**Grant Agreement N°:** 952189
**Topic:** ICT-53-2020

5G BLUEPRINT

Next generation connectivity for enhanced, safe & efficient transport & logistics

# D5.3
# Technical requirements and governance guidelines for MNO's, vendors and national authorities to support seamless cross border roaming

Revision: v.1.0

| | |
|---|---|
| Work package | WP 5 |
| Task | 5.3 |
| Due date | 30/9/2023 |
| Submission date | 29/9/2023 |
| Deliverable lead | KPN |
| Version | 1.0 |

# Abstract

The convergence of Tele-Operated (TO) Transport, particularly in a cross-border setting, and the methodologies involved to enable seamless handover using 5G technology, are more than just technical advancements. They hold the potential to significantly disrupt established industries, causing far-reaching consequences for governance and regulatory frameworks. This document introduces a theoretical approach designed to evaluate the consequences of implementing seamless transitions in cross-border regions and across entire nations. The methodology involves identifying deployment models suitable for mobile operators and aligning these models with the technical procedures required for seamless handover to facilitate TO services. The entire analysis involves identifying implications for operators, examining the effects on the commercial roaming business, and offering high-level recommendations regarding the practicalities of deploying seamless handover for TO services, whether in the short or long term. In summary, this document serves as comprehensive guidance for understanding the effects of supporting TO transport for the roaming business across commercial, operational, and regulatory perspectives when pursued in short, mid, or long term.


**Keywords:** Roaming, seamless cross border, Teleoperation, 5G networks, governance

**Document Revision History**

| Version | Date | Description of change | List of contributor(s) |
|---|---|---|---|
| V0.2 | 16/8/2023 | Draft for internal review | Leendert Koning (KPN),<br>Natasha Degroote (Telenet) |
| V0.3 | 11/9/2023 | Draft for internal review | Marloes van Caspel (KPN) |
| V1.0 | 29/9/2023 | Final review | Eric Kenis (MOW Vlaanderen), Joost Vandenbossche (Movias) Johann Marquez-Barja (imec-UAntwerpen), Nina Slamnik (imec-UAntwerpen), Peter Paul Schackmann (TNO), Wim Vandenberghe (Dutch Ministry IenW), Natasha Degroote (Telenet) and Leendert Koning (KPN) |

| Project co-funded by the European Commission under H2020-ICT-2018-20 | | |
|---|---|---|
| Nature of the deliverable: | R | |
| Dissemination Level | | |
| PU | Public, fully open, e.g. web | √ |
| CI | Classified, information as referred to in Commission Decision 2001/844/EC | |
| CO | Confidential to 5G-Blueprint project and Commission Services | |

* R: Document, report (excluding the periodic and final reports)
DEM: Demonstrator, pilot, prototype, plan designs
DEC: Websites, patents filing, press & media actions, videos, etc.
OTHER: Software, technical diagram, etc

# EXECUTIVE SUMMARY

This executive summary provides an exploration of the implications and potential transformations in the realm of international roaming business, with a specific focus on the support of Tele-Operated (TO) transport services. The primary objective is to assess the impact of implementing **seamless cross-border roaming for TO transport** and to offer recommendations for the future development of this evolving field.

Roaming is about providing users connectivity regardless of their location outside their home network, breaking down geographical barriers. Mobile Network Operators (MNOs) must navigate technical, operational, and regulatory complexities to ensure seamless mobile services for customers, negotiating agreements and configuring network interconnections.

The development of Tele-Operated Driving (TOD) services presents significant challenges for mobile networks, requiring high bandwidth and maximum availability, which will necessitate substantial network investments by operators across the EU.

**A theoretical framework** was introduced based on the use of models and technical mechanism to support the handover for TO services. The conclusions drawn from these challenges will directly influence the commercial model for TO services, as well as the cross-border roaming solution and governance guidelines. The analysis considers specific use cases such as automated barge control, Cooperative Adaptive Cruise Control (CACC)-based platooning, and Remote Take Over. Including as well essential considerations for the implementation of TOD and 5G-based TO services, such as Network Slicing, Coverage on Demand (CoD) and pathways for TOD implementations.

Two main approaches are outlined for implementing Tele-Operated Driving (TOD): a priority scenario focused on the rapid deployment of 5G infrastructure in specific areas to deliver immediate benefits, and a gradual evolution scenario involving phased development and integration of 5G technology with urban planning and transportation over time.

Furthermore, the framework involves an analysis based on **inter-operator models**, each with distinct characteristics and implications for cross-border roaming. These models are:

- **Shared Network Corridor Model**: exploring scenarios where multiple operators share network resources to facilitate seamless roaming.
- **Licensed Corridor Model**: in this model operators have a specific license for cross-border operations.
- **Competing Corridor Model**: analysing situations where operators from different regions compete to offer roaming services within a predefined area.
- **Business as Usual Model**: assessing the traditional model of international roaming, nationwide coverage without the use of corridors.

From a governance perspective, important **mechanisms to ensure seamless handover** are the inter-PLMN handover, the concept of optimized Steering of Roaming (SoR) and Dual IMSI.

- **Inter-PLMN**: Inter-PLMN handover, a technically advanced solution primarily intended for predefined locations, like neighbouring border areas, has shown near-seamless performance in controlled lab and pilot site tests. While it seems suitable for short-term deployment from a network perspective, its commercial implementation involves more complexities beyond technical aspects, including operational challenges and security considerations.
- **Optimized SoR**: the network selection procedure SoR is essential during roaming, ensuring the User Equipment (UE) connects to the most suitable network. While it serves general purposes well, it lacks specific support for TO services, necessitating the development of an optimized SoR concept. This approach aims to provide seamless handover tailored to TO service requirements and offers extensive geographical

coverage.

- **Dual IMSI**: with Dual IMSI the concept of using two SIMs to enable seamless handover during roaming is being explored. This technique allows for smooth transitions without the need for roaming adjustments, offering potential benefits for cross-border TO services. Testing and details will be provided in 5G Blueprint Deliverable D5.5.

Subsequently the various scenarios have been mapped to the different mechanisms, highlighting the differences, advantages, and limitations of each scenario while considering both short-term and gradual development needs.

The shared network corridor model enables multiple operators to share a single radio network infrastructure in a designated corridor, simplifying seamless roaming but limiting competition based on network quality. This model carries extensive technical, commercial, as well as regulatory consequences. Subsequently, it introduces challenges for cross-border scalability beyond neighbouring countries.

The licensed corridor model grants exclusive rights to a single operator for providing TOD services in a specific corridor, simplifying network selection but limiting competition and potentially causing bidding wars and regulatory complexities. This approach may not align with the goal of fair competition and could hinder service development due to a lack of backup coverage solutions.

In the competing corridor model, operators establish their TOD corridors, which may vary in coverage areas. Roaming subscribers can benefit from the combined coverage, but coordinating handovers where these networks intersect, especially across borders, poses technical complexities. While this strategy offers some advantages, it becomes more complex as services expand, particularly when dealing with borders beyond neighbouring countries.

The business-as-usual model, operating without distinct TOD corridors, delivers services primarily at key locations such as highways, reflecting today's situation. This model presents challenges in ensuring uninterrupted service throughout the entire route and securing favourable roaming rates without the capability of network selection. However, it is expected to have the least impact on existing regulations and can be combined with the concept of optimized SoR for flexibility and cost-effectiveness. The timing of introducing CoD and other 5G services plays a crucial role in this model's effectiveness.

In conclusion, TOD cross-border driving when implemented in a "business-as-usual" roaming model, combined with optimized SoR handover capabilities, represents a durable solution to address the changing requirements of TOD. This approach safeguards competition within the roaming industry, expands global coverage and has limited technical and regulatory implications. However, hybrid solutions may be required to meet the specific demands of TO use cases.

**Additional key aspects** include the importance of government engagement, specifically the Ministry of Transportation, in overseeing teleoperations within the transportation sector. This includes establishing legal frameworks, the definition of equipment safety standards, identification of scenarios requiring teleoperation, and the management of capacity needs through a CoD solution to optimize resource allocation.

Recommendations for future cross-border roaming roadmap emphasize the need for clarity in objectives and approaches, providing a **generic roadmap** with key milestones:

1) define the purpose and goal, considering the larger framework and varying requirements for seamless border crossings.
2) Develop a timeline that aligns with the defined goal, especially important in resource-intensive environments.
3) Select a suitable business model, exploring options across different countries.
4) Derive requirements for the chosen model, including coverage, capacity, and QoS considerations.
5) Ensure industry standards support requirements, particularly in the case of inter-PLMN

handovers.

6) Establish contractual arrangements between operators, outlining aspects like handovers, service levels, penalties, and reports.

The last chapter also includes **the governance between MNOs**, emphasizing prerequisites such as defining quality, having a well-defined business model and clear network crossing methods. Recommendations include implementing roaming SLAs, making financial commitments, and enhancing internal knowledge of network performance, following standardized measurements and parameters.

To conclude, three technical concepts for achieving seamless handover in cross-border teleoperations within the context of 5G were presented. While one concept is more detailed, all are based on 3GPP Release 16 standards. Trials of Inter-PLMN have shown promise in a controlled environment, but challenges remain, such as compliance, billing, and scalability. Dual-IMSI and Optimized SoR need to be further explored. The resolutions should be addressed in subsequent 3GPP releases.

Considering the ongoing evolution of mobile networks, the teleoperation for driving use cases is still a considerable distance away from its current state. To support specific use cases in an earlier stage, alternative business models, such as dedicated infrastructure for CoD, Network Slices, or hybrid models, may be advisable in the future.

The exploration of MNO services for support reveals that it's improbable for MNOs to provide 100% service guarantees, primarily due to factors beyond their control. Liability definitions will be subject to negotiations among involved parties and may be influenced by regulations, ultimately shaping the terms of responsibility within the operational and legal framework set by NRAs.

Evaluating QoS on roaming networks as the home operator is challenging, especially across multiple countries. Full cross-border teleoperation, from any point to any other, is practically unfeasible due to technical and governance issues. To address this, it is recommended to restrict border crossings to highways with secure autonomous passage and fallback measures. Indirect-control teleoperation, relying on AD capabilities, is suitable for cross-border operations, while direct-control teleoperation should be limited to private terrains and local roads, especially before AD systems are available.

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

## ABBREVIATIONS

| | |
|---|---|
| **5GBP** | 5G Blueprint Project |
| **5GC** | 5G Core |
| **5GS** | 5G System |
| **5G SA** | 5G Standalone |
| **AD** | Autonomous Driving |
| **AMF** | Access and Mobility Management Function |
| **CoD** | Coverage on Demand |
| **EF** | Enabling Function |
| **eMBB** | Enhanced Mobile Broadband |
| **HPLMN** | Home PLMN |
| **HSS** | Home Subscriber Server |
| **IMF** | Information Management and Services |
| **MNO** | Mobile Network Operator |
| **NR** | New Radio |
| **PLMN** | Public Land Mobile Network |
| **QoS** | Quality of Service |
| **RAEX** | Roaming Agreement Exchange |
| **S-NSSAI** | Single Network Slice Selection Assistance Information |
| **SIM** | Subscriber Identity Module |
| **SLA** | Service Level Agreement |
| **SoR** | Steering of Roaming |
| **TO** | Tele-Operations |
| **TOD** | Tele-Operated Driving |
| **UC** | Use Case |
| **UDM** | Unified Data Management |
| **UE** | User Equipment |
| **UL** | Update Location |
| **VPLMN** | Visited PLMN |

# 1 INTRODUCTION

## 1.1 Task goal

- Governance between MNOs at cross border section
- This task will discuss open standards for seamless cross border roaming in a level playing field environment. It also is to provide input and guidance for defining a general set of guidelines and recommendations for future cross border roaming which has been agreed upon with vendors and MNO's.

## 1.2 Scope

This document combines the result of two initially separate deliverables: technical requirements and governance guidelines.The guidelines provide a theoretical framework to support 5G Standalone (5G SA) seamless handover roaming in (1) cross-border areas and (2) nationwide, considering the high-level competitive playing field of roaming business.

The document is structured as follows: in Section 2, a general overview of the roaming business is presented, followed by the explanation of a model-based approach and the possible methods to provide seamless handover in the cross-country corridors/covered area of the visited mobile network operator.

In Section 3, the previously mentioned solutions are mapped to different models where specific challenges and characteristics are detailed for cross-border environments. Each model, combined with a specific technical solution, is described to underscore the limitations or benefits of each.

Section 4 outlines the possible impact on roaming agreements and outcomes concerning quality.

Finally, a generic roadmap for achieving efficient cross-border roaming is provided in Section 5, emphasizing on the governance aspects between Mobile Network Operators (MNOs) and providing prerequisites and recommendations for governance guidelines.

Business and technical requirements to deploy 5G SA Seamless Roaming are provided in the appendix.

# 2 OVERVIEW

## 2.1 International roaming business

For roaming connectivity, MNOs rely on radio coverage. The domestic operator that offers services within its network's coverage area to its customers is referred to as Home Public Land Mobile Network (HPLMN). In a roaming scenario, when a mobile subscriber travels to a different region or country, their device automatically connects to a Visited Public Land Mobile Network (VPLMN), which is the network operated by a different provider in that visited area. Roaming can be used either domestically (i.e., nationally) or abroad (i.e., internationally).

National roaming takes place when moving to a different region within the home country, leading the device to connect to a different mobile provider's network. International roaming is all access when travelling to another country, causing the device to connect to a foreign mobile provider's network. It is the responsibility of an MNO to arrange international roaming where desired/required commercially and technically. Additionally, national roaming is also an option. It can, for instance, be used to share coverage in scarcely populated areas within the same country.

Different network generations use different radio access technologies. MNOs may serve one or more network generations (2G to 5G and beyond), each with its own footprint. Each country or territory may have radio coverage from multiple MNOs. Which network is selected in case of roaming, depends on a variety of factors, e;g. signal strength of individual networks, weather conditions, customer preferences, and commercial considerations.

Various commercial forms exist. MNOs may for instance be part of an international group, use a roaming hub, a roaming exchange or unilaterally/bilaterally agree with every roaming partner individually.

Assuming a bilateral International Roaming Agreement, two MNOs have a legal framework for offering each other roaming services. Roaming services, e.g., Voice, SMS, LTE, VoLTE, etc., are for instance roaming access to specific network generations. Roaming services in general need to be configured and tested in advance, i.e., before their commercial launch. Partly due to the time it takes, not all roaming partners have (already) launched all their mutually available roaming services. Delays in launching roaming scenarios can pose several challenges, such as customer satisfaction, market competitiveness, revenue loss and operational complexities by introducing workarounds.

For historical reasons, the financial baseline for the use of roaming services is often/usually the MNO's Inter-Operator Tariff pricelist; currently for automation purposes, usually exchanged through Roaming Agreement EXchange (RAEX).[1] Roaming partners may choose to sign a discount agreement on that baseline.

An MNO is often able to influence the selected roaming network for its subscribers. Since there is often more than one MNO offering roaming services in the same area, there is a competition. The Home Network Operators have criteria for selecting the preferred partner network for a roaming subscriber. These criteria can include factors such as network quality, coverage, available services and cost. Therefore, not all networks may be equally suitable for every subscriber group. Operators usually do not use exclusive contracts, but instead, divide their traffic over networks in a country. MNOs will trade their traffic to achieve the best financial position, while considering the criteria mentioned earlier.

Mechanisms to influence the selected preferred partner network are known as Steering of

[1] Further information is available to GSMA members via Member Gateway. The Interoperability Data specifications and Settlement Group (IDS) is responsible for the development and implementation of this generally used RAEX industry solution.

Roaming (SoR) solution. The SoR solution can be based on signalling messages from roaming subscribers, attempting to access a network. As an alternative, or in combination with these methods, the operator can also perform steering by updating the content of the preferred PLMN list(s) in the roamer's SIM card (Subscriber Identity Module).

These signalling-based steering methods are not related to the update of SIMs but use the messages, which are in 4G addressed to the HPLMN Home Subscriber Server (HSS). In contrast to the earlier solutions, for 5G SoR is integrated in the specifications.[2] This results in roamers being redirected to more preferred network. Over-the-air SIM updates are more complex to set-up, e.g. it depends on network connectivity and device compatibility. Signalling based SoR is a more dynamic and cost-efficient solution than SIM updates.

Roaming is not just about crossing a border. It is about providing users connectivity, regardless of their location outside their HPLMN. It is about breaking down geographical barriers and enabling customers to stay connected and access services no matter where they are. Despite the deployment of 5G on a large scale, challenges persist in terms of cross-border coverage and maintaining continuous service across different MNOs. There is no easy way to determine the quality of a roaming network. The quality can vary per location and over time. There are numerous quality parameters, all can have different values. For instance: the bandwidth in a network can be high and the availability low. From a service perspective, the actual challenge may well be substantially bigger than a fast or seamless border crossing. Within this dynamic landscape, MNOs must deal with technical, operational, and regulatory complexities to ensure that customers can use mobile services wherever they go. Providing this service requires negotiating agreements, configuring network interconnections and meeting the needs of a diverse user base. This must be done while maintaining quality standards and complying with all applicable regulations in the countries where the service is offered. In essence, providing roaming services is a multifaceted effort that surpasses geographical borders.

Within an MNO's home country, an MNO can choose to add radio sites for improved coverage or capacity (in the defined and agreed service area). It can add/increase redundancy or backup power to a site for improved availability. However, when it comes to roaming, the MNO does not have the autonomy to make this decision independently. When roaming, these network improvements are subject to the cooperation with a foreign MNO and the need to comply to agreements and technical capabilities of both the home and visited networks.

With the introduction of 5G Standalone (5G SA) networks, the importance of quality in roaming increases. 5G SA networks enable a wide range of innovative services and use cases. Amongst those critical applications in areas like healthcare, manufacturing, and public safety. These applications or services require consistent, high-quality connectivity, even in roaming scenarios. The moment end user services rely on a specific minimum Quality of Service (QoS), roaming partners will need to agree on the delivery of QoS levels. The end-to-End agreeing and implementing Roaming-Service Levels Agreements (SLAs) is a complex process, e.g., due to different SLA-times of individual stakeholders. A framework to support the agreement of QoS between roaming partners, is already available [1]. Until now, QoS has operated as a service with the best possible effort. Currently, the GSMA is actively engaged in developing and incorporating SLAs.[3]

[2] See for further information 3GPP TS 23.501.

[3] Beginning of 2023, GSMA started a working group on Quality, residing under the Wholesale Agreements and Solution group. Further information is available to GSMA members on GSMA Member Gateway.

Roaming business is a worldwide business-to-business/wholesale-market based on competition. National MNOs compete with each other to receive roaming traffic and at the same time buy usage in other countries for their roaming end users/devices. This dynamic is facilitated the MNO's capability to direct and manage traffic through a SoR platform. For the roaming market to fully operate, the functionality of steering is an essential prerequisite.

## 2.2 Commercial operator business model

In the 5G-Blueprint Project (5GBP), several Deliverables describe the methodologies for establishing Tele-Operated Driving (TOD) as a service. Due to the diversity of stakeholders involved and the necessary investments, there is not a singular solution that unequivocally stands out as superior.

The Governance Guidelines for seamless roaming are based on (but not limited to) the Business models identified in 5G Blueprint D3.2 [2] and D3.3 [3].

In deliverable **Delineation of Business Models in 5G Blueprint D3.2** business model 6 refers to the transportation of goods across international boundaries. In this model Tele-Operations (TO) is used to assist trucks with a high level of automation to navigate on complex roads, particularly when road and weather conditions surpass the capabilities of autonomous driving systems. Broader implementations of TO for road transportation will only be realistic when more advanced levels of automation become available for driving on public roads, primarily due to safety considerations.

**The Techno-economic analysis carried out in 5G Blueprint D3.3** provides an in-depth (viability) study for providing the 5G-based TO services on a major transport axis – significant cross-border transport flows via road and water (referred to as Reference Scenario 3) for the deployment of UC4.1a (automated barge control), Use Case (UC) 4.3 (Cooperative Adaptive Cruise Control (CACC) based platooning) and UC4.4 (Remote Take Over), referred to as Deployment Scenario 5. Their recommendation is to initiate the deployment of TO services within a confined geographical region, including short road distances. The viability of providing 5G-based teleoperated transportation and especially in a cross-border environment, also depends on the amount of use cases to ensure the involvement of a larger fleet of connected vehicles. Subsequently, achieving a substantial uptake of TO services, the expansion efforts can be directed to cover major national and international transport routes.

In the business models, the international road holds substantial economic significance, as it connects vital transportation centres. The high-quality infrastructure and constant flow of goods make it ideal for repetitive routes. To realize on-demand coverage for teleoperations technologies such as network slicing and advanced network management become relevant.

TO use cases are likely to be addressed with the use of network slicing, creating virtual networks within the single physical network. Every operator deploying the 5G System (5GS) will deploy network slices fitting its business. Different types of network slices can be accommodated for roaming customers. It is also possible to allocate a subset of slices exclusively to support specific applications, such as autonomous driving. The technical guidelines to implement 5GS Roaming for network slices are described by the GSMA in "5GS Roaming Guidelines Version 6.0" [3]. In summary, this document outlines the technical aspects and recommendations of 5G roaming, focusing on network slices, the slice information values, UE configuration, and the role of network elements in ensuring connectivity while roaming.

Some key points of the technical guidelines are:

- Network Slice Deployment: As previously mentioned, operators deploying 5GS networks create network slices tailored to their business needs. These slices can use standard or non-standard Single Network Slice Selection Assistance Information (S-NSSAI) values and may be designated for various purposes, including inbound and outbound roaming support.

- Mapping S-NSSAI Values: When roaming, the S-NSSAI value of the home network must be mapped to the S-NSSAI value of the visited network. This mapping is established through agreements between roaming partners, specifying which Network Slice Template (NEST) is associated with a particular S-NSSAI of the home network.

- Subscribed S-NSSAI Information: The Unified Data Management (UDM) in the home network stores information about the Subscribed S-NSSAI(s) for each subscriber. When roaming, the UDM must provide the visited network with information only about the S-NSSAI(s) that the home network allows for the User Equipment (UE) in the visited network.

- AMF role: During the registration procedure, the network's Access and Mobility Management Function (AMF) determines which services can be used. It looks at the home network's settings (configured NSSAI), decides which services can be used in the visited network (allowed NSSAI), blocks any services that the UE is not supposed to use (rejected S-NSSAI), and handles with services that need special authentication (pending S-NSSAI).

To facilitate global roaming, it is recommended to support a standard S-NSSAI value for Enhanced Mobile Broadband (eMBB), especially for services like Internet access and IMS services. This means that this particular network slice configuration should be readily accessible to subscribers when they roam in different regions or networks worldwide.

Other S-NSSAIs can be provided as Subscribed NSSAIs if specific network configurations or services are required. This flexibility allows for customization and adaptation to different service needs while maintaining the global availability of the standard eMBB network slice for roaming.

The industry must also provide a solution to guarantee the interoperability of network slicing and explore strategies for ensuring the expected level of QoS. In general, the QoS configurations expected by the HPMN should align with the terms outlined in the Roaming Agreement.

However, the commercial guidelines, development of standardized slices, charging models and agreements are at the moment of writing under development within GSMA's working groups, known as Wholesale Agreements and Solutions Permanent Reference Documents (WAS PRDs). When required, operators are expected to reach a consensus on a resolution.

Based on the adoption of the 5G Blueprint's business models, the authors of this document identify primarily two pathways for the implementation of TOD:

1. Priority scenario (immediate term delivery)
2. Gradual Evolution scenario (long term delivery)

In the priority scenario the focus lies on the rapid adoption of TOD initiatives, involving fast deployment of 5G infrastructure and associated services in specific areas. The primary goal is to achieve immediate-term benefits, e.g. improved transportation efficiency, in areas where TOD can have immediate impact, such as transportation hubs.

The gradual evolution scenario takes a longer-term approach, with a phased development and expansion of TOD initiatives over time. The goal is to create sustainable solutions that integrate 5G technology with transportation planning, urban development, and stakeholders' engagement.

It is evident that the successful implementation of TOD relies on the right balance between supply and demand.

## 2.3 Models for cross-border roaming

Teleoperated driving services combine the most demanding requirements for mobile networks: high bandwidths and maximum availability. This will be reflected in required network investments essential for the competing operators across all EU countries.

The conclusions drawn and the approach taken as a result of this situation will directly shape the model used to commercialise the TO-service. Similarly, the commercial model relates to the cross-border roaming solution and the establishment of governance guidelines.

As provided in D3.2 [2], D3.3 [3], there are a few commercial business models to allow seamless handover between the network of the HPMN to the network of the VPLMN.

Some of the models are based on the use of corridors. These corridors refer to a pre-defined area or route to allow the efficient and reliable deployment of mobile coverage within the context of each operator individually.

Within the highly but not fully automated business models, autonomous vehicles are driven/sailed to a location near a cross-border highway by a human teleoperator, and then drive autonomously until they exit the highway, subject to a traffic control centre giving clearance for the routes on the basis of road and weather conditions. Examples of identified use cases include are Cooperative Adaptive Cruise Control (CACC), based platooning and Remote Take Over. The need for the vehicle to fallback to TO services depends on the capabilities of the Autonomous Driving (AD) system and its ability to anticipate and handle potential issues. The validated business models will be presented in D3.4 of 5GBP.

The theoretical approach with use of corridors is to provide a high level of reliability for TO Services. These corridor-based models involve a strategy from the operator where the planning and execution of various services and technologies are focused within distinct geographical corridors. Based on the models described further in this document, in some scenarios, it also implies that if an MNO experiences inadequate coverage or encounters a technical problem, the HPLMN has the choice to switch to an alternative network within the designated area.

Switching mobile networks today relies on proactive monitoring of network functions, taking into consideration current use cases. In this context, if a network failure is detected, the relevant departments within a mobile operator will initiate measures to switch to an alternative network, especially if this switch hasn't already been performed through SoR mechanisms.

In the existing SoR solutions, network issues that affect the Update Location (UL) failures can automatically trigger a change of network. However, when it comes to serving TO services, which often involve real-time control and critical applications, the measures taken to handle network failures become even more stringent.

Therefore, to ensure reliability, operators must go the extra mile in monitoring network performance and implementing failover mechanisms. Automatic network switching in response to UL failures is just one example of these measures, and additional strategies may include QoS policies, edge computing, and minimize latency and loss of data transmission.

Switching to a different operator in the event of a technical failure is typically a standard procedure that doesn't require a specific agreement. However, if this switch involves an inter-PLMN handover, it may be necessary to establish Service Level Agreements (SLAs) between national operators for the purpose of international roaming, in order to ensure the reliability and performance of this process.

All initiatives to establish corridors now are aligned with a short-term delivery scenario, as presented in section 2.2. We notice that the progression of TO within the network evolution is still a considerable number of steps away from our present situation. In this context, the term “present situation” refers to the current status of TO initiatives and their alignment with short-term delivery goals. The immediate-term scenario incurs significant costs (as indicated in D3.3 [3]), demanding special solutions that might not be necessary in a gradual evolutionary scenario.

Therefore, the authors of this deliverable have defined the following four models for further refinement: two immediate-term models (model 2 & 3 corridor-based models); one evolutionary model (model 4: business as usual model) and finally one intermediate solution model (model 1: shared network model).

In what follows, the four models are being explained (only public-public crossings are in scope).

The schematic figures illustrate two neighbouring countries A and B, along with their respective operators A, B, and C for the first country, and operators X, Y, and Z for the second country.

- **Model 1 – Shared network corridor-based model**: MNOs share a corridor in each country. In this document Radio Access Network (RAN) sharing is assumed. This framework allows for roaming capabilities through any designated roaming partner.

  Note that network sharing (usually explicitly regulated and complex to set up) means a co-investment of a limited number of MNOs, meaning some operators might be left out.
  The market context, the network sharing model and regulations will affect the magnitude of potential benefits and down sides.
  There is a trade-off between the advantages of network sharing, which include faster and broader deployment of 5G networks while reducing costs, and the potential drawbacks, such as reduced incentives for investment and diminished market competition.

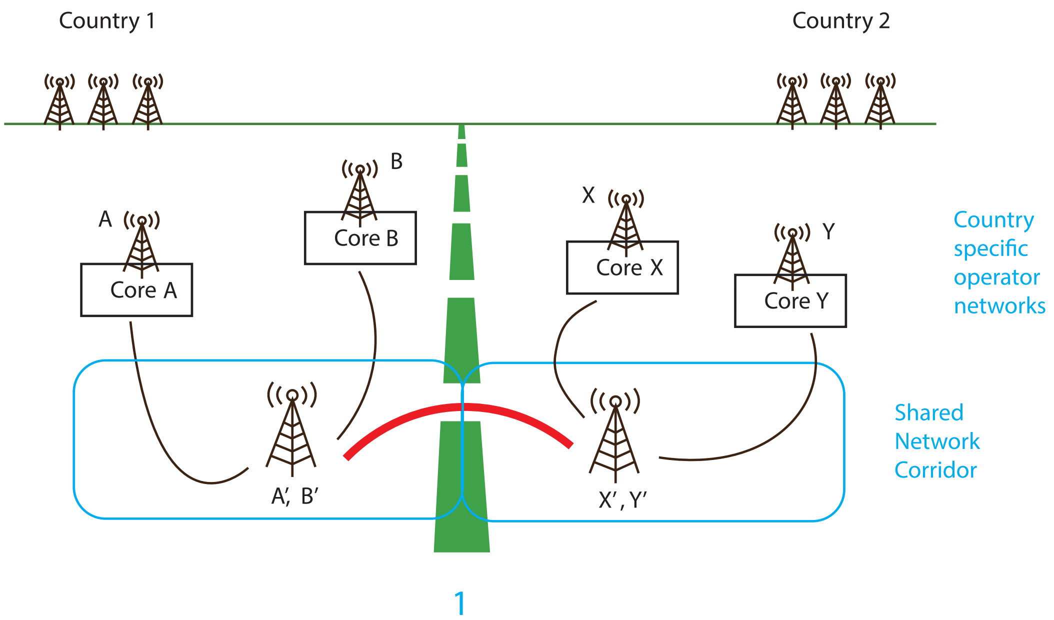


**Figure 1**: Shared Network Corridor Model

  In this scenario, two MNOs operate in the shared network corridor of each country.

- **Model 2 – Licensed corridor-based model**: a corridor, restricted to a single operator in each country, is granted a license exclusively to one national MNO. Roaming in the context of the TO use case, is viable solely through the designated licensed roaming partner.

  When a single MNO is licensed to operate the corridor, the HPMN lacks the option to select a VPMN. Consequently, both countries have limited choice for consumers and roaming partners, as there remains only one possible solution for implementing a seamless handover solution within the corridor.

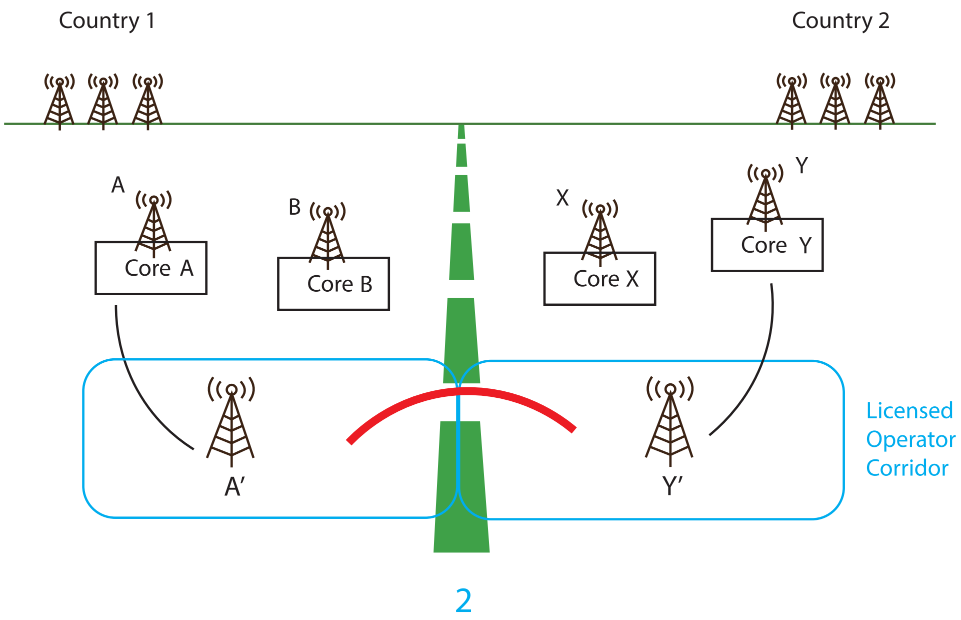


**Figure 2**: Licensed Corridor Model

The illustration above, Figure 2, demonstrates that each country is solely represented by a single operator within the corridor. As a result, the fair competition landscape is compromised, leading to a situation that resembles a monopoly.

- **Model 3 - Competing corridor-based model**: within this model each roaming partner presents their individual corridor, leading to the emergence of multiple corridors competing to offer the TO services.

  The HPMN keeps the flexibility to determine the VPMN to which it will direct its traffic in the defined area of the corridor. This approach fosters competition and provides backup options in case of network disruptions or poor performance from one of the competing networks.

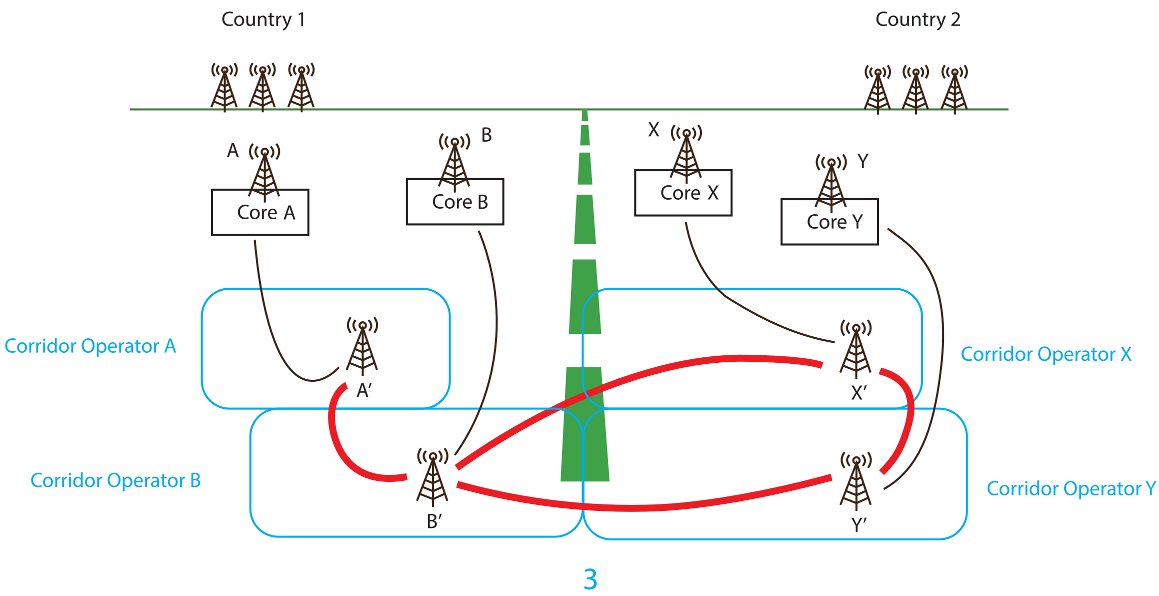


**Figure 3**: Competing Corridor Model

Figure 3 illustrates the visualisation of distinct corridors offered by MNOs A, B, and X, Y within their corresponding countries 1 and 2. The handovers are based on an international roaming agreement in case of crossing corridors within the Visited country.

- **Model 4 – Business as Usual Model**: Nationwide handover coverage offered by several MNOs in the neighbouring countries. This means that the need for specific corridors becomes obsolete, given the availability of truly uninterrupted handover functionality across the entire coverage area of the MNOs. At all possible entry points the MNO can provide seamless handover solutions. Each MNO builds capacity and is free to establish agreements for roaming SLAs, facilitating advanced services like tele-operated driving.

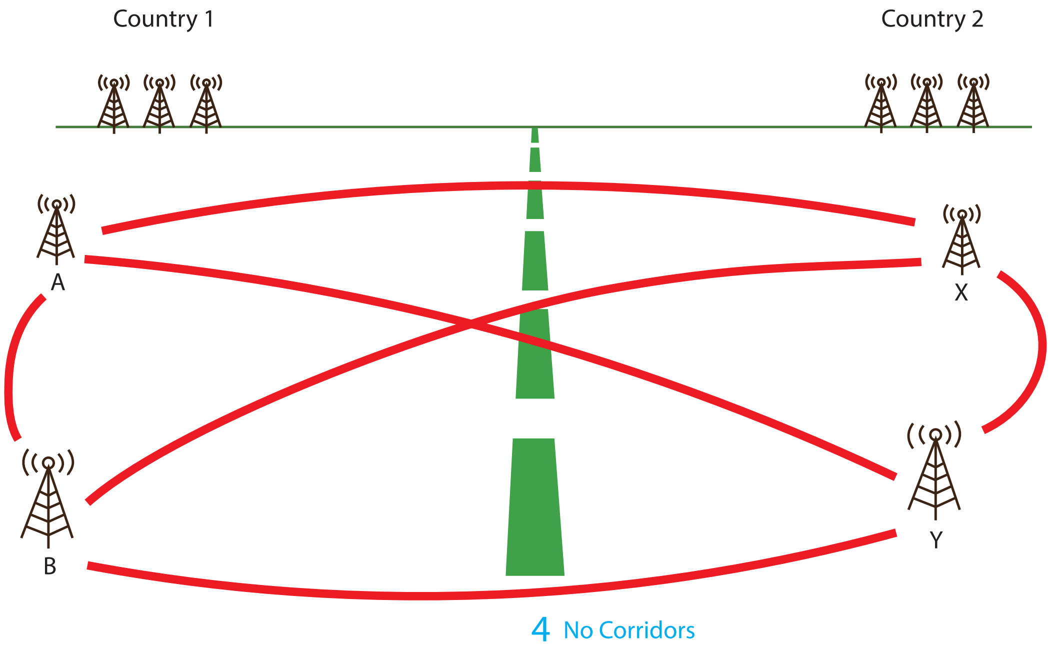


**Figure 4**: Business as Usual Model

The model suggests nationwide coverage for the TO use case. As goes for real life networks today, no network reaches a full 100% coverage. In advance, roaming partners will align on specific areas where the service is needed and can be supported.

## 2.4 Solution description to support cross border roaming

Earlier in the project, e.g., in D5.1 [5], potential solutions have been provided to support cross-border roaming.

In case of measures taken by the user equipment (UE) to lower the disconnect time or keep a redundant connection:

- fast registration
- dual modem

In case of measures from the network to the steering of roaming and providing a handover between bordering networks:

- optimization of roaming steering
- inter-PLMN handover

Care must be taken to avoid any misunderstanding. From a strict technical sense, seamless handover already implies inter-PLMN handover. For the purpose of this document, we will use the less technical definition to refer to a quick change of networks.

From a governance perspective, both optimized roaming steering and inter-PLMN handover are important mechanisms to ensure seamless roaming experience when mobile subscribers travel outside of their home network. However, there are some key differences between the two processes, as described in the next sections.

### 2.4.1 Optimization of roaming steering

Steering of Roaming aims at selecting a suitable network for the UE and its services. As explained in Section 2.1, the HPLMN in general has a choice of networks that it can use for roaming. No two networks are technically identical. They can, for instance, be different in coverage and available services. MNOs may already take these technical differences between networks into account in their steering decision. An MNO could define different steering profiles, depending on the type of service the UE needs. The QoS requirements related to the use cases in 5G Blueprint, which are to today's practice extremely challenging, may be reason for an MNO to implement a specific profile for these use cases.

The most common QoS requirements for TO service are characterized by the need for low latency, high bandwidth and ultra-reliability, and depending on the use case or enabling functionality, should also encompass redundancy, QoS guarantees and robust security measures. As an example:

UC Autonomous Vehicles:

- Autonomous Vehicles require extremely low-latency communication for real-time decision-making, especially in critical situations.
- AD vehicles have sensors and communication links. In case of failure detection, the failover mechanism automatically switches to a safety fallback solution.
- QoS guarantees may prioritize TO control signals and video streams (in case of remote operation) over regular data traffic.
- Enabling Functions (EF), such as Active collision avoidance and Vulnerable Road User Warnings should remain operational and capable of providing assistance even in situations where the AD system hands over control to TO.

In our corridor definition, applied in the highly but not fully automated vehicles (described in section 2.3), an MNO will need to agree in advance with one or more MNOs in every country the network service compliancy to the QoS requirements.

Full nationwide coverage as a scenario, especially related to high QoS demands, is most likely not very realistic in any network. Assuming that the QoS is expected in a predefined area, e.g. a road/waterway corridor, is new to the industry. As outlined in the viability study for 5G-based TO services 'The Techno-economic analysis D3.3', the investments needed to build the corridor, are likely to be substantial and building the technical infrastructure more than once, e.g. by every MNO, could prove to be economically unviable.

In case only one MNO would offer the service, steering of roaming becomes straightforward; it would clearly need to be the network of choice for the users of this service. For a level playing field between national MNOs, a shared network could be considered. Assuming that the shared network can be accessed through roaming agreements of multiple MNOs, the corridor would become available to international roamers as well and via the commercially selected roaming partner of choice.

If on the other hand, no single network can provide a QoS guarantee in advance for the full duration of the time the UE is in the roaming country, the best chance an HPMN has, is to rely on the coverage of more than one network. This is the way roaming usually works today: it is unknown in advance where the user will go. At any point during its stay, it can arrive at a place where coverage or capacity is lacking at that moment. If an alternative network is available, the network can be used instead.

From an operator/service provider perspective, the process starts with a clear understanding of the exact service to be delivered to the user. What is to be agreed regarding QoS? This includes defining the applicable coverage area or areas. Incidents must also be considered, such as situations where the QoS objectives can temporarily not be met. From this starting point, an operator/service provider needs to assess the feasibility of providing the requested service and if so, through what means?

Allowing the service to commence without a conclusion in advance regarding the economic viability of competing infrastructures, may result in additional complexity later on. With various operators providing different corridors, there is a possibility of market fragmentation. This could lead to discrepancies in service quality and coverage between different areas, potentially leaving some regions underserved. As a result, several MNOs may end up with partial coverage of the country, each with their own strongholds and less covered areas and possibly partly overlapping. Assuming a steering solution is in place (meaning border crossings will not be based on inter-PLMN handover), foreign roaming networks could benefit by changing MNO when needed.

**Steering of Roaming** primarily focuses on optimizing network selection for subscribers when roaming between different mobile networks. It helps to ensure that subscribers' devices connect to the most suitable network for voice, data, and standard services. While SoR plays a crucial role in providing a smooth and efficient transition between networks, its primary purpose is not specifically designed to support teleoperation services. The current SoR platforms designed for 5G, based on 3GPP Release 16 definitions for New Radio (NR) connected to 5GCore (5GC), do not support seamless handover functionalities that align the specific requirements of TO services.

The concept of **Optimized Steering of Roaming** is currently unavailable. As per 3GPP, release 16, there are no specifications or implementation guidelines for an Optimized SoR.

In this concept, SoR vendors are required to develop solutions that guarantee the seamless continuity of service for TO applications. It is worth noting that this approach provides the broadest geographical coverage, which can be advantageous for supporting TO services across various regions.

| |
|---|
| Evaluating the potential impact of an optimized SoR platform on the implementation and effectiveness of TO services is crucial. It is essential to consider addressing technical specifications in upcoming 3GPP releases if they demonstrate significant benefits for specific TO scenarios. |

#### 2.4.1.1 Operational processes: business as usual

Roaming steering is a more centralized process, as it is controlled by the home network operator. This means that the home network operator has more control over the process, and they can ensure that subscribers are connected to the best possible network.

- Negotiation of Roaming agreement including QoS parameters & SLA
- Define steering policy
- Monitoring the performance

#### 2.4.1.2 Security mechanisms for Steering of Roaming in 5GS

3GPP Technical Specification 33.501 outlines the security architecture and procedures for 5G networks, providing a framework to guarantee the security and privacy of the 5G ecosystem. The TS covers various aspects like security architecture and procedures, authentication, encryption, access control, subscriber privacy, and more.

The latest security functions to support the SoR in 5GS are defined in 3GPP TS 33.501, section 6.14 (Rel 16). The section describes the security functions necessary to support steering of the UE in the VPLMN during registration procedure and also after registration.

### 2.4.2 Inter-PLMN handover

To make inter-PLMN handover work, networks will need to establish connections with each other. Every network has this capacity, the difference is the level of alignment needed. Competing national operators, in general, primarily interface to enable communication between their respective subscribers. International mobile operators interface to facilitate roaming on each other's networks.

For inter-PLMN handover to be operational, interfaces need to be introduced to ensure that individual radio cells recognize their neighbouring cells. Doing that at a border means that roaming partners need to find a process to exchange the information on a few well-defined border locations.

Roaming subscribers in today's world may regularly change network during their travel through a country. This can for instance be due to a coverage issue with a roaming partner at a random place and time. The device looks for and finds an alternative network and continues. These Update Locations are at crucial points different from the described ones: they can appear anywhere in a country and require alignment between competing national operators instead of roaming partners. This alignment should not be considered lightly: tuning a radio network to the best possible configuration, is an ongoing process and can be different for each operator. Network tuning means adjusting various parameters and settings within the network infrastructure to optimize the performance of individual radio cells. This process involves fine-tuning parameters such as transmission power, antenna orientation, frequency allocation, handover thresholds, and more. However, tuning a network can also have unintended consequences. If these adjustments result in the inability to access neighbouring cells operated by a competing operator, it may lead to a potential issue: the inter-PLMN handover could experience failure. Finding a solution for this without impacting the ability of operators to tune their network to the highest quality they can, may prove to be extremely challenging.

As explained in previous research D5.1: 5G Network Requirements and Architecture [5], inter-PLMN handover has been extended to work across PLMN borders introducing an interface between bordering network operators. This allows for a seamless handover with no noticeable interruption and a latency of less than 100ms. Despite this, the interface has not yet widely been adopted by operators, due to several reasons, e.g., the complex integration required. The specific concept of Inter-PLMN mechanism have been governed by agreements and best practices, rather than standardized within 3GPP releases. Furthermore, this technology for achieving seamless roaming has some significant limitations, such as, making it challenging to implement across multiple countries in Europe.

The current standards do not support a selection mechanism based on preferences of the HPLMN. It is up to the RAN configuration at the border to hand-over to the base-station of the VPLMN, ignoring user specific subscriptions or roaming agreements (D5.1 [5], section 3.7.3).

Inter-PLMN handovers may be technically feasible between two networks at a small/limited number of geographical locations/border crossings. However, it may not be the optimal technology in case a UE is already roaming abroad to handover to a different roaming partner. As a result, it may not be suitable for enhancing the coverage by switching to another network in such scenarios.

Specifically for inter-PLMN handover, two different border crossings will need to be considered:

- crossing between the home country of an MNO and a network in a neighbouring country, and
- crossing between two visiting networks.

Within the inter-PLMN handover the HPLMN can still pre-select to a certain level, to which neighbouring roaming partner to handover a UE. The situation will become more complex in case of a handover from a roaming network to yet another roaming network in a different country. In inter-PLMN handover, the two neighbouring VPLMNs configure and may determine the handover, not the HPLMN.

As an illustration, consider a teleoperated vehicle embarking on a journey from its home network in the Netherlands, heading towards France. Along its route, the vehicle will initially cross the border into the neighbouring country, Belgium, and subsequently move across the border between Belgium and France, ultimately reaching its destination in France. The network through which the Dutch vehicle will maintain connectivity in France will be determined by the existing agreement between the Belgian and French operators. As a result, the Dutch home operator no longer has control over the preferred network in this scenario. In general, the selected roaming network can change. That is: not only at the border, but at any moment. This typically happens the moment device measurements of the signal strength drop below a minimum level. The device will look for alternative available networks with an acceptable signal level and in an automated network selection mode, it will attempt to attach. Commercial models for teleoperated driving, in which the used/visited network is fixed, there is no need to consider alternative networks; there is only one network. However, in case the service can make use of more than one roaming network covering the same country or area, the border crossing is just one of the moments a device may change network. This reflects the standard situation in roaming.

Inter-PLMN handover, a technical solution supported in predefined locations, typically in neighbouring border areas, has been demonstrated in a controlled lab and pilot site environment to be nearly seamless. Given these strict technical requirements, from a network perspective it may be suited to be engaged for short term deployment. In a commercially operated network environment, a solution needs to comply to more than network considerations. The next two sections illustrate the operational complexity and security considerations. In Appendix A an overview of more related requirements is provided.

| |
|---|
| Inter-PLMN handover is a technical solution that enables two neighbouring MNOs to seamlessly change network in an area where both MNOs have coverage. This results in a fixed, predefined crossing to one specific MNO. To establish a scalable nationwide solution, it would require coordination and alignment among competing networks across the entire country. In a subsequent phase, attention should be given to addressing the handover between two VPLMNs. |

#### 2.4.2.1 Operational processes

Inter-PLMN handover is a more decentralized process, as it involves the coordination of several different network elements of two PLMNs. This means that the process is more complex, and there is a greater risk of errors/failures. The operational procedures for inter-PLMN handover involves among other things:

- Coordination between PLMNs on the coverage area of neighbouring cells; sufficient overlap is a prerequisite for a successful handover
- Coordination of several network components
- Compatibility of radio standards & protocols
- Optimization and alignment of handover procedure
- Monitoring the performance and quality of handovers

The nature of the operational process restricts its geographical coverage. To address fallback possibilities, the solution should be implemented with at least two operators within the pre-defined area. The complex set-up, based on cell-level coordination requires substantial coordination, investment and maintenance.

#### 2.4.2.2 Security mechanisms for Inter-PLMN handover

In a normal mobile procedure, a subscriber is authenticated (by the VPMN) as very first step before access to the network is granted.

For the inter-PLMN scenario the UE is not authenticated before entering the network, instead, the UE is authenticated in its home PLMN before it is allowed to connect to the visited network. The MNO receiving the handover must trust that the MNO initiating the handover has done its due diligence to authenticate the UE.

In a normal situation, this re-authentication process, triggered in tens of milliseconds after the handover, is referred to as inter-AMF handover.

It is important to note the UE triggers this registration and not the MNO. This may result into a security risk[4].

Regarding inter-AMF handover and the necessary conditions to fulfil lawful intercept, the situation is comparable to regular roaming scenarios. The N9 interface will be home-routed, which implies that the User Plane Function (UPF) is located within the home network. Consequently, the user's data traffic could potentially be intercepted in both the visited network (when the user is roaming) and the home network.

### 2.4.3 Dual SIM

In the context of a handover roaming process, there is a concept of using two SIMs from one network to another. When crossing a border, SIM 1 would remain connected to the existing network, while simultaneously, SIM 2 would initiate a connection with the appearing network as soon as the signal strength permits. Once a stable connection is established via SIM 2, the first SIM can disconnect from the old network and initiate a connection with the new network as well or even with a different network in the visited country. Such setup could mimic the implementation of an inter-PLMN 'make before break' approach. This specific scenario will be tested and reported on in the 5G Blueprint Deliverable D5.5, Report on dual SIM for seamless cross-border TO.

Technically it makes sense to explore this possibility as it could allow seamless handover without any further roaming adjustments such as steering optimization or the limitations of pre-defined corridors. In theory, the handover could happen at any time at any place while crossing border and extend beyond this geographical scope. Throughout this process, the HPMN would at all times maintain control and be in charge of its own subscriber and UE.

The use of more than one SIM introduces additional complexity at the equipment side: logic needs to be implemented to coordinate the timing of the border crossings of the SIMs thereby preventing a simultaneous crossing of the connections. Also the TO solution needs to be setup with redundant communication routes.

The inter-PLMN benefit is a fast crossing with hardly any interruption of the connection, however the challenge remains due to fixed and pre-defined handover locations. To mitigate this issue, the project developed this dual SIM solution.

> For Further Study: dual IMSI method to perform seamless handover at cross-border areas and in situations of poor coverage quality. Does the used radio spectrum have an influence on the time taken for the handover process? What would be the chance of a successful dual-SIM handover in case SoR is applied on SIM 2?

[4] A UE could be adapted so that the registration trigger is delayed or completely ignored, given the UE access to a network without being authenticated. Risk assessment and potential implications go beyond the scope of this deliverable.

## 2.5 Approach

As evidenced in this chapter several scenarios/models have been defined for providing seamless handover for cross-border transport flows for TO services. Additionally, diverse mechanisms are available to ensure seamless roaming while traveling outside the HPMN. Mapping these different options all together leads to multiple deployment scenarios. The subsequent chapter describes the difference, limitations, advantages of each scenario mapped with the different mechanisms, and this considering the need for a short-term delivery of priority features and a gradual development over time.

# 3 ANALYSIS OF INTER-OPERATOR MODELS

In subsection 2.3., four commercial models have been introduced. In theory, each of these models can be used in combination with 'inter-PLMN handover' or 'optimization of roaming steering' as a solution for border crossings. The impact on the model, however, can be very different. This chapter explains what is needed for each of these models in combination with these border crossing solutions, to function technically, commercially, and regulatorily.

## 3.1 Differences per model

### 3.1.1 Shared network corridor model

#### 3.1.1.1 Technical

Network sharing exist in various forms. Although more technical solutions may be possible, in the context of this document, RAN sharing is assumed. In a network sharing model, there is no need to change roaming partner within the country borders. That is assuming that the complete corridor is shared. Since the radio network is shared and therefore equal for all participating national operators, changing roaming partner will result in reusing the same RAN, i.e., without any difference in quality. If the service needs to be expanded to an area where the shared corridor is not active, a handover is needed. In case of inter-PLMN handover, this means that for the handover location, collaboration on cell-level is required, i.e., a process for aligning neighbouring cells is needed. A strict network sharing model is assumed here, without any other national radio infrastructures/networks to take over the service. In case of optimization of roaming steering or in short: optimized SoR, switching to a different network can be done anywhere.

#### 3.1.1.2 Commercial

**Retail**

When the radio network is shared, it is realistically not possible to compete on quality, i.e., which network is best or has the best coverage: operators offer their domestic service based on the same radio network.

**Roaming**

Similar to the domestic situation, in a network sharing model, there is no room for competition based on quality. Operators provide their roaming services utilizing the same network.

Within the boundaries of the EU roaming regulation, MNOs can commit roaming volumes with one or more of its roaming partners in a country. Steering of Roaming is the fundament to fulfil these commitments. When using an inter-PLMN handover procedure, the home operator faces challenges in both predefining and adjusting how different roaming partners manage specific portions of the traffic volume. This is because the inter-PLMN handover procedure allows the mobile device to switch between roaming partners without the HPMN's control. In turn, it decreases the operator's ability to effectively negotiate favourable rates. Consequently, Inter-PLMN handover, in its current state of development, limits the flexibility of an MNO to engage in optimal rate negotiations for roaming services in a particular country.

Using Optimized SoR means that MNOs can still use a solution to steer the traffic to the preferred network. In case of technically equivalent networks, this means that the tooling can be used to negotiate the best roaming rates. As an example, previously agreed commitments with various participants in the shared network may have been made. It may be necessary to adapt the amount of traffic on one network in favour of another, so that the commitments are achieved in the most profitable way.

One more disadvantage of inter-PLMN handover becomes apparent when considering not the home – visiting network border crossing, but instead a border crossing between two visiting networks. In the context of international roaming, the home operator determines to what extent a roaming partner is used in any country. Inter-PLMN handover between networks, is based on a bilateral agreement between two neighbouring networks. This means that, in case the crossing is different from the home country of the subscriber, a visiting network holds the authority to determine the next network to be connected to.

In a shared network solution, guaranteeing quality could even be more complex than with non-shared models. Consortium participants need to agree a way to share the commonly used spectrum and how to solve potential non-performance issues and/or avoid/limit temporary drops in quality. Additionally, if a roaming agreement involves an SLA with penalty clauses and the shared network fails to meet its obligations, the MNO must have mechanisms in place to address and rectify such situations with the consortium.

#### 3.1.1.3 Regulatory

Network sharing is from a resource usage and cost perspective more efficient than separate infrastructure per operator. Network sharing may co-exist with own networks. For a specific area or in this case purpose, a shared network can be added. Which part is shared is not predetermined. An implementation could be that all operators use their own core and only share a radio network.

In the considered scenario, RAN network sharing does not imply spectrum sharing. This means that operators can share the physical infrastructure of their networks, while still using their own dedicated spectrum allocations. Participating companies could join in a consortium for the realisation of the required shared infrastructure. BEREC published a preliminary report on the arrangements for infrastructure sharing [6]. Regarding areas beyond the scope of this deliverable, but deserving further investigation, additional research may be essential to determine regulatory guidelines. This might involve exploring factors such as the desired rollout pace, the baseline quality standards, and how to prioritize which areas to investigate first.

#### 3.1.1.4 Conclusion

A shared network reduces the need to change network. At the same time, you lose the possibility to compete on quality. Inter-PLMN Handover has been proven to be a successful network technology to support TO services when vehicles cross neighbouring frontiers. In the early stages of providing TO services, it would be logical to combine this technology within a shared RAN network model. Looking beyond the scope of a neighbouring country border crossing, it has until today for instance an unsolved scalability challenge towards non-neighbouring country crossings.

### 3.1.2 Licensed corridor model

#### 3.1.2.1 Technical

If in a country only a single network exists as corridor, there is no need to change roaming partner within the coverage area of the national corridor. A license for providing TO services within the corridor has been exclusively granted to one MNO, and no other network is permitted to provide the service as an alternative. Only when reaching a country border or when exiting the corridor, a change of network needs to take place. Selecting a network becomes almost trivial: only one complies. No flexibility is needed in finding the best network. Inter-PLMN handover may be used, provided it can be applied within the boundaries of the requirements as formulated in Appendix A.

#### 3.1.2.2 Commercial

**Retail**

Within this licensed model, a single operator is holding exclusive rights. Only one of the domestic operators is able to offer TO driving services. In essence this means that to support the TO driving use case, providing communication services goes back to the time before liberalisation. In the event of technical failure there is no alternative network available to guarantee service continuation.

**Roaming**

Under a monopolistic licensed model, all choices are gone, thereby limiting competition and eliminating the possibility for backup coverage solutions. MNOs may participate in tenders to secure the licence to provide the TO services. Depending on the business case, acquiring a license could involve fierce competition among operators vying for the same corridor. This might result in bidding processes that drive up costs, making it difficult for smaller operators to compete.

#### 3.1.2.3 Regulatory

If there is just one corridor accessible through a sole operator, the operator's selection process will take place during the licensing phase. However, obtaining and maintaining such a license can involve several challenges. The legal authorization granted by the regulatory body will include aspects such as compliancy requirements, spectrum allocation, financial investments, consumer needs, etc. This also means government, National Regulator Authorities, MNO's and any other relevant entity, will engage to define the terms and conditions for TO services within the corridor.

It is important to note that the assumption here is that the RAN related to the corridor is separate from any other regular license the operator may have. Combining the two may have effects beyond the scope of this document.

#### 3.1.2.4 Conclusion

Inter-PLMN handovers have the potential to operate effectively within a licensed corridor framework. However, seen the complexity to engage in a licensing process and the potential restrictions on expanding the service, might not be the preferred strategy, nor starting point.

The licensed corridor model does not align with the goal of a level playing field, which aims to ensure that all operators, regardless of their size or market position, have an equal chance of success and compete based on the quality of their services and offerings rather than regulatory advantages. As a result, adopting an approach that could restrict service development due to regulatory obstacles or create entry barriers for potential competitors could undermine the principle of fair competition.

### 3.1.3 Competing corridor model

#### 3.1.3.1 Technical

In case operators build their own corridor, the corridors will be different from each other. They can for instance be different in coverage area. When that happens, an operator may wish to use the corridor of roaming partner A during the first part of the journey and of roaming partner B for the next part. In other words: handovers are needed at locations where the networks intersect. For inter-PLMN handover, intersecting locations need to be aligned at cell level between nationally competing operators. With the (expected) growth in coverage area of the corridors, the number of cells where handovers need to be facilitated will grow as well.

In a model where competing operators work on coverage, roaming subscribers may be able to enjoy the combined footprint of corridors. Regular mobile standards make roaming to a different network possible. Mandating inter-PLMN handover would however likely lead to technical complexity. Existing handover processes do not include the type of service or subscriber in the decision. This means that once networks are configured for inter-PLMN handover, every subscriber is likely to use that route. As a concluding point, it is worth addressing the challenge of ensuring a seamless handover from private networks to a public infrastructure. This requires addressing the issue of preventing public subscribers from gaining access to the private network beforehand.

Once subscribers are able to roam into another network, measurement reports showing the performance of the other party's radio network are automatically shared in 4G and 5G networks.

#### 3.1.3.2 Commercial

Roaming subscribers enjoy the use of the combined footprint of all operators in a roaming country.

Clear agreements will need to be in place who will be responsible for continuous service delivery in a predefined geographical area abroad. In the operator's home country, an MNO relies on its own network. However, the situation becomes more complex abroad, particularly, when two operators provide coverage in the same area, and a failure occurs with the selected operator at some point. The home operator may be able to switch to the other roaming partner to continue the service. While operators may never be willing to accept full 100% liability for coverage, this model provides additional protection by means of backup plans involving alternative operators within the corridor in case of failures.

#### 3.1.3.3 Regulatory

To provide uninterrupted international service, corridors must connect at the borders. All operators need overlapping coverage with neighbouring networks that can support high bandwidth demand. The spectrum of neighbouring countries may interfere with each other, so all participating operators may need to coordinate their use of spectrum. This could also impact international agreements on frequency usage and coordination in border areas, such as the agreement between Belgium and the Netherlands [7].

For the best roaming experience, the combination of all available corridors in a country, i.e. belonging to different operators, may deliver the largest coverage area. It may not be in the interest of individual national operators to enable inter-PLMN handovers to support these roaming cases.

#### 3.1.3.4 Conclusion

Using inter-PLMN handovers along with competing corridors is a possible strategy, but it is more feasible when operators cooperate and agree to share their network coverage areas instead of competing for them. The greater the extent of overlapping areas, the more attractive the concept of optimized SoR becomes, offering the flexibility to switch networks in case of failures and a streamlined centralized operational process.

The competing corridor-based model appears to be realistic in the initial phase of TO services. However, as the service expands, inter-PLMN becomes increasingly complex (especially when dealing with borders beyond neighbouring countries).

### 3.1.4 Business as usual model

#### 3.1.4.1 Technical

Key difference with the previous model lies in the absence of distinct corridors. As in today's situation, networks lack specific corridors, but continue to provide service along critical points, such as highways.

#### 3.1.4.2 Commercial

In the current model, the challenge of ensuring uninterrupted service delivery throughout the entire route is even more pronounced than in previous model.

Without corridors, it is impossible to know in advance which network a subscriber will use. This makes it difficult to negotiate attractive roaming rates, as the MNO cannot guarantee that their customers will be using the best network available. In order to secure favourable roaming rates through negotiation, it becomes imperative to possess a controllable solution for influencing network selection. In some cases, it might be reasonable to switch to the only network that meets the coverage and capacity requirements within the required QoS levels. However, in situations where alternative networks are available, the MNO needs the freedom to choose which network to connect their customers to, instead of leaving it to chance.

#### 3.1.4.3 Regulatory

Compared to the other described models, ‘business as usual’ is expected to have the least impact on existing regulation. TO driving is ‘just another service’ and once mobile operator networks are ready to offer related services, the service can be offered against competitive rates.

The options to prioritize the TO service in combination with this ‘business as usual’ model depend on the chosen solution. In case of Coverage on Demand (CoD), see section 3.2, TO assistance may only be expected where complex road conditions occur. Providing coverage at a limited number of clearly defined locations may be substantially more likely to be feasible at an earlier moment in time.

#### 3.1.4.4 Conclusion

The business-as-usual model is preferable in combination with the concept of optimized SoR. It is also the most logical and flexible candidate for the future development of 5G supported services, such as teleoperations. Defining separate networks will in the long run prove to be cost ineffective.

The timing and rollout of the first commercial introduction of TOD compared to other 5G services, is an important or possibly one of the most important questions. Between the mobile services of today and TOD, it is expected that services with increasing QoS demands will emerge. These evolving services can pave the way for TOD, but only if TOD is introduced at the right time. This is the fundamental assumption behind the business-as-usual model.

## 3.2 Coverage on Demand

In the first deployment scenarios (i.e., private terrain and nearby local roads), the implicit assumption is to teleoperate the non-autonomous vehicle 100% of the time. This means a human operator remotely controls the vehicle, from the moment a corridor or service area is entered until the end point or end of the corridor/service area is reached. Only in later deployment scenarios (i.e., longer roads, highways, first national, then international) automation is added for the highway part of the route. On the highway journey the vehicle is capable to drive autonomously and may request temporary assistance from a TO driver when potentially complex traffic situations are expected: Coverage on Demand (CoD). Although on the face of it, this may look like the same service, the service requirements may be very different. The complexity involved in capacity reservation over an unknown route within an unknown time frame, almost disappears. Guaranteeing a service for a specified quality level during a few minutes, may well decrease the complexity substantially.

## 3.3 Summary of all combinations

**Table 1** below, highlights the key differences and similarities across the various models, including their corresponding technical aspects.

| Model | Border crossing | Impact | | |
|---|---|---|---|---|
| | | **Technical** | **Commercial** | **Regulatory** |
| **Shared Network** | **Inter-PLMN** | Fast border crossing (<0.1s)<br>Limited to neighbouring countries<br>Reduced need to change network | Competition on price only | Shared network needed.<br>Decreased competition between networks |
| | **Optimized SoR** | Reduced need to change, however still possible | Competition on price only.<br>Scalable to non-neighbouring countries | Shared network needed<br>Decreased competition between networks |
| **Licensed corridor** | **Inter-PLMN** | Fast border crossing (<0.1s)<br>Limited to neighbouring countries | Competition limited to licensing | Engage in license procedure<br>Least/no competition between networks |
| | **Optimized SoR** | Simple SoR; expected to be fast (not available) | Competition limited to licensing | Engage in license procedure<br>Least/no competition between networks |
| **Competing corridors** | **Inter-PLMN** | Short term solution<br>Limited to neighbouring cross-borders | Competition on price and quality possible | |
| | **Optimized SoR** | Potential mid-term concept<br>Expansion to all countries cross-borders | Competition on price and quality possible | Potentially different roaming and national interest in corridor alignment |
| **Business as usual** | **Inter-PLMN** | Not feasible due to nationwide MNO handovers.<br>Limited to neighbouring cross-borders | Competition on price and quality possible | Least/no changes needed. Solution potentially possible within current regulatory framework |

| **Model** | **Border crossing** | **Impact** | | |
|---|---|---|---|---|
| | | **Technical** | **Commercial** | **Regulatory** |
| | **Optimized SoR** | Long term preferred concept<br>Expansion to all countries cross-borders | Competition on price and quality possible | Least/no changes needed. Solution potentially possible within current regulatory framework |

**Table 1**: Inter-operator models and border crossing solutions

Not all combinations of model and technical solution for border crossing are compatible. The technical complexity to set-up inter-PLMN, which can be resource-intensive, limits TO Services to fixed predefined areas in a liberalized mobile world. Additionally, the technologies deployed in different scenarios underscore distinct strategies for implementing the service, whether focusing on short-term or long-term delivery.

In the last two chapters we have illustrated that the first question should be around timing: when is TOD needed? If a fast solution is needed, the licensed corridor or competing corridor model should be considered. On a network level, there is a seamless solution available: inter-PLMN handover. However, before this solution is implemented in a live network, other challenges will need to be solved, such as cell alignment, roaming billing and security. The scalability of inter-PLMN handover towards more countries and within a country is also open. An alternative approach for short term could be to limit TOD to selected highway border crossings and ensure that these crossings are sufficiently safe to cross without compliance to seamless handover.

For a mid-term solution, a shared network may be considered. It also has the challenge for scalability, with regard to inter-PLMN handover. In case the expectation is that TOD can come available once 5G networks have matured, then it may well be possible that challenges appearing today have been solved through the gradual commercial introduction of other mobile services.

# 4 POTENTIAL CONSEQUENCES ON ROAMING DOCUMENTS/AGREEMENTS

This chapter provides guidelines to support the use case of TO cross border driving within a 'business-as-usual' roaming model, combined with the concept of optimized SoR handover capabilities.

As shown in **Table 1**, this model offers a sustainable, long-term solution to meet the evolving needs of TOD by:

- Maintaining the competitive nature of the roaming business.
- Offering the largest global coverage.
- Expecting to have the least impact on technical implementations.
- Adhering to current roaming regulations.

In other words, the business-as-usual model is a practical and effective way to support TOD cross-border driving, without disrupting the dynamics of the roaming market.

## 4.1 Assumptions

The assumptions in this chapter describe a business-as-usual approach with an optimized SoR functionality. It is assumed that some basic services have already been established using the capabilities of 5GSA roaming. It is important to note that there is no mandatory requirement for MNOs to provide the TO service.

Given the current dynamics of the mobile industry, MNOs are providing service availability based on best-effort practices. In the context of 5GBP initiative, particularly addressed in D3.5 Governance models and recommendations, there is a recognition that MNOs may not assume full accountability for ensuring 100% service availability for TO. Instead, the discussion focusses on the feasibility of achieving safe TO in a best-effort capacity and the associated risks involved. The preliminary conclusion is that for small-scale niche scenarios, TO with best-effort connectivity can be run safely. However, when considering more ambitious TO scenarios, such as highway corridors, it becomes more challenging. In this realm TO service can only exist to serve AD systems with necessary fallback.

The first TO deployment scenarios, on private terrain and nearby local roads, are intended to deploy teleoperation without AD. This would lead to the eventual introduction of a hybrid solution. As an example, the introduction of initial TOD Services within very limited areas (corridor-based model) using Inter-PLMN handover functionalities, within the broader concept of the business-as-usual model serving the long-term projection. In this context the corridor would imply a very limited area, in order for operators to provide the most optimal coverage requirements and limiting the risks of failure to a minimum.One key concept in these assumptions is Coverage on Demand, as introduced in section 3.2.

## 4.2 Indicative steps towards TO driving

The table below provides a high-level overview of decisions and/or steps that can be considered as part of an ongoing process towards the introduction of a TO driving service. At this stage, there are many options and alternatives available, some of which are beyond the scope of any individual operator. The real challenge in implementing TOD services may not solely be about the technical aspects like handovers, but also involves broader considerations and complexities that require attention.  Assuming that the service will evolve towards a coverage on demand solution, it is important to contextualize the focus on border crossing.

To get this in perspective, Table 2 is intended to provide some guidance in that process.

| Step | Rationale | Potentially responsible |
|---|---|---|
| Segmentation of the service | The overall service can be solved in different ways. E.g., better road conditions and/or advances in automated driving may lead to less intervention from a TO driver. | TO service provider or Consortium |
| Forecast: capacity, QoS, time, location | Coverage is directly linked to capacity. More capacity means: more radio sites. | TO service provider |
| Allow AD vehicles/ trucks and platooning.<br><br>Liability into law. | Prerequisite | Ministry of Transportation |
| Insurance | Prerequisite | TO service provider |
| Develop self-driving vehicles/trucks | Prerequisite | Equipment provider |
| Safe road conditions for AD | Prerequisite | Ministry of Transportation |
| Arrange sufficient line of sight antenna installation points throughout corridors, accessible to all involved MNOs | Depending on the segmentation, at least needed at the locations with complex road conditions. | MNO, Tower Infrastructure Provider or Consortium |
| Determine impact on coverage/capacity in own coverage area | Prerequisite | MNO |
| Find/negotiate with roaming partners to agree requested capacity against specified QoS and locations | Prerequisite | MNO |
| Optional: agree on an industry standard for the deployment of TO driving. | To ensure a solution that is easily recognised and accepted throughout the industry, MNOs may decide to agree on an agreement template first to support the specific business case. | MNO |

**Table 2**: Steps towards teleoperated driving

The table illustrates that the actual involvement of operators may come at the end of this process, instead of at the beginning.

The Ministry of Transportation can play a significant role in facilitating and regulating teleoperations within the transportation sector. The ministry can organize legal provisions, for example for the liability of autonomous driving vehicles, trucks and platooning. Additionally, the Ministry of Transportation can assist in addressing the following inquiries:

- **Equipment providers' compliance**: defining the rules equipment providers must comply to in order to demonstrate the safety of their solution. Such as, specifying the lead time for the equipment to signal a situation where TO is required and prescribing the equipment response in the absence of TO availability.

- **Automated versus teleoperation necessity**: Providing clarity on the situations where automated driving is essential and identifying scenarios that necessitate teleoperation as a backup solution.
- **Capacity requirements**: defining whether there are capacity requirements for drivers for the availability of TO services.
- **CoD approval condition**: outlining the conditions under which operators can refuse a request for coverage on demand. In the event of an accident, specifying the steps an operator must take to demonstrate that the service was available, but due to external signal disturbance not accessible (e.g., a jammer or atmospheric conditions).

Under the given assumptions of the business-as-usual model combined with optimized SoR, there may be minimal requirements for additional measures involving operators. As Table 2 suggests, operators can, under these assumptions, use existing GSMA roaming agreement templates [8], e.g., to support a TO service through mutual roaming service delivery.

In comparison, the complexity to set-up inter-PLMN handovers, would require additional steps such as (but possibly not limited to):

- Define the locations where inter-PLMN handovers are required or alternatively the circumstances under which inter-PLMN handover is required.
- Define inter-PLMN handover as a roaming service.
- Inter-operator process arrangements to continuously align cell information.
- Mandate that the minimum 3GPP release is implemented.
- Carry out new IREG/TADIG tests (this means conducting tests to ensure that the inter-PLMN handovers are working correctly in a roaming context).
- Update IR.21/RAEX, an international roaming reference document containing technical and operational network information for an MNO.
- Creating a new annex to the International Roaming Agreements that specifically addresses inter-PLMN handovers.
- Submitting change requests (CRs) to other documents.
- Understanding and determining the relevance of parameters in SLAs on GSMA level.
- Considering non-binding legal and regulatory requirements.

As explained in the previous chapter, adopting an alternative approach instead of the business-as-usual model may necessitate additional steps. Depending on the chosen model, these steps could include:

- Defining the scope of the service: determining the extent of service coverage, such as whether the service spans from entry to exit point of the coverage area or operates on a COD basis. Additionally, specifying which providers can access the service, like EU/non-EU, public/private, international/national access.
- Regulating rollout pace.
- Regulating wholesale price caps for TO service usage in case of limited competition.
- Mandating Roaming SLAs, including the required QoS and measurement solution.
- Regulating penalties in case of non-compliance to the QoS.

## 4.3 Consequences related to Quality

Quality is the basis for TO driving, regardless of the form it takes. While this notion might be clear in a general sense, it is currently not well understood how this can be translated into a clear agreement between two parties.

Quality, coverage, and capacity, for instance, are related and depending on their specific definitions. An MNO may offer QoS level X, but only as far as its coverage allows it.

The use of corridors in TO services is not considered a long-term solution due to several limitations and challenges associated with this approach. Quality in TO services requires the ability to adapt to changing demands and scenarios. Although a corridor may start as a straightforward linear path, the service area must be able to expand as the service evolves. Corridor-based solutions might struggle providing consistent quality in dynamic situations that deviate from pre-defined routes. Furthermore, as TO technology progress, vehicles are expected to become more capable of navigating autonomously in a variety of environments. Restricting operations to corridors could hinder the adoption of advanced AD capabilities and limit the potential for improved service quality.

Over time, TO services are likely to expand beyond corridor limitations. Customers will seek solutions that offer teleoperation capabilities across a broader range of geographic areas and scenarios. MNOs need to meet these customer demands to remain competitive. Guaranteeing capacity in an unknown area, over an unknown time period, will be inefficient in terms of the actual use of the scarce/limited bandwidth on the radio interface and therefore costly. Network slicing may provide the technical capabilities to build it but will not solve this inefficiency. In a capacity on demand service, addressing the quality issue potentially becomes easier to solve as it allows for dynamic allocation of resources. This flexibility enables the MNO to allocate capacity where they are needed the most, which can help mitigate quality issues caused by corridor restrictions.

In summary, capacity on demand ensures that the right resources are available at the right time, increases performance, and provides the flexibility needed to enable effective and high-quality TO services. However, the different deployment scenarios identified for TO may not all be compatible with the use of COD. Therefore, it is highly probable that, considering short-term objectives and technical prerequisites, hybrid solutions will be developed to address the specific requirements of distinct teleoperation use cases.

# 5 RECOMMENDATIONS FOR FUTURE CROSS BORDER ROAMING

In this document, an analysis has been conducted of various business models, highlighting substantial differences between them. As explained in the previous chapter, in order to ensure the fulfilment of necessary roles and responsibilities and to maintain coordination among stakeholders, it is important to obtain more clarity regarding the specific objectives and approaches. Within this chapter general steps to achieve more clarity are outlined.

## 5.1 Generic roadmap

An overview of key-milestones and tasks are presented below, allowing for better understanding, planning and decision-making.

The following steps can be identified:

1. **Definition of purpose and goal**. By itself, the objective of crossing borders with a neighbouring country, is not an end goal, rather, it may serve as a means in a substantially larger framework. Only when that framework is understood, the various options towards that end goal can be compared. The requirements for border crossing can vary significantly depending on whether or not teleoperators need to be involved on regular basis and whether the crossing is for short-term or long-term delivery. Requirements for seamless border crossings must fit in an end-to-end solution design, covering more than an inter-operator connectivity service.
2. **Provisioning of a timeline**. Depending on the defined goal, it may be necessary to explore several solutions. Requirements related to the TOD use case are challenging in terms of coverage and capacity combined with ultra reliability and low latency, particularly in low density areas. Networks need time to evolve to meet the demands of TO driving. If there is a need to support the TO-use cases on a short-term basis, before networks can handle such requests as a general service, a different approach may be needed. To ensure the successful introduction of TO Services and gain the support of stakeholders, it is important to develop and present a clear and well-advanced timeline. This is especially important in busy environments where there are many competing demands on resources and attention.
3. **Selection of a business model**. Choosing a TO business model requires exploring a variety of options. This document provides guidelines for what is possible. However, it is important to consider several models per country and how these models could work together across different countries.
4. **Derive requirements for the chosen model**. Coverage, capacity and QoS are typically the first considerations when developing a mobile solution. Once these factors are clear, steps towards a solution for the mobile service can be taken. Assuming that the realisation is based on competition, MNOs can make their business case and decision to provide a suitable service.

   **Ensure that industry standards support the requirements**. The current 3GPP standards, in Release 16, cover certain technical specifications for Inter-PLMN Handovers and the existing SoR functionalities. Nevertheless, there is a need for these standards to be revised and updated to incorporate more flexible and advanced features to enable cross-border handovers beyond neighbouring countries while adhering to defined and acceptable latency criteria for various use cases.
5. **Contractual arrangements between operators**. To ensure TO services across multiple countries, new aspects, such as handovers, service levels, penalties, reports and geographical aspects, will need to be outlined in the International Roaming Agreements between operators. These contracts are essential to guarantee secure seamless operations, allocate responsibilities, and manage potential disputes.

## 5.2 Governance between MNOs

### 5.2.1 Prerequisites

As explained in section 4.3, a clear definition of quality in relation to required coverage and capacity will be a prerequisite before any agreement between MNOs is meaningful.

Furthermore, it is essential to have a well-defined business model and a clear method for network crossing. Building upon this, as explained in section 5.1, there is a need to translate these considerations into specific requirements for mobile service. For instance:

- Determine whether the service will operate on a COD basis or provide continuous service delivery.
- Define a network slice with all required QoS parameters.
- Identify which roaming country or countries, including forecasted or committed volumes per country.
- Specify the expected traffic pattern, including locations with high density and seasonal fluctuations.
- Clearly outline the usage process, along with procedures for service limitations and termination.
- Establish agreements and protocols for addressing instances of non-compliance, as well as defining compensation fees.

### 5.2.2 Recommendations

Roaming partners regularly establish agreements based on the estimated amount of data volume that will be used on each other's networks. This arrangement may be sufficient in some cases, but it is not always possible to predict how much data a subscriber will use while roaming. The moment a subscriber requests for additional capacity while roaming, the network they are roaming on will assess if the requested service can be provided. If it cannot, the request will be denied.

It is unlikely for MNOs to make guarantees without having corresponding financial commitments in place. Roaming partners need to make these commitments before they can offer guaranteed services to their customers.

As part of these new deals, roaming SLAs will need to be in place. Roaming SLAs are the basis of many new 5G services but have not yet gained enough traction. Therefore, operators are recommended to start agreeing at least a first baseline SLA with their partners on bilateral basis.

A next step may be to improve internal knowledge on one's network performance. Standardized measurements and parameters have been defined and are about to be updated for 5G specifically. For further details, operators are referred to GSMA PRD IR.81: Global Roaming Quality Measurement implementation [9].

# 6 CONCLUSION AND RECOMMENDATIONS

Three technical concepts, with the one more elaborated than the other, have been introduced to provide seamless handover in a cross-border region within the context of teleoperations. The starting point for the technical solutions introduced in 5GBP are based on 3GPP Release 16 standards.

1. In WP5 Inter-PLMN has successfully been trialled in a controlled lab and pilot site environment. The trials have demonstrated the capability to ensure uninterrupted TO operations, while complying with the specified latency criteria. To enable deployment in real-world use cases within a roaming context, further assessment in real environments is necessary.
   Several ongoing challenges that need to be addressed are:
   - Compliancy with requirements formulated in Appendix A, especially the concern of cross-border areas beyond neighbouring countries, where the home operator has no control in foreign-to-foreign handovers.
   - Handling outstanding issues related to billing, security and guarantees of service quality in foreign-to-foreign handover situations.
   - Evaluating the scalability of the solution, taking into account the complex operational process, which involve cell-coordination.

   In its current phase, the Inter-PLMN solution, can only be implemented in extremely limited areas. There is a directive for the 6G initiative to develop solutions that automate all manual actions currently associated with inter-PLMN operations, addressing the cumbersome aspects of the existing processes.
2. Dual-IMSI: The technical results will be documented in 5GBP's D5.5 report, which focusses on dual SIM implementation for seamless cross-border TO. An important aspect to make this solution compliant with the competitive roaming industry, is to include the network selections procedure based on SoR. A potential challenge remains in effectively managing 2 SIMs, which in turn, requires attention for scalability issues.
3. Optimized SoR: The notion of an optimized SoR is conceptual and has the potential for nationwide deployment. The specific provisions to handle seamless handover or a handover in a short time, are not included in the 3GPP Release 16. Therefore, it is crucial to address this in the future releases and assess the extent to which the latency criteria can be fulfilled, as well as determining which TO UC may benefit from this rapid handover solution.

This document has introduced four distinct TO business models for roaming, with one of them being the 'business as usual' model. This model, combined with the optimized SoR concept, underlies the dynamic roaming industry. It allows a competitive landscape and provides nationwide coverage. However, looking at the evolutionary progression of mobile networks, the TO driving use case is a long way from where services are today. If a specific use case needs to be supported in an earlier phase, a different business model from 'business as usual' may be recommendable. This could involve making use of dedicated infrastructure to support TOD, and even the introduction of hybrid models as a future advancement.

Teleoperation is likely to be provided as a backup solution in case the autonomous driving system fails. Consequently, the utilization of teleoperation is expected to be limited in such situations. This leads to the potentially only realistic application: through coverage on demand. Since an autonomous driving failure occurs sporadically and at any location, service provision would only be viable in a coverage on demand solution. This underscores its primary practical purpose: fulfilling coverage requirements as needed.

The options for providing support through MNO services have been explored. It is unlikely that MNOs will provide 100% service guarantees. This because, several factors that can lead to signal loss, are beyond the control of an MNO. The notion that best-effort connectivity can be safe for small-scale niche scenarios while acknowledging the challenges for more ambitious TO scenarios aligns with the complexities of real-world deployment. The extent to which liability will be defined, depends on discussions between the parties involved. If applicable, these liability considerations might also be influenced by the enforced regulation. In essence, the terms of responsibility will take shape through negotiations and potentially be further defined within the operational and legal framework established by NRAs.

Furthermore, as the home operator, evaluating the QoS on roaming networks presents significant challenges, especially when the transport involves more than two countries. Implementing cross-border teleoperation in its most ambitious form (allowing operation from any point A to any point B) is practically unfeasible due to both technical and governance considerations.

It is recommended to restrict border crossings to highways and ensure that these crossings are sufficiently secure for autonomous passage. Additionally, they should be designed to provide security fallback measures in case of issues. Indirect-control TO, which rely on AD capabilities, are suitable for cross-border operations. In contrast, direct-control TO, which can be implemented before AD systems are available, should be limited to private terrains and local roads.

# APPENDIX A BUSINESS REQUIREMENTS/PREREQUISITES

## Business requirements

1. Choice for specific seamless roaming solution MUST be made and is final before any potential discussions with GSMA start
2. Clarity on inter-operator consequences
3. Regulatory approval; in compliance with company security policy
4. Liability issue solved: Teleoperated vehicles can rely on the availability of coverage/capacity to a certain degree – to be explicitly provided in measurements.
5. Solution MUST be scalable to at least pan-European. A solution covering only two countries is assumed to be pointless.
6. Choice of the service scope MUST be: per network or pan-European.
7. Entry and exit criteria MUST be defined: under what conditions can a requested service be refused and be terminated. Solutions may need to be in place to cater for the bandwidth reservation throughout the service scope.
    - In case of service per network, entry and exit criteria apply to each network change, i.e. border crossing and if applicable, within the coverage area.
    - In case of a pan-European service scope, bandwidth reservation without prior knowledge with regard to the requested route/service area, is assumed to be unrealistic. Therefore additionally required: prior knowledge of the route, from start to endpoint or first planned stop, where that shall be defined as endpoint. Including the time window for the requested service.
8. Deliverable will cover 5G SA, with(out?) a temporary 4G/5G NSA fallback solution
9. Solution shall not impact the Steering of Roaming abilities of home operators.
10. Uniform definition of service and coverage area
11. Uniform QoS requirements/model needed
12. If additional processes are needed between MNOs, this MUST NOT materially restrict MNOs in their business, operation and obligations. For instance alignment on a multitude of neighbouring cells, may result in restricting MNOs to properly tune their individual radio networks.
13. Company confidential information SHALL NOT be shared with competing MNOs. For instance cell coverage is generally considered confidential between MNOs and cannot be shared with MNOs within the same country. Cell information is the basis for the quality of one's network.
14. No solution SHALL negatively affect the level playing field between MNOs, domestically nor on the international roaming business.
15. **REGULATORY**. Solution MUST comply with national laws and regulation of all individual countries. For instance, but not limited to lawful interception and data privacy.

## Technical requirements

1. Architecture of chosen solution MUST comply with 3GPP standard
2. UE MUST comply with chosen solution
3. **HPLMN→VPLMN**. It MUST be possible to determine to which roaming network users of the TO use case change, while crossing the border towards a neighbouring country.
4. **VPLMN→HPLMN**. It MUST be possible to determine to which network users of the TO use case change, while crossing the border from any neighbouring network towards the home country. Depending on the chosen business model, this could be restricted to the home network.
5. **VPLMN→VPLMN**. It MUST be possible to determine to which roaming network users of the TO use case change, while crossing the border towards a non-neighbouring country.

6. It MUST remain possible to flexibly steer the roaming network for other users than the TO use case, while crossing the border towards any other country.
7. It MUST remain possible to determine to which network other users than the TO use case change, while crossing the border from any neighbouring network towards the home country. Depending on the chosen business model, this could be restricted to the home network.
8. It SHOULD be possible to flexibly steer the roaming network for users of the TO use case, while crossing the border towards any other country.
9. It MUST remain possible to prevent home network users other than the TO use case to change network within the home country.
10. It MUST remain impossible for regular users of a public network to enter into a private network, in case private – public crossings are configured.
11. Depending on the chosen business model, users of the TO use case, SHOULD be able to change network within the home country.
12. **BILLING**. It MUST be possible to account for and charge all roaming (user data) usage in the used network. This includes roaming billing, roaming invoice verification and true up/settlement reporting. Depending on the used network generation, this can be in the context of TAP or BCE. Depending on the chosen business model, this may apply to national roaming as well.
13. **BILLING**. It MUST remain possible for every MNO to measure and report all visited usage on its network. That is: it SHALL NOT depend on measurements of any other MNO.
14. **BILLING**. It MUST remain possible for every MNO to measure and report all outbound roaming usage per roaming partner network. That is: it SHALL NOT depend on measurements of any other MNO.
15. **BILLING**. User data usage on different networks MUST never be indistinguishable for (billing) reports. Meaning that usage on one network, can never end up as apparent usage on a different network.
16. **SECURITY**. It MUST never be possible that usage is generated before a subscriber is authenticated on the network and by the network it is using.
17. **SECURITY**. Solution MUST be in full compliance with GSMA 5G security scenarios, including Roaming VAS and Roaming hubbing.

## Operational requirements

1. Roaming SLAs agreed and implemented between involved MNOs, covering all essential requirements for TOD.

# APPENDIX B TECHNICAL REQUIREMENTS

This section describes:

- General description changes for seamless handover
- Standardisation aspects taken into in release 18/19 3GPP to be implemented by vendors
- Technical and configuration changes on-site
- Procedural changes
- Inter-MNO configuration changes compared to current way of working

Current 3GPP 5G specifications support two types of roaming implementations in standalone (SA): Local breakout (LBO), where data traffic is directly routed from the UPF of the Visited PLMN to the Data Network, and Home-Routed (HR), where traffic is sent back to the UPF of the Home PLMN to be classified and routed. However, the roaming call-flows are specified under the assumption that the PDU session is terminated at the home PLMN, and a new one is established at the visited PLMN, which leads to interruption.

On the other hand, a procedure is defined for performing a N2 handover between two gNBs within a PLMN via the N14 interface, where the UE context is transferred between two gNBs through the N14 interface connecting their AMFs in two phases: a preparation phase where the context is proactively transferred to the gNB of the PLMN, and an execution phase where the UE leaves the PLMN and connects to the PLMN. In the latest Release of the 5G specifications (I.e., Release 18), a clarification has been added to the call-flow to specify the exchanged messages between AMFs in an inter-PLMN handover scenario. However, this addition is not sufficient as more changes and configurations are required to support inter-PLMN handover for a seamless roaming in 5G SA in both directions (I.e., HPLMN to VPLMN and back).

To this end, the solution developed in 5G Blueprint combines the Home-Routed roaming and the N2 handover procedures over the N14 interface with further enhancements to reduce downtime. The combination of those procedures allows the user context to be transferred across PLMNs so that the Visited PLMN can reuse it. Moreover, since this is done in the N2 preparation phase, the PDU session can be set up in advance (i.e., before the N2 execution phase). This way, the downtime can be minimized.

Figure 5 shows the simplified call-flow for seamless 5G SA roaming from HPLMN to VPLMN, which merges messages from the N2 handover and inter-PLMN N2 handover.

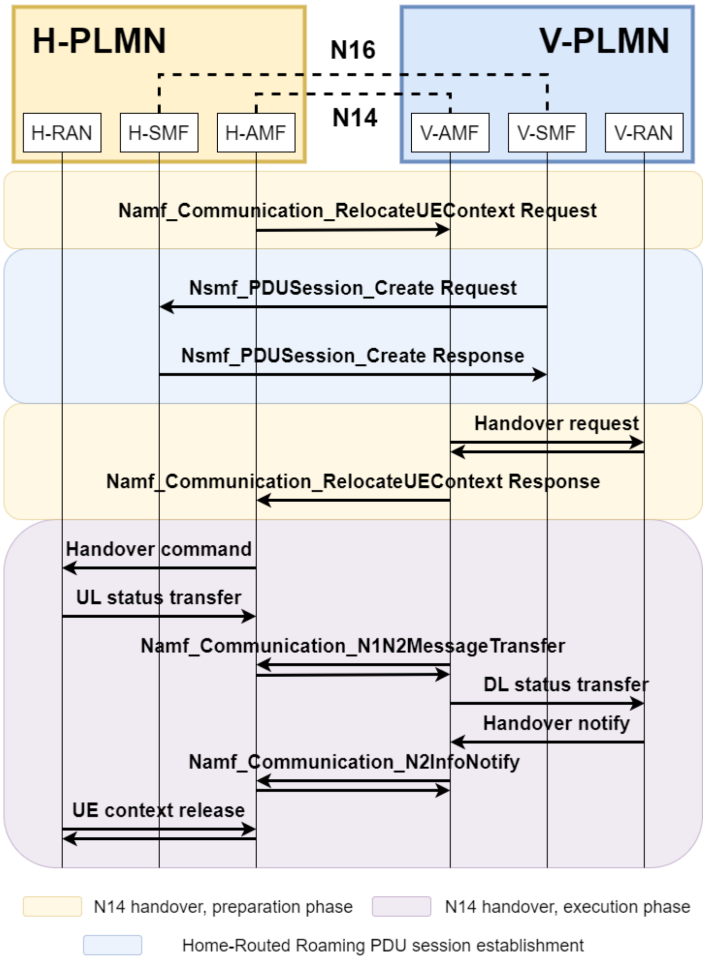


**Figure 5:** Simplified call-flow for seamless roaming implemented in 5G Blueprint

In the merged call-flow in Figure 5, a few duplicate messages from the N2 handover call-flow could be removed because the information was already conveyed by messages from the Home-Routed roaming call-flow. Additionally, it was observed from experiments and measurements that the service interruption (i.e. downtime) started at the N4 modification message to the S-UPF to set up the N9 tunnel. Thus, delaying this message allows for a reduced downtime, with observed interruption times that are similar to those achieved in a normal intra-PLMN N2 handover procedure.

Finally, to support a handover between the gNBs of different PLMNs, each gNB should be configured with the PLMN ID of the other network as an Equivalent PLMN, to enable UE context transfer between the gNBs.

Those changes will be submitted to 3GPP standards for Release 18/19.

## Onsite cell configuration

RAN

| RAN KPN – NL | |
|---|---|
| Center frequency | 3.525 MHz |
| Bandwidth | 40 MHz |
| Cells | 2 |
| Technology | 5G NR TDD |
| Brand | Huawei |

**Table 3:** Onsite cell configuration KPN

| RAN Telenet – BE | |
|---|---|
| Center frequency | 3.490 MHz |
| Bandwidth | 50 MHz |
| Cells | 3 |
| Technology | 5G NR TDD |
| Brand | Ericsson |

**Table 4:** Onsite cell configuration Telenet

# APPENDIX C HANDOVER CONFIGURATION HUAWEI GNB

## Configuration MML commands

## Modify external cell configuration

MOD NREXTERNALNCELL:MCC="206",MNC="20",GNBID=5216,CELLID=30,PHYSICALCELLID=134,CELLNAME="nei-131",TAC=801,SSBDESCMETHOD=SSB_DESC_TYPE_GSCN,SSBFREQPOS=7839,NRNETWORKINGOPTION=SA,FREQUENCYBAND=N78;

## Set handover thresholds for A1, A2 and A5:

MOD NRCELLINTERFHOMEAGRP:NRCELLID=32,INTERFREQHOMEASGROUPID=0,COVINTERFREQA5RSRPTHLD1=-88,COVINTERFREQA5RSRPTHLD2=-98,COVINTERFREQA2RSRPTHLD=-80,COVINTERFREQA1RSRPTHLD=-70;
MOD NRCELLRELATION:NRCELLID=32,MCC="206",MNC="20",GNBID=5216,CELLID=30,BLINDSCELLCONFIGFLAG=FALSE,NOHOFLAG=PERMIT_HO,NORMVFLAG=FORBID_ANR_RMV,BLINDHOFLAG=COV_BASED_BLIND_HO_FLAG-0&DIALING_TEST_HO_FLAG-0,POWERSAVINGCELLFLAG=NOT_CONFIG,MLBHOFLAG=FALSE,INTERGNODEBFLAG=FALSE,INTERGNODEBSULFLAG=FALSE,HIGHSPEEDINTRFAVOIDFLAG=NO_INTRF_AVOID;
MOD NRCELLRELATION:NRCELLID=33,MCC="206",MNC="20",GNBID=5216,CELLID=30,BLINDSCELLCONFIGFLAG=FALSE,NOHOFLAG=PERMIT_HO,NORMVFLAG=FORBID_ANR_RMV,BLINDHOFLAG=COV_BASED_BLIND_HO_FLAG-0&DIALING_TEST_HO_FLAG-0,POWERSAVINGCELLFLAG=NOT_CONFIG,MLBHOFLAG=FALSE,INTERGNODEBFLAG=FALSE,INTERGNODEBSULFLAG=FALSE,HIGHSPEEDINTRFAVOIDFLAG=NO_INTRF_AVOID;

## Add equivalent PLMN

ADD GNBEQVPLMN:OPERATORID=0,EQUIVALENTMCC="206",EQUIVALENTMNC="20";

## Enable EPLMN Handover:

MOD GNODEBPARAM:EQVPLMNALGOSWITCH=INTRA_RAT_HO_WITH_GNB_EPLMN_SW-1;

## Set gnbidlength:

ADD GNBEXTERNALPLMN:MCC="206",MNC="20",GNBIDLENGTH=24;

## Overview handover settings

```
LST NREXTERNALNCELL:;
Sas van Gent

+++    Sas van Gent        2023-04-24 23:03:40 DST

O&M    #2686462947

%%/*1879123575*/LST NREXTERNALNCELL:;%%

RETCODE = 0  Operation succeeded.

List NR External Neighboring Cell
---------------------------------
             Mobile Country Code  =  206
             Mobile Network Code  =  20
                    gNodeB ID  =  5216
                      Cell ID  =  30
```

```
              Physical Cell ID  =  134
                   Cell Name  =  nei-131
         RAN Notification Area ID  =  65535
              Tracking Area Code  =  801
SSB Frequency Position Describe Method  =  Global Synchronization Channel Number
            SSB Frequency Position  =  7839
             NR Networking Option  =  Standalone
                 Frequency Band  =  n78
          Additional Frequency Band  =  NULL
              PLMN Reserved Flag  =  False
                High Speed Flag  =  Low-speed Cell
       Mobility Function Indication  =  VoNR Handover Switch:On
                              =  Coverage Threshold Adaptation Switch:On
                              =  Cell Reservation Status Switch:Off
(Number of results = 1)
---    END
LST NRCELLINTERFHOMEAGRP:NRCELLID=32;
Sas van Gent

+++    Sas van Gent        2023-04-24 23:06:48 DST

O&M    #2686462951

%%/*1879123579*/LST NRCELLINTERFHOMEAGRP:NRCELLID=32;%%

RETCODE = 0  Operation succeeded.

List Measurement Parameter Group Related to Inter-frequency Handover

-------------------------------------------------------------------

                              NR Cell ID  =  32
       Inter-freq Handover Measurement Group ID  =  0
 Inter-freq Measurement Event Time to Trigger(ms)  =  320
   Inter-freq Measurement Event Hysteresis(0.5dB)  =  2
       Inter-frequency A1A2 Time to Trigger(ms)  =  320
         Inter-frequency A1A2 Hysteresis(0.5dB)  =  2
  Freq Priority Inter-freq A2 RSRP Threshold(dBm)  =  -89
  Freq Priority Inter-freq A1 RSRP Threshold(dBm)  =  -86
  Cov Inter-freq Handover A5 RSRP Threshold1(dBm)  =  -88
  Cov Inter-freq Handover A5 RSRP Threshold2(dBm)  =  -98
   Cov Inter-freq Handover A2 RSRP Threshold(dBm)  =  -80
   Cov Inter-freq Handover A1 RSRP Threshold(dBm)  =  -70
  Freq Priority Inter-freq A4 RSRP Threshold(dBm)  =  -104
    MLB-based Inter-Frequency RSRP Threshold(dBm)  =  -104
 Operator Ded Pri Inter-freq HO A4 RSRP Thld(dBm)  =  -104
     Srv-Based Inter-freq A4 RSRP Threshold(dBm)  =  -104
         Cov Inter-freq HO RSRQ Threshold(0.5dB)  =  -24
      Cov Inter-freq HO A2 RSRQ Threshold(0.5dB)  =  -30
      Cov Inter-freq HO A1 RSRQ Threshold(0.5dB)  =  -26
  Intrf-based Inter-Freq HO A3 RSRP Offset(0.5dB)  =  3
       Intrf-based Inter-Freq HO RSRP Thld(dBm)  =  -104
      SSB SINR Inter-freq HO A1 Threshold(0.5dB)  =  16
      SSB SINR Inter-freq HO A2 Threshold(0.5dB)  =  10
    A3 Inter-freq Handover A2 RSRP Threshold(dBm)  =  -100
    A3 Inter-freq Handover A1 RSRP Threshold(dBm)  =  -96
       Inter-frequency Handover A3 Offset(0.5dB)  =  2
       UL Cov Inter-freq A5 RSRP Threshold1(dBm)  =  -110
              High-Speed UE A2 Thld Offset(dB)  =  0
Mll-based Inter-Freq Handover A5 RSRP Thld 2(dBm)  =  -105

(Number of results = 1)
---    END
LST NRCELLRELATION:NRCELLID=32;
Sas van Gent

+++    Sas van Gent        2023-04-24 23:09:36 DST

O&M    #2686462952

%%/*1879123581*/LST NRCELLRELATION:NRCELLID=32;%%

RETCODE = 0  Operation succeeded.

List NR Cell Relationship
```

```
------------------------
                       NR Cell ID  =  32
                Mobile Country Code  =  206
                Mobile Network Code  =  20
                        gNodeB ID  =  5216
                          Cell ID  =  30
          Cell Individual Offset(dB)  =  0 dB
       Blind SCell Configuration Flag  =  False
                  No Handover Flag  =  Handover Permitted
                   No Removal Flag  =  Forbid ANR Removal
Neighboring Cell Reselection Offset(dB)  =  0 dB
         Neighboring Cell Class Label  =  Formal
                Blind Handover Flag  =  Coverage-based Blind Handover Flag:No
                                   =  Dialing Test Handover Flag:No
              Power Saving Cell Flag  =  Not Configured
             MLB-Based Handover Flag  =  Not Allowed
                  Inter-gNodeB Flag  =  No
               Inter-gNodeB SUL Flag  =  No
 High Speed Interference Avoidance Flag  =  No Interference Coordination
                         ANR Flag  =  No

(Number of results = 1)
---    END
LST GNBEQVPLMN:;
Sas van Gent

+++    Sas van Gent        2023-04-24 23:12:26 DST

O&M    #2686462953

%%/*1879123583*/LST GNBEQVPLMN:;%%

RETCODE = 0  Operation succeeded.

Lst GNBEQVPLMN
--------------
               Operator ID  =  0
Equivalent Mobile Country Code  =  206
Equivalent Mobile Network Code  =  20
(Number of results = 1)

---    END
LST GNODEBPARAM:;
Sas van Gent

+++    Sas van Gent        2023-04-24 23:13:28 DST

O&M    #2686462954

%%/*1879123585*/LST GNODEBPARAM:;%%

RETCODE = 0  Operation succeeded.

List gNodeB Parameter

--------------------
                            Frame Offset(Ts)  =  0
          Application Packet Size Threshold(Byte)  =  500
                 Board Processing Policy Switch  =  Data Forwarding Policy Switch:Off
                                             =  Task Scheduling Balancing Switch:Off
        SNR Threshold for AOA Measurement(0.01dB)  =  -800
                       X2-U Transmission Type  =  Through Internal Network
          NSA DC Resource Coordination Scenario  =  Sync NSA DC Zero Frame Ofs
                Clock Out-of-sync Detect Switch  =  Clock Detection Switch:On
                                             =  Clock Out-of-Sync Postprocessing Switch:Off
         Clock Out-of-sync Intrf Report Thld(dBm)  =  -90
         Silence Detect Intrf Difference Thld(dB)  =  6
                    NSA DC Optimization Switch  =  NSA DC SRB3 Switch:Off
                                             =  NSA DC Fast Retrans Switch:Off
                                             =  LNR Relative Frame Offset Adapt Switch:Off
                                             =  Non-CA NSA DC Combination Select Switch:Off
                                             =  S1-U Status Sending Switch:Off
                                             =  SCG Addition PLMN Select Policy Switch:Off
                                             =  Post-Random-Access Data Split Switch:Off
                                             =  SCG Fail Process Conflict SCG Release Sw:Off
                                             =  LTE and NR Process Conflict Optimize Sw:Off
```

```
                                     =  Inter-Freq HO Band Combine Change Sw:Off
                                     =  Simultaneous Intra-SgNB Inter-Freq HO Sw:Off
                                     =  T304-based Msg3 Detection Switch:Off
                                     =  NSA Frequency Conflict Avoid Switch:Off
                                     =  NSA Delay-based Retransmission Switch:Off
                                     =  NSA Data Split Adaptive Recovery Switch:Off
                                     =  NSA PDCP Data Split Optimization Switch:Off
                                     =  DRX NSA Data Split Optimization Switch:Off
                                     =  NSA NCGI Measurement DRX Config Switch:Off
       Base Station Deep Dormancy Switch  =  Baseband Shutdown Energy Saving Switch:Off
     LF Holdover Duration After GPS Failure  =  Holdover for 24 Hours
   Synchronization Difference Detect Switch  =  Gap-based Sync Deviation Detect Switch:On
          Max FH Fiber Length Adapt Switch  =  Off
         Max X2 Transmission Rate(100Mbps)  =  1
      Service Interface Alarm Config Switch  =  X2 Lower Layer Link Alarm Shield Switch:On
                                     =  Xn Lower Layer Link Alarm Shield Switch:On
                                     =  NG Lower Layer Link Alarm Shield Switch:On
                          CHR Switch  =  Trace ID User Identification Switch:Off
                                     =  S-TMSI Record Forbidden Switch:Off
   Auto Cell Bind Baseband Equipment Switch  =  On
    Transport Layer Lost Packet Meas Switch  =  Cell CHR Reporting Switch:Off
                                     =  User Trace Switch:Off
                                     =  App-based CHR Log Switch:Off
    Transport Layer Lost Pkt Meas User Type  =  Common User
      Uplink Flow Control Algorithm Switch  =  UL Air Interface Flow Control Switch:Off
                                     =  UL Air Interface Flow Control Enh Switch:Off
      Ethernet Port State Auto Dea Cell Sw  =  On
                 PWS Indication Switch  =  PWS Restart Indication Switch:Off
                                     =  PWS Fault Indication Switch:Off
     Service Differentiation Process Switch  =  Sparse Service Diff Processing Switch:Off
                                     =  gNodeB Adaptive Fast Processing Switch:Off
          Soft Failure Self-healing Switch  =  BBP Reset Switch:Off
                                     =  RF Unit Reset Switch:Off
                                     =  BBP Reset Delay Switch:Off
                                     =  RF Unit Reset Delay Switch:Off
                                     =  KPI Abnormal Alarm Switch:On
              LTE Handover Algo Switch  =  LTE-to-DSS-NR HO Optimization Switch:Off
         Equivalent PLMN Algorithm Switch  =  Intra-RAT Inter-PLMN HO with AMF EPLMN:Off
                                     =  EPLMN-based Intra-RAT Inter-PLMN HO Sw:On
                                     =  Inter-RAT Inter-PLMN HO with AMF EPLMN:Off
                                     =  EPLMN-based Inter-RAT Inter-PLMN HO Sw:Off
Intra-Site Max X2 Transmission Rate(100 Mbit/s)  =  0
            Mobility Optimization Switch  =  Redirection Optimization Switch:Off
                                     =  NR-to-LTE Handover Success Identify Sw:Off
                                     =  NG Fault Notification Switch:Off
                                     =  Context-Absent Reestablishment Switch:Off
          Compatibility Algorithm Switch  =  23501-based GBR Service Admission Sw:Off
                                     =  SRS Antenna Selection Capability Sw:Off
                                     =  Uplink PDCP SN Abn Compatibility Opt Sw:Off
                                     =  PDU Session Modify Compat Opt Switch:On
                                     =  GTP-U Extension Header V1530 Switch:On
                                     =  PDCP SN Exception Full Config Switch:Off
                                     =  Xn Service Area Info Processing Switch:On
                                     =  Counter Check Compatibility Switch:Off
                                     =  R16 CSI-RS-related UE Capability Use Sw:Off
                                     =  Xn Service R16 Incompatibility Switch:Off
                                     =  SRS Reconfiguration Method Switch:Off
                                     =  Xn UE Security Capb Processing Sw:Off
                                     =  R16 100MHz Chn Bw UE Capb Use Sw:On
                                     =  Init Context Failure Release Request Sw:Off
           DRB Load Sharing Threshold(%)  =  60
            PDCP Process Optimize Switch  =  Encrypted Packet Hardware Process Switch:Off
                                     =  Integrity Protection HW Process Switch:Off
                                     =  DRB Load Sharing Switch:Off
             Packet Measurement Switch  =  Packet Delay Measurement Switch:Off
              Networking Option Opt Sw  =  DL-based NSA/SA Selection Opt Switch:Off
                                     =  NSA/LTE Selection Optimization Switch:Off
                                     =  UL-based NSA/SA Selection Opt Switch:Off
      Speed Turbo UE Identification Switch  =  SPID-based Identification Switch:Off
                                     =  Large-Packet-based Identification Switch:Off
                                     =  Packet-Size-based Identification Switch:Off
                                     =  App-based Identification Switch:Off
UL PDCP SN Abnormal Detection Threshold(packet)  =  10000
  Abnormal DL Data Split Penalty Period(100ms)  =  600
            NSA/SA Selection Opt Period(s)  =  60
         TDD Channel Calibration Opt Switch  =  Off
```

```
                    Module Process Opt Switch  =  Q922 UI Frame-based Info Transfer Switch:On
                     Schedule Grouping Period  =  5 Minutes
                               Process Switch  =  RRC Reconfiguration Procedure Opt Switch:Off
                                               =  UE Capability Query Procedure Opt Switch:Off
                                               =  RRC Release Procedure Opt Switch:Off
                                               =  Init Ctx Setup Fail NAS PDU Delivery Sw:Off
                                               =  RRC Message Segmentation Switch:Off
                                               =  UE E-UTRAN Capability Query Opt Switch:Off
                                               =  PDCP COUNT Wrap Around Switch:Off
                       UE Optimization Switch  =  Single Carrier Band Comb Select Opt Sw:On
UL PDCP SN Out Reordering Win Packet Num Thld(packet)  =  150
        UL Abnormal PDCP SN Packet Num Thld(packet)  =  150
                     Cell State Policy Switch  =  NG Faulty OMCH Normal Auto Deactv Sw:Off
                                               =  NG and OMCH Faulty Auto Deactv Sw:Off
                                               =  NG Fault Identification Policy Switch:Off
                                               =  S1-U and OMCH Faulty Auto Deactv Sw:Off
                                               =  Slice NG Fault Identification Policy Sw:Off
                 NR Board Performance Switch  =  Channel Measure CPU Usage Reduce Switch:On
                                               =  CSI-RS Transmit CPU Usage Reduce Switch:On
                                               =  UL Schedule CPU Usage Reduce Switch:On
                                               =  DL Schedule CPU Usage Reduce Switch:On
                                               =  Control Channel Configure Optimize Sw:On
                 RLC/MAC Performance Switch  =  RLC DL SDU RX and Release HW Process Sw:Off
                                               =  Downlink Rank 4 Enhancement Switch:Off
                  NR User Processing Load Mode  =  RRC_CONNECTED UE Number and CPU Load
           NR User-Plane Load Balancing Threshold  =  80
          NR Coordinate Service Flow Control Switch  =  On
                  Ng Interface Algorithm Switch  =  AMF Selection Enhancement Switch:Off
                                               =  AMF Set Backup Switch:On
             Baseband Resource Allocation Mode  =  Normal
          Interface Type for Coordination Service  =  Xn
          LF Holdover Duration After GNSS Failure  =  Holdover for 24 Hours
             RRC Setup Request Punish Threshold  =  0
       Clock Out-of-Sync C-Intrf Report Interval  =  30 Minutes
           Service Experience Algorithm Switch  =  Speed Turbo UE Opt Switch:Off

(Number of results = 1)

---    END
LST NRCELLFREQRELATION:NRCELLID=32;
Sas van Gent

+++    Sas van Gent        2023-04-24 23:36:11 DST

O&M    #2686462960

%%/*1879123607*/LST NRCELLFREQRELATION:NRCELLID=32;%%

RETCODE = 0  Operation succeeded.

No matching result is found

---    END
```

# APPENDIX D ERICSSON SETUP AT TELENET, BORDER ZELZATE

## Handover relations

```
crn GNBCUCPFunction=1,NRNetwork=1,NRFrequency=635040-30-20-0-2
arfcnValueNRDl 635040
bandListManual 78
smtcDuration 2
smtcOffset 0
smtcPeriodicity 20
smtcScs 30
end
```

```
crn GNBCUCPFunction=1,NRCellCU=$cell131,NRFreqRelation=635040-30-20-0-2
anrMeasOn true
cellReselectionPriority 7
cellReselectionSubPriority
intraFreqMCFreqRelProfileRef
mcpcPCellNrFreqRelProfileRef GNBCUCPFunction=1,Mcpc=1,McpcPCellNrFreqRelProfile=Default
mcpcPSCellNrFreqRelProfileRef
mdtMeasOn true
nRFrequencyRef NRNetwork=1,NRFrequency=635040-30-20-0-2
pMax 23
plmnIdList mcc=204,mnc=69;mcc=206,mnc=20
plmnRestriction false
qOffsetFreq 0
qQualMin
qRxLevMin -140
sIntraSearchP 62
sIntraSearchQ
tReselectionNR 2
tReselectionNrSfHigh
tReselectionNrSfMedium
threshXHighP 4
threshXHighQ
threshXLowP 0
threshXLowQ
trStSaNrFreqRelProfileRef
ueMCNrFreqRelProfileRef GNBCUCPFunction=1,UeMC=1,UeMCNrFreqRelProfile=Default
end
```

```
crn GNBCUCPFunction=1,NRCellCU=$cell132,NRFreqRelation=635040-30-20-0-2
anrMeasOn true
cellReselectionPriority 7
cellReselectionSubPriority
intraFreqMCFreqRelProfileRef
mcpcPCellNrFreqRelProfileRef GNBCUCPFunction=1,Mcpc=1,McpcPCellNrFreqRelProfile=Default
mcpcPSCellNrFreqRelProfileRef
mdtMeasOn true
nRFrequencyRef NRNetwork=1,NRFrequency=635040-30-20-0-2
pMax 23
plmnIdList mcc=204,mnc=69;mcc=206,mnc=20
plmnRestriction false
qOffsetFreq 0
qQualMin
qRxLevMin -140
sIntraSearchP 62
sIntraSearchQ
tReselectionNR 2
tReselectionNrSfHigh
tReselectionNrSfMedium
threshXHighP 4
threshXHighQ
threshXLowP 0
threshXLowQ
trStSaNrFreqRelProfileRef
ueMCNrFreqRelProfileRef GNBCUCPFunction=1,UeMC=1,UeMCNrFreqRelProfile=Default
end
```

```
crn GNBCUCPFunction=1,NRCellCU=$cell133,NRFreqRelation=635040-30-20-0-2
anrMeasOn true
cellReselectionPriority 7
cellReselectionSubPriority
intraFreqMCFreqRelProfileRef
mcpcPCellNrFreqRelProfileRef GNBCUCPFunction=1,Mcpc=1,McpcPCellNrFreqRelProfile=Default
mcpcPSCellNrFreqRelProfileRef
mdtMeasOn true
nRFrequencyRef NRNetwork=1,NRFrequency=635040-30-20-0-2
pMax 23
plmnIdList mcc=204,mnc=69;mcc=206,mnc=20
plmnRestriction false
qOffsetFreq 0
qQualMin
qRxLevMin -140
sIntraSearchP 62
sIntraSearchQ
tReselectionNR 2
tReselectionNrSfHigh
tReselectionNrSfMedium
threshXHighP 4
threshXHighQ
threshXLowP 0
threshXLowQ
trStSaNrFreqRelProfileRef
ueMCNrFreqRelProfileRef GNBCUCPFunction=1,UeMC=1,UeMCNrFreqRelProfile=Default
end


crn GNBCUCPFunction=1,NRNetwork=1,ExternalGNBCUCPFunction=20469-99001
amfRegionInfoList
gNBId 99001
gNBIdLength 22
isRemoveAllowed false
pLMNId mcc=204,mnc=69
end


crn GNBCUCPFunction=1,NRNetwork=1,ExternalGNBCUCPFunction=20469-99001,ExternalNRCellCU=20469-99001-31
cellLocalId 31
nRFrequencyRef NRNetwork=1,NRFrequency=635040-30-20-0-2
nRPCI 31
nRTAC 2
plmnIdList mcc=204,mnc=69;mcc=206,mnc=20
sNSSAIList sd=1,sst=2;sd=2,sst=1;sd=16777215,sst=1
end


crn GNBCUCPFunction=1,NRNetwork=1,ExternalGNBCUCPFunction=20469-99001,ExternalNRCellCU=20469-99001-32
cellLocalId 32
nRFrequencyRef NRNetwork=1,NRFrequency=635040-30-20-0-2
nRPCI 32
nRTAC 2
plmnIdList mcc=204,mnc=69;mcc=206,mnc=20
sNSSAIList sd=1,sst=2;sd=2,sst=1;sd=16777215,sst=1
end


crn GNBCUCPFunction=1,NRNetwork=1,ExternalGNBCUCPFunction=20469-99001,ExternalNRCellCU=20469-99001-33
cellLocalId 33
nRFrequencyRef NRNetwork=1,NRFrequency=635040-30-20-0-2
nRPCI 33
nRTAC 2
plmnIdList mcc=204,mnc=69;mcc=206,mnc=20
sNSSAIList sd=1,sst=2;sd=2,sst=1;sd=16777215,sst=1
end
```

```
crn GNBCUCPFunction=1,NRCellCU=5216131,NRCellRelation=20469-99001-31
cellIndividualOffsetNR 0
coverageIndicator 0
includeInSIB true
isHoAllowed true
isRemoveAllowed false
nRCellRef NRNetwork=1,ExternalGNBCUCPFunction=20469-99001,ExternalNRCellCU=20469-99001-31
nRFreqRelationRef NRCellCU=5216131,NRFreqRelation=635040-30-20-0-2
sCellCandidate 0
end


crn GNBCUCPFunction=1,NRCellCU=5216132,NRCellRelation=20469-99001-32
cellIndividualOffsetNR 0
coverageIndicator 0
includeInSIB true
isHoAllowed true
isRemoveAllowed false
nRCellRef NRNetwork=1,ExternalGNBCUCPFunction=20469-99001,ExternalNRCellCU=20469-99001-32
nRFreqRelationRef NRCellCU=5216132,NRFreqRelation=635040-30-20-0-2
sCellCandidate 0
end


crn GNBCUCPFunction=1,NRCellCU=5216133,NRCellRelation=20469-99001-33
cellIndividualOffsetNR 0
coverageIndicator 0
includeInSIB true
isHoAllowed true
isRemoveAllowed false
nRCellRef NRNetwork=1,ExternalGNBCUCPFunction=20469-99001,ExternalNRCellCU=20469-99001-33
nRFreqRelationRef NRCellCU=5216133,NRFreqRelation=635040-30-20-0-2
sCellCandidate 0
end


set NRCellCU=521613. mcpcPCellProfileRef GNBCUCPFunction=1,Mcpc=1,McpcPCellProfile=Default
set NRCellCU=521613. mcpcPCellEnabled true
set UeMC=1,UeMCNrFreqRelProfile=Default,UeMCNrFreqRelProfileUeCfg=Base connModeAllowedPCell true
```

## Thresholds

```
2132                    GNBCUCPFunction=1,Mcpc=1,McpcPCellProfile=Default,McpcPCellProfileUeCfg=Base
===========================================================================================
=============
lowHighFreqPrioClassification    7
mcpcPCellProfileUeCfgId          Base
mcpcQuantityList                 i[1] = 0 (RSRP)
prefUeGroupList                  i[0] =
rsrpCandidateA5                  Struct{4}
>>> 1.hysteresis = 10
>>> 2.threshold1 = -95
>>> 3.threshold2 = -109
>>> 4.timeToTrigger = 640
rsrpCandidateB2                  Struct{4}
>>> 1.hysteresis = 10
>>> 2.threshold1 = -156
>>> 3.threshold2EUtra = -140
>>> 4.timeToTrigger = 640
rsrpCritical                     Struct{4}
>>> 1.hysteresis = 10
>>> 2.threshold = -156
>>> 3.timeToTrigger = 160
>>> 4.timeToTriggerA1 = -1
rsrpCriticalEnabled              false
rsrpSearchTimeRestriction        -1
rsrpSearchZone                   Struct{4}
>>> 1.hysteresis = 10
>>> 2.threshold = -95
>>> 3.timeToTrigger = 160
>>> 4.timeToTriggerA1 = -1
```

```
ueConfGroupList                  i[0] =
ueGroupList                    i[0] =
userLabel
===============================================================================================
=============
Total: 2 MOs
```

## Used cell id's

```
MO          cellLocalId nRPCI nRTAC

===============================================================================================
=============

NRCellDU=5216131 131      132   801

NRCellDU=5216132 132      133   801

NRCellDU=5216133 133      134   801
```

```
MO          cellLocalId nRPCI nRTAC ssbFrequency

===============================================================================================
=============

NRCellDU=5216131 131      132   801   632640

NRCellDU=5216132 132      133   801   632640

NRCellDU=5216133 133      134   801   632640
```

# REFERENCES


[1] GSMA (2021). GSMA PRD BA.51: Roaming Service Level Agreement Guidelines. Version 7.0. Available to GSMA members via GSMA Member Gateway.

[2] 5G-Blueprint (2022). D3.2: Delineation of Business Models. Available at: https://www.5gblueprint.eu/library/deliverables/

[3] 5G-Blueprint (2022). D3.3: Techno-economic analysis. Available at: https://www.5gblueprint.eu/library/deliverables/.

[4] GSMA (2022). 5GS Roaming Guidelines, Version 6.0. Available at: NG.113-v6.0.pdf (gsma.com).

[5] 5G-Blueprint (2021). D5.1: 5G Network Requirements and Architecture. Available at: https://www.5gblueprint.eu/library/deliverables/

[6] BEREC (2018). BEREC Report on infrastructure sharing. Available at: https://www.berec.europa.eu/sites/default/files/files/document_register_store/2018/6/BoR_%2818%29_116_BEREC_Report_infrastructure_sharing.pdf

[7] RDI et al. (2017). AGREEMENT between the administrations of Belgium, France, Germany, Luxembourg, the Netherlands and Switzerland on frequency usage and frequency coordination in border areas for terrestrial systems capable of providing electronic communications services in the frequency band 3400-3800 MHz. Available at: https://www.rdi.nl/binaries/agentschap-telecom/documenten/publicaties/2017/oktober/2/internationale-overeenkomsten/Multilateral+Agreement+3400-3800+MHz.pdf

[8] GSMA (2021). GSMA PRD WA.30: Operator to Operator Service Level Agreement Template. Available to GSMA members via GSMA Member Gateway.

[9] GSMA (2020). GSMA PRD IR.81: Global Roaming Quality Measurement implementation. Available to GSMA members via GSMA Member Gateway.