink packets are sent from the T-RAN to T-UPF and UPF (PSA). Downlink packets are sent from the UPF (PSA) to S-RAN via S-UPF. The S-RAN should start forwarding downlink data from the S-RAN towards the T-RAN for QoS Flows or DRBs subject to data-forwarding. This may be either direct (step 3a) or indirect forwarding, step 3b).
    - In order to assist the reordering function in the T-RAN, the UPF (PSA) sends one or more 'end marker' packets for each N3 tunnel on the old path, immediately after switching the path, and the source NG-RAN forwards the 'end marker' packets to the target NG-RAN. Thus, the UPF (PSA) starts sending downlink packets to the T-RAN, via T-UPF. Since it is a home routed roaming scenario, the H-SMF responds with the Nsmf_PDUSession_Update Response service operation to V-SMF once the H-UPF (PDU Session Anchor) is updated with the UL Tunnel Information from the T-UPF.

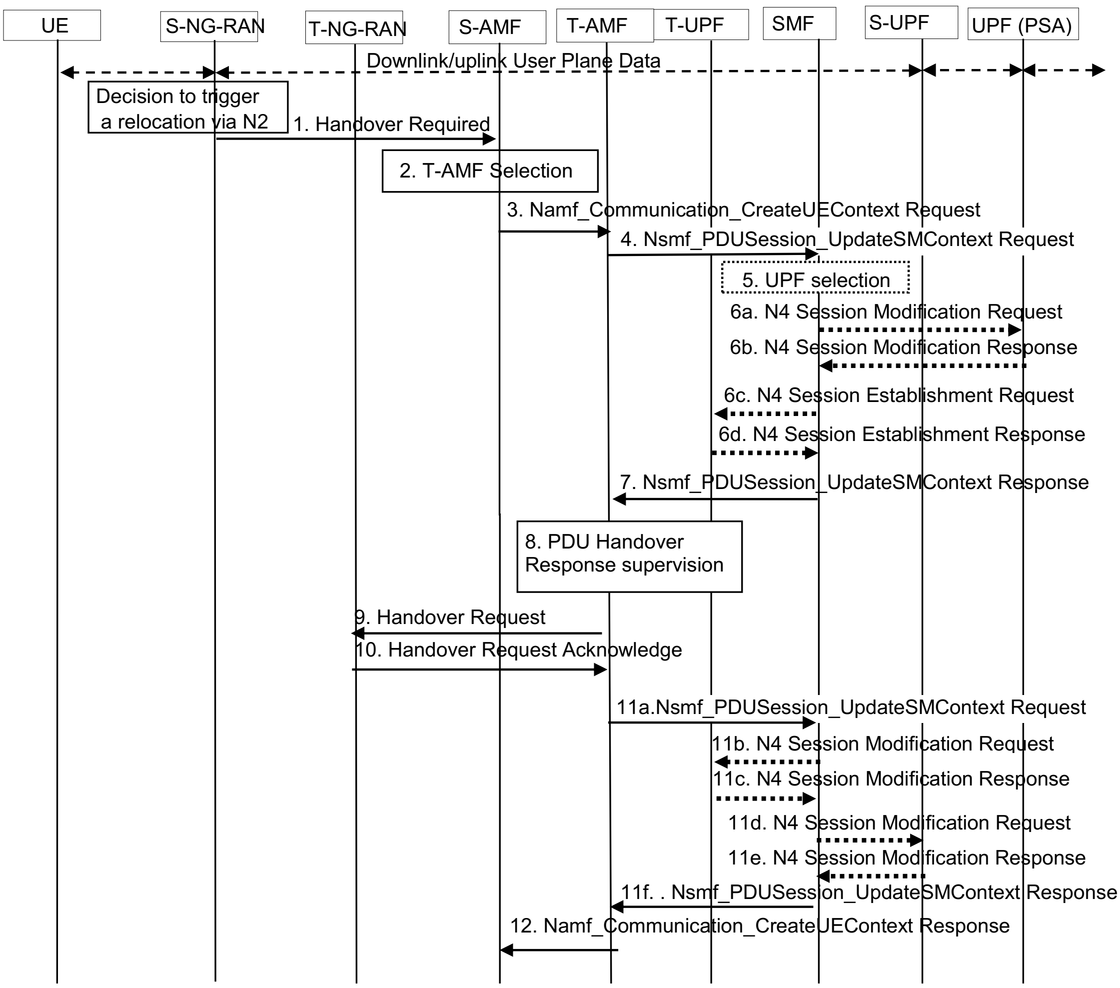

Figure IV: Inter-NG-RAN node N2 based handover, preparation phase [TS23502]

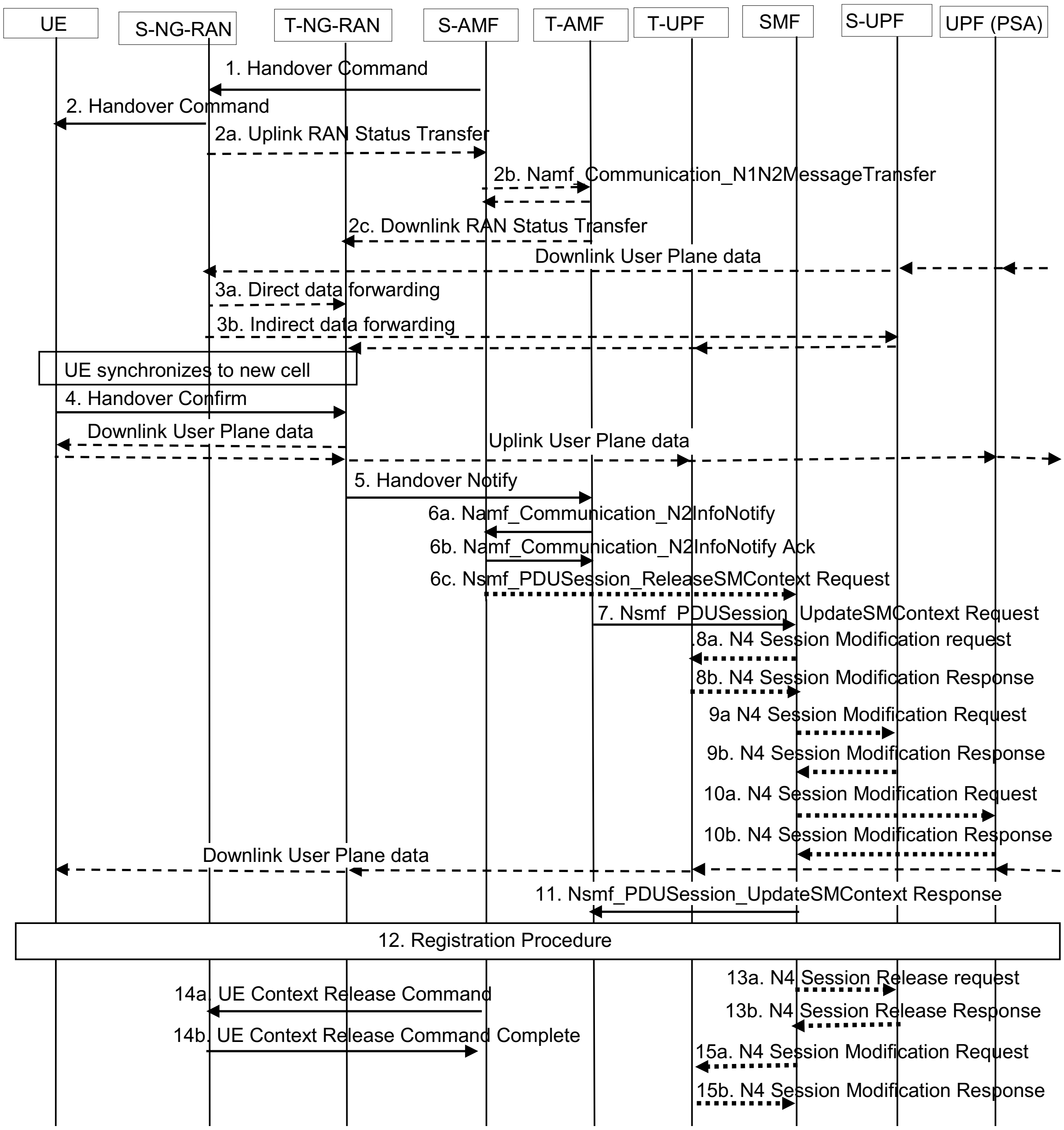

Figure V: Inter-NG-RAN node N2-based handover, execution phase [TS23502]

Annex C: UC thoughts

This annex contains some initial thoughts regarding UC sensitivity to interruption and how to evaluate it.

Here, three groups have been defined according to what can be achieved based on existing 3GPP specifications. The three groups are: ‘Idle mode mobility’, ‘Inter-PLMN HO’, and ‘Additional measures’. For each of these, a few sample UCs are evaluated regarding the likelihood that PLMN/MNO change would occur, potential implications, potential mitigations, etc.

C.1 Idle mode mobility

In this group use cases, ~1 second connection interruption is indicated. Note, several of these UCs can operate with higher interruption times.

C.1.1 Traffic jam warning and route information

This is a frequently cited UC today in the automotive industry, e.g. among OEMs and in various projects such as Nordic Way, this UC is not considered to be particularly sensitive.

C.1.2 In-vehicle entertainment (IVE)

This UC contains multiple sub-cases, i.e. high-definition content delivery (HDCD), on-line gaming and virtual reality, and it is assumed that HDCD will operate properly with a 1 second interruption, i.e. because content is normally buffered to mitigate delays in packet delivery, or ‘jitter’.

C.1.3 UC tele-operated parking

This UC indicator allows for a maximum 100 ms interruption, according to some literature. However, this UC is executed at low speeds and in confined areas, e.g. parking lot/garage where MNO coverage is feasible and there is a commercial incentive to cover such a spot. The multi-MNO coverage could be achieved by network-sharing agreements or when the parking lot owner provides site access, but also potentially backhaul and a power source for the MNO’s equipment in a similar way as a tower company. If, however, network reselection is needed for this UC, it is assumed that an interruption time of ~1 second could be acceptable, i.e. due to the low speed.

C.2 Inter-PLMN HO

In this group, indicative UCs can sustain ~100 ms of connection interruption.

C.2.1 High definition map collecting & sharing

Even though this UC is indicated as requiring a maximum of ~100 ms interruption, it is likely that higher interruptions can be tolerated because map data is normally downloaded in advance. This could also be addressed with (advance) knowledge of the upcoming PLMN change.

C.2.2. Interactive VRU-crossing

The problem with interruption for this UC can be mitigated by planning where PLMN change should take place, i.e. the point for change can be moved to avoid a VRU-crossing area.

C.3 Additional measures

In this group, indicative UCs require less than 100 ms of connection interruption. Additional measures might be necessary to reduce interruption time. One way to mitigate this is to raise awareness of an upcoming interruption. For example, industry is discussing the use of coverage maps and other prediction features, such as NESQO, eNESQO.

C.3.1 UC tele-operated driving/support

This type of UC will likely appear in different phases; first in confined areas, and later in more open public areas. These two scenarios are elaborated below.

C.3.1.1 First phase, confined areas

Tele-operated driving/support for self-driving vehicles in confined areas is a reasonable initial approach to provide area coverage within the same network, i.e. first usage is likely to be at ports, airports, transport hubs, mines, industrial areas, etc. When public transportation becomes automated, it is likely to be similar to confined areas (i.e. separate lanes) and known routes in cities where coverage can be built, if not already in place. For this set of UCs, one single network could be expected to provide the coverage, since the beneficiaries (industries served) would rather sign up with one MNO who can provide and ensure coverage throughout the area in question. This UC could thus be supported without a corresponding NRI.

C.3.1.2 Second phase, public areas

For self-driving private vehicles on public roads, a network connection is required and assumed in many ongoing trials and proofs of concept. This is because the provider of the self-driving system is liable for the vehicle's behaviour in self-driving mode and needs to be able to hand over control to the driver. A network connection is also required in some early legislation in this field, e.g. in California, see reference [3]. One way this is handled today is that certain roads or road sections are flagged as 'allowed routes' for self-driving where connectivity is in place and no driving problems are likely or expected, e.g. no accidents on the road stretch ahead. When vehicles leave these areas, control is handed back to the driver.

For these scenarios, tele-operated driving/support UCs can be handled by a single MNO, providing control is handed back to the driver when connection to the serving MNO is lost. Or it can be covered by a standing NRI to increase the benefits of self-driving. Here, a 1-second connectivity interruption caused by the idle mode mobility solution is expected to be acceptable if the self-driving system is made aware of the upcoming interruption in advance. The advanced notification could, for example, be based in known inter-PLMN zones where short interruptions take place.

For Level 5 autonomous vehicles without a steering wheel or even place for a person in the vehicle to take over, connectivity is clearly more crucial. This scenario can be handled if the vehicle only uses routes where the active MNO has coverage, or an NRI is applied. A short interruption is acceptable if the self-driving system is made aware of the upcoming event in advance. It is worth noting that Level 5 vehicles are not likely to be present on public roads for quite some time. Constant improvements in coverage are expected to be able to handle such an eventuality.

These UCs could also use mobile network QoS to ensure that enough capacity is available if it becomes necessary to activate teleoperated driving/support.

Annex D: Change history

Date	Meeting	TDoc	Subject/Comment
29-Nov-2019	NRI Call #1	XWG7-190002	First structure presented
3 to 7-Feb-2020	F2F #13	XW7-200001	Consolidation of sections on 4G and 5G
12-Mar-2020	NRI Call #4	XW7-200004	Progress on Problem Description Section
11 to 15-May-2020	F2F #14	XW7-200008	Consolidation of OEM and MNO considerations
27 to 31-July-2020	F2F #15	XW7-200012	Refinement of conclusive parts of the Report
April 2021	Offline	XW7-200012 r2	Editorial checks and text polish

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