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| 3GPP TR 33.743 V1.1.0 (2025-02) | |
| Technical Report | |
| 3rd Generation Partnership Project;  Technical Specification Group Services and System Aspects;  Study on Security Aspects of Enhancement for Proximity-based Services (ProSe) in the 5G System (5GS) phase 3  (Release 19) | |
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| ***3GPP***  Postal address  3GPP support office address  650 Route des Lucioles - Sophia Antipolis  Valbonne - FRANCE  Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16  Internet  http://www.3gpp.org |
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# Foreword

This Technical Report has been produced by the 3rd Generation Partnership Project (3GPP).

The contents of the present document are subject to continuing work within the TSG and may change following formal TSG approval. Should the TSG modify the contents of the present document, it will be re-released by the TSG with an identifying change of release date and an increase in version number as follows:

Version x.y.z

where:

x the first digit:

1 presented to TSG for information;

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y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.

z the third digit is incremented when editorial only changes have been incorporated in the document.

In the present document, modal verbs have the following meanings:

**shall** indicates a mandatory requirement to do something

**shall not** indicates an interdiction (prohibition) to do something

The constructions "shall" and "shall not" are confined to the context of normative provisions, and do not appear in Technical Reports.

The constructions "must" and "must not" are not used as substitutes for "shall" and "shall not". Their use is avoided insofar as possible, and they are not used in a normative context except in a direct citation from an external, referenced, non-3GPP document, or so as to maintain continuity of style when extending or modifying the provisions of such a referenced document.

**should** indicates a recommendation to do something

**should not** indicates a recommendation not to do something

**may** indicates permission to do something

**need not** indicates permission not to do something

The construction "may not" is ambiguous and is not used in normative elements. The unambiguous constructions "might not" or "shall not" are used instead, depending upon the meaning intended.

**can** indicates that something is possible

**cannot** indicates that something is impossible

The constructions "can" and "cannot" are not substitutes for "may" and "need not".

**will** indicates that something is certain or expected to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document

**will not** indicates that something is certain or expected not to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document

**might** indicates a likelihood that something will happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

**might not** indicates a likelihood that something will not happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

In addition:

**is** (or any other verb in the indicative mood) indicates a statement of fact

**is not** (or any other negative verb in the indicative mood) indicates a statement of fact

The constructions "is" and "is not" do not indicate requirements.

# 1 Scope

The present document investigates and identifies the security (including privacy) threats, corresponding security (including privacy) requirements and potential solutions for Proximity Based Services (ProSe) in 5G System (5GS) phase 3, based on the architecture and system level enhancements studied in TR 23.700-03 [1], including

* ProSe multi-hop UE-to-Network Relay (both Layer-2 and Layer-3 Relays).
* ProSe multi-hop UE-to-UE Relay (Layer-3 Relay only).

# 2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non‑specific.

- For a specific reference, subsequent revisions do not apply.

- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] 3GPP TR 23.700-03: "Study on system enhancement for Proximity based Services (ProSe) in the 5G System (5GS) Phase 3".

[2] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[3] 3GPP TS 22.261: "Service requirements for next generation new services and markets; Stage 1".

[4] 3GPP TS 23.304: "Proximity based Services (ProSe) in the 5G System (5GS)".

[5] 3GPP TS 33.503: " Security aspects of Proximity based Services (ProSe) in the 5G System (5GS)".

[6] 3GPP TS 33.501: "Security architecture and procedures for 5G System".

# 3 Definitions of terms, symbols and abbreviations

## 3.1 Terms

For the purposes of the present document, the terms given in 3GPP TR 21.905 [2] , TS 33.503 [5] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in 3GPP TR 21.905 [2] , TS 33.503 [5].

## 3.2 Symbols

Void

## 3.3 Abbreviations

For the purposes of the present document, the abbreviations given in 3GPP TR 21.905 [2] , TS 33.503 [5] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in 3GPP TR 21.905 [2] , TS 33.503 [5].

# 4 Overview and Security Assumptions

Based on the normative Stage-1 requirements in TS 22.261 [3] and 5G ProSe architecture principles as defined in TS 23.304 [4], TR 23.700-03 [1] aims to enhance the architecture aspects of 5G system to support multi-hop over NR PC5 reference point for Layer-2 and Layer-3 UE-to-Network Relays, and support multi-hop over NR PC5 reference point for Layer-3 UE-to-UE Relays.



Figure 4-1: Example scenario of 5G ProSe multi-hop UE-to-Network Relay

As shown in the figure 4-1 above, the Layer-2 and Layer-3 5G ProSe multi-hop UE-to-Network Relay allow the Remote UE to communicate with the network via 5G ProSe Intermediate UE-to-Network Relay(s) and UE-to-Network Relay, and vice versa.

NOTE 1: void.



Figure 4-2: Example scenario of support of Layer-3 multi-hop UE-to-UE Relay

As shown in the figure 4-2 above, the Layer-3 5G ProSe multi-hop UE-to-UE Relay allows the End UEs to communicate each other via more than one UE-to-UE Relays.

The security architecture and procedures for 5G ProSe are specified in TS 33.503 [5]. The current mechanisms of TS 33.503 [5] cover the scenarios of "single-hop relay" (i.e. UE-to-Network Relay and UE-to-UE Relay) and hence potential enhancements are needed for the scenarios above.

The architecture with the following security assumption:

- The architecture assumptions and principles as defined in TR 23.700-03 [1] are used as architecture assumptions in this study.

- The security architecture defined in TS 33.503 [5] is used as basis security architecture for supporting 5G ProSe security phase 3.

- The security architecture needs to enable secure multi-hop UE-to-UE Relay discovery and communication when the Source UE, Target UE as well as the Layer-3 UE-to-UE Relay (s) can be in coverage and out of coverage.

- The security architecture needs to enable secure multi-hop UE-to-Network Relay discovery and communication when the Remote UE as well as the multi-hop UE-to-Network Relay(s) can in coverage and be out of coverage.

- It is assumed that the multi-hop UE-to-Network Relay(s) and the multi-hop Layer-3 UE-to-UE Relay (s) are trusted entities.

# 5 Key issues

## 5.1 Key issue #1: Security for multi-hop UE-to-Network Relay

### 5.1.1 Key issue details

Based on the information exchange between Remote UE and network via the UE-to-Network Relay in previous releases, the multi-hop UE-to-Network Relay scenario in TR 23.700-03 [1] further allows the Remote UE connecting to the network via one or more Intermediate UE-to-Network Relay(s) in proximity, by using either Layer-2 or Layer-3 connection methods. The Key Issue #1 (Support of multi-hop UE-to-Network Relays) in TR 23.700-03 [1] has the following note:

*NOTE 3: Security and privacy aspects will be handled by SA WG3.*

The 5GS is supposed to be able to provide security (and privacy) protection of messages from the Remote UE, via Intermediate UE-to-Network Relay(s) and UE-to-Network Relay, to the network and vice versa. Failure to provide security (and privacy) protection of these messages may lead to various attacks, e.g. information manipulation or information leakage. Therefore, the security and privacy aspects of the discovery and communication messages in 5G ProSe multi-hop UE-to-Network Relay should be investigated.

This key issue focuses on the security (and privacy) issues for 5G ProSe multi-hop UE-to-Network Relay over NR PC5 reference point, including both discovery and communication scenarios.

### 5.1.2 Threats

If the exchanged messages are not confidentiality protected, integrity protected or replay protected, the parameters included can be obtained, modified or replayed by an attacker. Consequently, it may lead to various attacks such as information manipulation (e.g. Relay Service Code, hop count), privacy information (e.g. Relay Service Code) leakage or unable to discover each other for an intended service.

An attacker may impersonate the Remote UE, Intermediate UE-to-Network Relay or UE-to-Network Relay. If the authentication and authorisation of UEs cannot be verified, an attacker UE may impersonate the Remote UE, Intermediate UE-to-Network Relay or UE-to-Network Relay.

### 5.1.3 Potential security requirements

The 5G System shall provide a means for confidentiality protection, integrity protection and replay protection of discovery and communication messages in multi-hop UE-to-Network Relay discovery and communication scenarios.

The 5G System shall provide a means for mitigating trackability and linkability attacks on UEs in multi-hop UE-to-Network Relay discovery and communication scenarios.

The 5G System shall provide a means for authentication and authorisation of the UEs in multi-hop UE-to-Network Relay communication scenarios.

The 5G system shall provide a means to securely provision the security materials for multi-hop UE-to-Network Relay discovery.

NOTE: The specific E2E information, and support of E2E protection of the E2E information between the Remote UE and the UE-to-Network Relay will be determined at the normative stage, the alignment with architecture aspects in TR 23.700-03 [1] and TS 23.304 [4] need to be considered.

## 5.2 Key Issue #2: Security for Multi-hop UE-to-UE Relay

### 5.2.1 Key issue details

When a pair of 5G ProSe End UEs cannot establish PC5 communication via one Layer-3 UE-to-UE Relay, they can still communicate by transmitting their messages through multiple Layer-3 UE-to-UE Relays. These UE-to-UE Relays act as multi-hop UE-to-UE relay nodes, receiving messages from one UE and forwarding them to the next until the message reaches the intended 5G ProSe End UE. To support the multi-hop UE-to-UE Relay service, relevant solutions are studied in TR 23.700-03 [1].

The 5G System is supposed to be able to protect security (and privacy) of message exchange between End UEs, via more than one Layer-3 UE-to-UE Relays. Unsecured message exchange in multi-hop UE-to-UE Relay scenario will open vulnerability to allow different attacks such as information manipulation or privacy leakage. Thus the discovery and communication messages are needed to be protected in order to protect the security (and to preserve privacy).

Therefore, it is necessary to study how to secure the multi-hop relay discovery and communication and protect the UE privacy in the multi-hop UE-to-UE relay service.

### 5.2.2 Security threats

Failure to protect discovery messages or communication messages will open vulnerability in 5GS and allow various attacks such as modification of information (e.g. Relay Service Code, hop count), replay attack, etc.

An attacker may impersonate the End UE or multi-hop UE-to-UE Relay if the authentication and authorisation of UEs are not performed during multi-hop UE-to-UE Relay communication scenario.

Failure to protect the privacy of the involved UEs during the multi-hop UE-to-UE Relay discovery procedure or multi-hop UE-to-UE Relay communication procedure will open vulnerability in 5GS and allow various privacy attacks including tracing and tracking of identities.

### 5.2.3 Potential security requirements

The 5G System shall provide a means for confidentiality protection, integrity protection and replay protection of discovery messages and communication messages in the multi-hop UE-to-UE Relay discovery and communication scenarios.

The 5G System shall provide a means for authentication and authorization of the UEs in multi-hop UE-to-UE Relay communication scenarios.

The 5G System shall provide a means for mitigating trackability and linkability attacks on UEs in multi-hop UE-to-UE Relay discovery and communication scenarios.

The 5G system shall provide a means to securely provision the security materials for multi-hop UE-to-UE relay discovery.

### 

# 6 Solutions

## 6.1 Solution #1: Security for multi-hop UE-to-Network Relay using an intermediate key

### 6.1.1 Introduction

This solution addresses "*Key issue #1: Security for multi-hop UE-to-Network Relay".*

The solution proposes to reuse mechanisms described in TS 33.503 [5], clauses 6.3.3.2 and 6.3.3.3 with the following enhancements:

* Remote UE that wishes to connect to U2N Relay via an Intermediate Relay, sends securely a PRUK ID and a new ProSe Intermediate Relay Key (PIRK), derived from (UP-PRUK or CP-PRUK), to the Intermediate Relay after PC5 link security is established between Remote UE and Intermediate Relay.
* The Intermediate Relay in direct proximity to the U2N Relay (i.e., last hop Intermediate Relay) establishes the PC5 link security based on the PIRK (i.e., derives PC5 link root key from PIRK). If not in direct proximity to the U2N, the Intermediate Relay forwards securely the PRUK ID and PIRK to the next Intermediate Relay in the path after PC5 link security is established between the Intermediate Relays.

### 6.1.2 Solution details

#### 6.1.2.1 Security procedure over User Plane



Figure 6.1.2.1-1: PC5 security establishment procedure for multi-hop 5G ProSe UE-to-Network relay communication over User Plane

1. The Remote UE authorized for multi-hop discovery and communication is provisioned with U2N Relay discovery and communication parameters. Remote UE and Relays are provisioned with RSC, where RSC is configured with an indicator allowing multi-hop support indicator.
2. Remote UE sends a ProSe Remote User Key request to its PKMF. PKMF verifies that the Remote UE is authorized for U2N Relay services including via multi-hop. If the Remote UE is authorized, PKMF sends a response including UP-PRUK and UP-PRUK ID to the Remote UE as per existing provisioning mechanisms defined in TS 33.503 [5], clause 6.1.3.2.
3. The Remote UE discovers the U2N Relay via the Intermediate Relay discovery messages. It is assumed that U2N discovery is performed according to discovery solutions for KI#1 using Model B.
4. The Remote UE sends a DCR message to the Intermediate Relay, including RSC, user info of U2N Relay and UP-PRUK ID.
5. The Remote UE and Intermediate Relay perform a mutual authentication using a Long-Term Credential (LTC). The mechanism defined in 6.6.3.2 of TS 33.503 [5] is reused with End UE replaced by Remote UE and U2U Relay replaced with IM Relay, with DCA sent to Remote UE as per security procedure in clause 6.2 of TS 33.503 [5].
6. The Remote UE receives a Direct Security Mode Command message from the Intermediate Relay that includes conventional security parameters (e.g., security policy, freshness parameters, etc) to initiate the PC5 link security establishment.

As the Remote UE is connecting to the U2N Relay via an Intermediate Relay, Remote UE derives a UP-PIRK using UP-PRUK and nonce1.

Remote UE sends a fully protected (encrypted, integrity, replay) Direct Security Mode Complete message to the Intermediate Relay including PIRK, nonce1.

If more than one Intermediate Relay are involved (not shown in the figure), the Intermediate Relay behave similarly to the Remote UE towards the next Intermediate Relay (except for the UP-PIRK derivation) and forwards securely the UP-PIRK to the next hop Intermediate Relay, up to the last hop Intermediate Relay.

Since for U2N Relaying a PC5 link security context is established on a per RSC, the security context for intermediate hops (between IM relays) is also established on a per RSC basis and therefore can be reused for different pairs of Remote UE and U2N that use the same RSC.

1. The last hop Intermediate Relay sends a DCR message to the U2N Relay including UP-PRUK ID, RSC, U2N user info, nonce1 and a multi\_hop\_indication to indicate that the request is for a Remote UE multi-hop connection.
2. The U2N Relay sends a key request to the Remote UE PKMF via its PKMF. The request includes UP-PRUK ID, RSC, nonce1 and the multi\_hop\_indication.

If Remote UE PKMF receives a multi\_hop\_indication in the request, the Remote UE PKMF derives a UP-PIRK from UP-PRUK using nonce1 and derives a K\*NRP from UP-PIRK using RSC, and a nonce2 i.e., instead of deriving a KNRP using UP-PRUK. The corresponding key hierarchy for multi-hop U2N security is described in 6.Y.2.3.

Remote UE PKMF sends the K\*NRP and nonce2 to the U2N Relay via U2N Relay PKMF.

1. U2N Relay derives a session key using K\*NRP and security keys using the session key. U2N Relay sends a Direct Security Mode Command message integrity protected to the Intermediate Relay including nonce2.

Intermediate Relay derives K\*NRP from UP-PIRK using RSC and nonce2, the same way as Remote UE PKMF. Intermediate Relay derives a session key using K\*NRP and security keys using the session key. The Intermediate Relay verifies the security of the Direct Security Mode Command with the generated security keys. The Intermediate Relay determines that U2N Relay and Remote UE are authorized for multi-hop U2N Relay connectivity if the verification is successful.

Intermediate Relay sends a fully protected Direct Security Mode Complete message to the U2N Relay.

U2N Relay verifies the security of the Direct Security Mode Complete with the generated security keys. The U2N Relay determines that Intermediate Relay and Remote UE are authorized for multi-hop U2N Relay connectivity if the verification is successful.

1. The U2N Relay sends a DCA message to the Intermediate Relay confirming successful relayed connection.

The U2N Relay proceeds with the regular remaining steps to complete the procedure including sending UP-PRUK ID in a Remote UE Report procedure to identify the Remote UE that is using the multi-hop U2N Relay connectivity service.

The Intermediate Relay sends a DCA message to the Remote UE confirming successful establishment of multi-hop relayed connection.

#### 6.1.2.2 Security procedure over Control Plane

The security procedure over Control Plane applies the same principles as above to the mechanisms described in TS 33.503 [5], clause 6.3.3.3, with the following differences:

* If the Remote UE possesses a CP-PRUK/CP-PRUK ID from a previous direct U2N Relay connection, it uses CP-PRUK/CP-PRUK ID instead of UP-PRUK and UP-PRUK ID and derives a CP-PIRK from CP-PRUK.
* The last hop Intermediate Relay derives K\*NR\_ProSe from CP-PIRK.
* On the network side, AUSF derives CP-PIRK from CP-PRUK and K\*NR\_ProSe from CP-PIRK.

#### 6.1.2.3 Key Hierarchy



Figure 6.1.2.2-1: PC5 Key Hierarchy for multi-hop 5G ProSe UE-to-Network Relay security over User Plane (left) and Control Plane (right)

The key hierarchy for multi-hop U2N Relay (UP or CP) support shown in Figure 6.Y.2.2-1 is proposed in addition to the existing key hierarchy for single-hop connection (TS 33.503, clause 6.3.3.2.3 or 6.3.3.3.3). This key hierarchy applies when Remote UE connects to U2N via multi-hop, as follows:

* The proposed Intermediate Relay Key PIRK (respectively UP-PIRK and CP-PIRK) is derived from PRUK (respectively UP-PRUK and CP-PRUK) to enable the PC5 link security establishment between the last hop Intermediate Relay and the U2N Relay.
* PIRK is sent securely from the Remote UE to the last hop Intermediate Relay (directly or via other Intermediate Relay(s)).
* The network and last hop Intermediate Relay derive a PC5 root key (respectively K\*NRP or K\*NR\_ProSe) from the PIRK. The network sends the PC5 root key derived from PIRK to the U2N.
* K\*NRP is used instead of KNRP, and K\*NR\_ProSe instead of KNR\_ProSe for the derivation of the session key, used to derive the security keys for the connection security between the last hop Intermediate Relay and U2N relay.

### 6.1.3 Evaluation

The solution addresses the communication security related requirements of Key Issue #1.

The solution is applicable for the case where discovery Model B is performed.

The security procedure between the last IM Relay and the U2N Relay reuses the existing security procedure defined in clause 6.3.3 for TS 33.503 [5].

A PIRK derived from PRUK key by Remote UE and the network is used as root key for security establishment between the last IM relay and U2N Relay. For the U2N Relay, the security procedure is the essentially the same as for the single hop scenario, except for the transparent forwarding of the optional multi-hop indication. The network decides whether to derive a PIRK or proceed with existing single-hop key derivation based on the indication presence.

The PIRK is used by the 5G System to ensure that each node is authorized to act according to its respective role i.e., IM Relay, Remote UE or U2N Relay.

The solution assumes that PC5 signalling confidentiality security policy is set to "REQUIRED" in the case of multi-hop for the full protection of the PIRK while transmitted to the IM Relay.

A security context is established between the Remote UE and IM Relay and between the IM Relays based on the security mechanism without network assistance principles to support IM relay being in or out of coverage. When LTC based mechanism is used, the Remote UE is required to be provisioned with two sets of security materials, i.e. the LTC and UP-PRUK.

The solution supports the CP procedure if the Remote UE possesses a CP-PRUK/CP-PRUK ID from a previous direct U2N Relay connection. If the Remote UE does not have a valid CP-PRUK/CP-PRUK ID, it can select a U2N Relay with single hop connection or user plane-based security can be used.

6.2 Solution #2: Security of multi-hop UE-to-Network Relay discovery Model A

6.2.1 Introduction

This solution addresses key issue #1: Security for multi-hop UE-to-Network Relay.

The announcing 5G ProSe U2N and the monitoring 5G ProSe Remote UE performs protected relay discovery as specified in clause 6.3.2.3.2 of TS 23.304 [4] and clause 6.1.3.2.2.1 of TS 33.503 [5]. The information included by the original announcing 5G ProSe U2N e.g. RSC, User info of the announcing 5G ProSe U2N, Accumulated QoS is protected by the relay discovery security material.

The intermediate U2N can relay and forward the discovery Announcement message sent by the announcing 5G ProSe U2N. The intermediate U2N can additionally insert necessary information (e.g. hop count, Announcer Info (User info of the intermediate U2N)) required to support multi-hop U2N relay in the forwarded messages.

To protect the integrity and/or confidentiality of the information inserted/updated by the intermediate U2N, the intermediate U2N needs to obtain also a set of relay discovery security material from its own HPLMN, called as intermediate relay discovery security material in this solution for brevity. So that the forwarded relay discovery message contains both original relay discovery announcement message protected by the relay discovery security material associated with the announcing U2N and also the additional information protected by the intermediate relay discovery security material associated with the intermediate U2N. The intermediate relay discovery security material associated with the intermediate U2N #n is identified based on the HPLMN ID of the intermediate U2N #n.

NOTE 1: The complete additional information (e.g. hop count) updated by the intermediate U2N that is required for multi-hop U2N relay discovery is out of scope of the present document.

NOTE 2: There could be one or more intermediate U2Ns in the discovery message path. The maximum number of intermediate U2N(s) in the path is out of scope of the present document. This solution shows only two intermediate U2Ns as example.

There could be possibly additional input parameters or extensions to security material provisioning procedure of 6.1.3.2.2.1 of TS 33.503 needed to differentiate the intermediate relay discovery security material with the relay discovery security material.

NOTE 3: The solution assumes that additional information is added/appended by the Intermediate U2N Relay to the original discovery message received from the initiator (UE-to-Network relay in Model A or Remote UE in Model B) and the Intermediate U2N Relay protects the original discovery message and the additional information using the intermediate relay discovery security material.

6.2.2 Solution details

The security procedure for multiple hop 5G ProSe UE-to-Network Relay Discovery with Model A is described as follows.



**Figure 6.2.2-1: Example Model A Discovery operation supporting multi-hop UE-to-Network Relay**

0a. The announcing 5G ProSe U2N is provisioned with the relay discovery security materials from its HPLMN as acting as Announcing UE specified in clause 6.1.3.2.2.1 of TS 33.503[5].

Each intermediate 5G ProSe U2N(s) and the remote UE are provisioned with the relay discovery security materials associated with announcing U2N acting as Monitoring UE as specified in clause 6.1.3.2.2.1 of TS 33.503[5].

NOTE 1: The intermediate U2N(s) and the Remote UE are provisioned with the U2N discovery security material to verify the integrity of the information originally announced by the 5G ProSe U2N, e.g. RSC, User info of the 5G ProSe U2N, Accumulated QoS if available etc.

0b. Each 5G ProSe intermediate U2N UE (e.g. U2N #1, U2N #2) is also provisioned with the intermediate relay discovery security material used for protection of the forwarded announcement message from its own HPLMN, acting as announcing UE as specified in clause 6.1.3.2.2.1 of TS 33.503 [5].

The neighbors of this intermediate 5G ProSe U2N(other intermediate 5G ProSe U2N(s), the remote UE or the 5G ProSe U2N) are also provisioned with the intermediate relay discovery security materials associated with this intermediate U2N, acting as Monitoring UE as specified in clause 6.1.3.2.2.1 of TS 33.503 [5].

See clause 6.2.2.1 for provisioning of the intermediate relay discovery security material for Model A.

1. The announcing U2N reuses the 5G ProSe UE-to-Network Relay Discovery Announcement message as Discovery Solicitation specified in clause 6.1.3.2.2.1 of TS 33.503 [5] with the information e.g. hop count=1, RSC, User info of the announcing 5G ProSe U2N, Accumulated QoS required for multi-hop U2N relay and protects the message with relay discovery security material obtained from step 0a. The announcing message also includes the HPLMN ID of the announcing U2N in cleartext to identify the relay discovery security materials as specified in clause 6.1.3.2.2.1 of TS 33.503 [5].
2. The intermediate U2N #1 receives the protected announcement message, obtains the information originally announced by the 5G ProSe U2N e.g. RSC and the User info of the 5G ProSe U2N and verifies the Announcement message based on the relay discovery security material associated with the announcing U2N obtained from step 0a. If the verification is successful, the intermediate U2N #1 updates the hop information (e.g. hop count) and forwards the original Announcement message with the additional information (e.g. updated hop count and its own User info ID as Announcer Info). The forwarded message is protected by the intermediate relay discovery security material that the intermediate U2N #1 obtained from its HPLMN from step 0b. The intermediate U2N #1 also includes it's Home PLMN ID in clear text in the forwarded message to identify the intermediate discovery security material.
3. The intermediate U2N #2 received the protected message, obtains the information originally announced by the 5G ProSe U2N e.g. RSC and the User info of the 5G ProSe U2N and verifies the original Announcement message based on the relay discovery security material associated with the announcing U2N obtained from step 0a and the additional information inserted by the sending intermediate U2N #1 (e.g. hop count, Announcer Info) based on intermediate relay discovery security material associated with the intermediate U2N #1 which was obtained from step 0b. The intermediate U2N #2 identifies the intermediate relay discovery security material associated with the intermediate U2N #1 based on the clear text HPLMN ID included by the intermediate U2N #1 in step 2. If the verification is successful, the intermediate U2N #2 stores the received information (e.g. a record of the RSC, the User info of the 5G ProSe U2N, Announcer Info and the associated Hop-Count value), updates the hop information (e.g. hop count) and forwards the original Announcement message with the additional information (e.g. updated hop count and its own User info ID as Announcer Info). The forwarded message is protected by the intermediate relay discovery security material that the intermediate U2N #2 obtained from its HPLMN from step 0b. The intermediate U2N #2 also includes it's Home PLMN ID in clear text in the forwarded message to identify the intermediate discovery security material.

4. On receiving the Announcement message from the intermediate U2N #2 , the monitoring 5G ProSe Remote UE obtains the information originally announced by the 5G ProSe U2N e.g. RSC and the User info of the 5G ProSe U2N, identifies the relay discovery security materials to process the original discovery message based on the HPLMN ID of the announcing U2N included in the discovery message as in step 1 and verifies the received Announcement message using the relay discovery security material associated with the announcing U2N obtained from step 0a. The monitoring 5G ProSe Remote UE also identifies the intermediate relay discovery security material associated with the intermediate U2N #2 based on the clear text HPLMN ID included by the intermediate U2N #2 in step 3, obtains and verifies the additional information inserted by the sending intermediate U2N #2 (e.g. hop count, Announcer Info) based on intermediate relay discovery security material associated with the intermediate U2N #2 which was obtained from step 0b. If the verification is successful, the monitoring 5G ProSe Remote UE shall process the relay announcement message as specified in clause 6.1.3.2.2.1 of TS 33.503[5].

NOTE 2: According to TS 23.304 [4] clause 6.3.2.5, based on configuration, the 5G ProSe Intermediate UE-to-Network Relay may need to establish a Layer-2 link with the relay identified by the Announcer Info in the discovery entry before sending the 5G ProSe UE-to-Network Relay Discovery Announcement message.

6.2.2.1 Provisioning the intermediate relay discovery security material

**Figure 6.2.2.1-1:** **Intermediate Relay Discovery Key request**



The security procedure to retrieve intermediate relay discovery security material uses the procedure of clause 6.1.3.2.2.1 of TS 33.503 [5] for 5G ProSe UE-to-Network Relay as baseline with extension. Differences to clause 6.1.3.2.2.1 of TS 33.503 [5] are mentioned below:

- Each sending intermediate 5G ProSe U2N acts as announcing UE of clause 6.1.3.2.2.1 of TS 33.503[5], and the neighbours of this intermediate 5G ProSe U2N(other intermediate 5G ProSe U2N(s), or the 5G ProSe Remote UE etc.) receiving forwarded message act as Monitoring UEs. They are called as sending UE (S-UE) and receiving UE (R-UE) accordingly.

- Steps 1-4 refer to a sending UE (e.g. intermediate U2N #1);

- Step 1, the Relay Discovery Key request message also includes an indication that intermediate relay discovery security material is requested.

- Step 4, the Relay Discovery Key response message contains the intermediate relay discovery security materials associated with the HPLMN ID of the sending UE (intermediate U2N #1)

- Steps 5-10 refer to a receiving UE(e.g. intermediate U2N #2);

- Step 5,7, the Relay Discovery Key request message also includes an indication that intermediate relay discovery security material is requested.

- Step 9,10, the Relay Discovery Key response message contains the intermediate relay discovery security materials and the HPLMN ID of the sending UE (intermediate U2N #1).

- If there are multiple hops, the Steps 1-16 are repeated with the receiving UE taking the role of a sending UE and the next hop intermediate relay taking the role of the new receiving UE.

6.2.3 Evaluation

The solution addresses key issue #1 and provides methods for security protection (confidentiality protection, integrity protection and replay protection, and mitigating trackability and linkability attacks) of multi-hop UE-to-Network Relay discovery Model A.

The solution proposes to reuse the existing Restricted 5G ProSe UE-to-Network Discovery Model A security methods, with extensions to support two sets of discovery security material i.e. the relay discovery security material and the intermediate relay discovery security material.

Apart from the relay discovery security material the intermediate U2N relay nodes need to obtain also a set of intermediate relay discovery security material from their own HPLMNs. A separate procedure for the acquisition of these keys is proposed. For this purpose, when nodes belong to different HPLMNs the Announcement message includes the HPLMN ID of the transmitting node.

This solution does not address potential retransmission of protected discovery messages by an unauthorized entity.

## 6.3 Solution #3: Security of multi-hop UE-to-Network Relay discovery Model B

### 6.3.1 Introduction

This solution addresses key issue #1: Security for multi-hop UE-to-Network Relay.

The discoveree 5G ProSe U2N and the discoverer 5G ProSe Remote UE performs protected relay discovery as specified in clause 6.3.2.3.3 of TS 23.304[4] and clause 6.1.3.2.2.2 of TS 33.503[5]. The information included by the original sending UE (i.e. The Remote UE and the 5G ProSe U2N) e.g. RSC, User info of the Remote UE, User info of the 5G ProSe U2N, the selected path info (the list of User Info IDs of intermediate Relays in the path) is protected by the relay discovery security material.

The intermediate U2N can relay and forward the discovery Solicitation/Response messages sent by the discoveree 5G ProSe U2N and the discoverer 5G ProSe Remote UE. The intermediate U2N can additionally insert necessary information (e.g. by including its own User Info ID in the path) required to support multi-hop U2N relay in the forwarded messages.

To protect the integrity and/or confidentiality of the information inserted/updated by the intermediate U2N, the intermediate U2N needs to obtain also a set of relay discovery security material from its own HPLMN, called as intermediate relay discovery security material in this solution for brevity. So that the forwarded relay discovery messages contain both original relay discovery Solicitation/Response message protected by the relay discovery security material associated with the discoveree U2N and also the additional information protected by the intermediate relay discovery security material associated with the intermediate U2N. The intermediate relay discovery security material associated with the intermediate U2N #n is identified based on the HPLMN ID of the intermediate U2N #n.

NOTE 1: The complete additional information (e.g. hop count) updated by the intermediate U2N that is required for multi-hop U2N relay is out of scope of the present document.

NOTE 2: There could be one or more intermediate U2Ns in the discovery message path. The maximum number of intermediate U2N(s) in the path is out of scope of the present document. This solution shows only two intermediate U2Ns as example.

There could be possibly additional input parameters or extensions to security material provisioning procedure of 6.1.3.2.2.1 of TS 33.503 [5] needed to differentiate the intermediate relay discovery security material with the relay discovery security material.

### 6.3.2 Solution details

The security procedure for multiple hop 5G ProSe UE-to-Network Relay Discovery with Model B is described as follows.



Figure 6.3.2-1: Example Model B Discovery operation supporting multi-hop UE-to-Network Relay

0a. The discoveree 5G ProSe U2N is provisioned with the relay discovery security materials from its HPLMN, acting as discoveree UE as specified in clause 6.1.3.2.2.2 of TS 33.503[5].

Each intermediate 5G ProSe U2N(s) and the remote UE are provisioned with the relay discovery security materials associated with discoveree U2N, acting as discoverer UE as specified in clause 6.1.3.2.2.2 of TS 33.503[5].

NOTE 1: The intermediate U2N (s) and the Remote UE are provisioned with the U2N discovery security material to verify the integrity of the information originally sent by the 5G ProSe U2N, e.g. RSC, User info of the 5G ProSe U2N, the selected path info (the list of User Info IDs of intermediate Relays in the path) etc..

0b. Each 5G ProSe intermediate U2N UE (e.g. U2N #1, U2N #2) is also provisioned with the intermediate relay discovery security material used for protection of the forwarded discovery Solicitation/Response messages from its own HPLMN, acting as discoveree UE as specified in clause 6.1.3.2.2.2 of TS 33.503[5].

The neighbors of this intermediate 5G ProSe U2N(other intermediate 5G ProSe U2N(s), the remote UE or the 5G ProSe U2N) The 5G ProSe intermediate U2N, the discoveree 5G ProSe U2N and the remote UE are also provisioned with the intermediate relay discovery security materials associated with the neighbouring intermediate U2Ns, acting as discoverer UE as specified in clause 6.1.3.2.2.2 of TS 33.503[5].

See clause 6.3.2.1 for provisioning of the intermediate relay discovery security material for Model B.

1. The discoverer Remote UE reuses the 5G ProSe UE-to-Network Relay Discovery Solicitation message as specified in clause 6.1.3.2.2.2 of TS 33.503[5] with the information e.g. RSC, User info of the sending Remote UE, optionally User info of the target 5G ProSe U2N required for multi-hop U2N relay and protects the message with relay discovery security material obtained from step 0a. The Discovery Solicitation message also includes the HPLMN ID of the discoveree U2N in cleartext to identify the relay discovery security materials.
2. The intermediate U2N #1 receives the protected Relay Discovery Solicitation message, obtains the RSC and verifies the Relay Discovery Solicitation message based on the relay discovery security material associated with the discoveree U2N obtained from step 0a. If the verification is successful, the intermediate U2N #1 includes its own User Info ID in the path and forwards the original Relay Discovery Solicitation message with the additional information (e.g. updated path info). The forwarded message is protected by the intermediate relay discovery security material that the intermediate U2N #1 obtained from its HPLMN from step 0b. The intermediate U2N #1 also includes it's Home PLMN ID in clear text in the forwarded message to identify the intermediate discovery security material associated with the intermediate U2N #1.
3. The intermediate U2N #2 received the protected message, obtains the RSC and verifies the original Relay Discovery Solicitation message based on the relay discovery security material associated with the discoveree U2N obtained from step 0a and the additional information based on intermediate relay discovery security material associated with the intermediate U2N #1 which was obtained from step 0b. The intermediate U2N #2 identifies the intermediate relay discovery security material associated with the intermediate U2N #1 based on the clear text HPLMN ID included by the intermediate U2N #1 in step 2. If the verification is successful, the intermediate U2N #2 updates includes its own User Info ID in the path and forwards the original Relay Discovery Solicitation message with the additional information (e.g. updated path info). The forwarded message is protected by the intermediate relay discovery security material that the intermediate U2N #2 obtained from its HPLMN from step 0b. The intermediate U2N #2 also includes it's Home PLMN ID in clear text in the forwarded message to identify the intermediate discovery security material associated with the intermediate U2N #2.
4. On receiving the Relay Discovery Solicitation message from the intermediate U2N #2 , the discoveree 5G ProSe U2N verifies the received Relay Discovery Solicitation message using the relay discovery security material associated with the discoveree U2N obtained from step 0a and the additional information based on intermediate relay discovery security material associated with the intermediate U2N #2 which was obtained from step 0b. The discoveree 5G ProSe U2N identifies the intermediate relay discovery security material associated with the intermediate U2N #2 based on the clear text HPLMN ID included by the intermediate U2N #2 in step 3. If the verification is successful, the discoveree 5G ProSe U2N shall process the Relay Discovery Solicitation message as specified in clause 6.1.3.2.2.2 of TS 33.503[5].

5. The discoveree U2N reuses the 5G ProSe UE-to-Network Relay Discovery Response message as specified in clause 6.1.3.2.2.2 of TS 33.503[5] with the information e.g. RSC, User info of the 5G ProSe U2N, the selected path info (the list of User Info IDs of intermediate Relays in the path) required for multi-hop U2N relay and protects the message with relay discovery security material obtained from step 0a.

6. The intermediate U2N #2 verifies the protected Relay Discovery Response message and forward the message with the updated additional information if available and protect the forwarded message with the intermediate relay discovery security material that the intermediate U2N #2 obtained from its HPLMN from step 0b, same as step 3. In addition, the intermediate U2N #2 includes it's Home PLMN ID in clear text in the forwarded message to identify the intermediate discovery security material associated with the intermediate U2N #2.

7. The intermediate U2N #1 verifies the protected Relay Discovery Response message. The intermediate U2N #1 identifies the intermediate relay discovery security material associated with the intermediate U2N #2 based on the clear text HPLMN ID included by the intermediate U2N #2 in step 6. The intermediate U2N #1 forwards the message with the updated additional information if available and protect the forwarded message with the intermediate relay discovery security material that the intermediate U2N #1 obtained from its HPLMN from step 0b, same as step 2. In addition, the intermediate U2N #1 includes it's Home PLMN in clear text in the forwarded message to identify the intermediate discovery security material associated with the intermediate U2N #1.

8. On receiving the Relay Discovery Response message from the intermediate U2N #1 , the discoverer 5G ProSe Remote UE verifies the received Relay Discovery Response message using the relay discovery security material associated with the discoveree U2N obtained from step 0a and the additional information based on intermediate relay discovery security material associated with the intermediate U2N #1 which was obtained from step 0b. The discoverer 5G ProSe Remote UE identifies the intermediate relay discovery security material associated with the intermediate U2N #1 based on the clear text HPLMN ID included by the intermediate U2N #1 in step 7. If the verification is successful, the discoverer 5G ProSe Remote UE shall process the Relay Discovery Response message as specified in clause 6.1.3.2.2.2 of TS 33.503[5].

#### 6.3.2.1 Provisioning the intermediate relay discovery security material

 Figure 6.2.2.1-1: Intermediate Relay Discovery Key request

The security procedure to retrieve intermediate relay discovery security material uses the procedure of clause 6.1.3.2.2.1 of TS 33.503[5] for 5G ProSe UE-to-Network Relay as baseline with extension. Differences to clause 6.1.3.2.2.1 of TS 33.503 are mentioned below:

- Each sending intermediate 5G ProSe U2N acts as announcing UE of clause 6.1.3.2.2.1 of TS 33.503[5], and the neighbours of this intermediate 5G ProSe U2N(other intermediate 5G ProSe U2N(s), or the 5G ProSe Remote UE etc.) receiving forwarded message act as Monitoring UEs. They are called as sending UE and receiving UE accordingly.

- Steps 1-4 refer to a sending UE (e.g. intermediate U2N #1);

- Step1, the Relay Discovery Key request message also includes an indication that intermediate relay discovery security material is requested.

- Step4, the Relay Discovery Key response message contains the intermediate relay discovery security materials associated with the HPLMN ID of the sending UE (intermediate U2N #1)

- Steps 5-10 refer to a receiving UE(e.g. intermediate U2N #2);

- Step5,7, the Relay Discovery Key request message also includes an indication that intermediate relay discovery security material is requested.

- Step9,10, the Relay Discovery Key response message contains the intermediate relay discovery security materials and the HPLMN ID of the sending UE (intermediate U2N #1).

NOTE 2: The sending or receiving UE role for intermediate U2N (s) in multi-hop U2N discovery Model B procedure depends on which entity forwards the discovery Solicitation and/or discovery Response message. E.g. the intermediate U2N #1 is the sending UE and the intermediate U2N #2 is the receiving UE when the intermediate U2N #1 forwards the discovery Solicitation message to the intermediate U2N #2. In the other direction, the intermediate U2N #1 is the receiving UE and the intermediate U2N #2 is the sending UE when the intermediate U2N #2 forwards the discovery Response message to the intermediate U2N #1.

### 6.3.3 Evaluation

The solution addresses key issue #1 and provides methods for security protection (confidentiality protection, integrity protection and replay protection, and mitigating trackability and linkability attacks) of multi-hop UE-to-Network Relay discovery Model B.

The solution proposes to reuse the existing Restricted 5G ProSe UE-to-Network Discovery Model B security methods, with extensions to support two sets of discovery security material i.e. the relay discovery security material and the intermediate relay discovery security material.

Apart from the relay discovery security material the intermediate U2N relay nodes need to obtain also a set of intermediate relay discovery security material from their own HPLMNs. A separate procedure for the acquisition of these keys is proposed. For this purpose, when nodes belong to different HPLMNs the Discovery Solicitation and Discovery Response messages include the HPLMN ID of the transmitting node.

This solution does not address potential retransmission of protected discovery messages by an unauthorized entity.

## 6.4 Solution #4: Security of multi-hop UE-to-Network Relay communication

### 6.4.1 Introduction

This solution addresses key issue #1: Security for multi-hop UE-to-Network Relay.

Each hop of multi-hop UE-to-Network Relay communication (e.g. between Remote UE and intermediate UE-to-Network Relay, between target UE-to-Network Relay and intermediate UE-to-Network Relay, or between two intermediate UE-to-Network Relays) performs PC5 link security establishment procedure and sets up PC5 security context, reusing the methods as specified in clause 6.6.3 of TS 33.503[5].

Once hop-by-hop security for PC5 link establishment has been performed, the Remote UE and the target UE-to-Network Relay triggers e2e security between them, reusing the security methods (UP based or CP based solution) as specified in clause 6.3.3 of TS 33.503[5]. The signaling of the selected security method is overlay over the secured PC5 link of each hop.

NOTE: There could be one or more intermediate UE-to-Network Relays in the discovery message path. The maximum number of intermediate UE-to-Network Relays in the path is out of scope of the present document. This solution shows only one intermediate UE-to-Network Relay as example.

Additionally, to support authorization between the Remote UE and the target U2N, this solution proposes to reuse the existing UP or CP based security procedure between the Remote UE and the target U2N as specified in TS 33.503 so that the Remote UE and the target U2N can authorize each other after security context is established between the two.

### 6.4.2 Solution details

The security procedure for multi-hop 5G ProSe UE-to-Network Relay communication is described as follows.



Figure 6.4.2-1: Security for multi-hop UE-to-Network Relay communication

0. The 5G ProSe Remote UE, the intermediate UE-to-Network Relay(s) and the target 5G ProSe UE-to-Network Relay sets up hop by hop PC5 link security, reusing the methods as specified in clause 6.6.3 of TS 33.503[5].

After this procedure, secured PC5 transport messages can be exchanged between PC5 links of each hop and protected by the PC5 link security context of each hop.

NOTE: It is assumed existing methods e.g. security for Direct Communication as specified in clause 6.2 of TS 33.503 [5], or security for UE-to-Network Relay Communication (UP or CP based solution) as specified in clause 6.6.3 of TS 33.503 [5] can be used to set up per hop PC5 security.

For example, in case 5G ProSe Intermediate UE-to-Network Relay(s) are out of coverage, the security procedure specified in clause 6.2 is used to establish a secure PC5 link for each hop. If 5G ProSe Intermediate UE-to-Network Relay(s) are in-coverage, the CP-based/UP-based procedures as specified in clauses 6.3.3 of TS 33.503 [5] can be used.

Whether there is any need of enhancement of the existing the security methods to set up per hop PC5 security, it is not addressed in this solution.

1. The 5G ProSe Remote UE is to set up e2e security with the target 5G ProSe UE-to-Network Relay and chooses a security method to be used (i.e. UP based or CP based solution). The 5G ProSe Remote UE forms U2N security container to be sent to the target 5G ProSe UE-to-Network Relay over intermediate UE-to-Network Relay(s) , which contains Direct Communication Request (DCR) messages that contains the UP-PRUK ID/CP-PRUK ID or SUCI, RSC and freshness parameter Nonce\_1, as specified in clause 6.3.3.2.2 or clause 6.3.3.2.3 of TS 33.503[5]. The 5G ProSe Remote UE protects U2N security container using the relay discovery security material associated with the target 5G ProSe UE-to-Network Relay, by reusing the protection method as specified in clause 6.3.5 of TS 33.503[5].

The 5G ProSe Remote UE sends the U2N security container and possible other additional information (e.g. hop counter) required for multi-hop UE-to-Network Relay over a secured PC5 transport message to the intermediate UE-to-Network Relay.

NOTE: The content of possible additional information (e.g. hop count) that is required for multi-hop UE-to-Network relay is out of scope of the present document.

1. The intermediate UE-to-Network Relay forwards the secured transport PC5 message to the target 5G ProSe UE-to-Network Relay.
   1. The target UE-to-Network Relay performs UP based solution (step 4 of clause 6.3.3.2.2 TS 33.503[5]) or CP based solution (step 3-13 of clause 6.3.3.3.2 TS 33.503[5]). The messages, if available, exchanged between the Remote UE and the target 5G ProSe UE-to-Network Relay are sent within the U2N security container over secured PC5 transport messages via PC5 link of each hop. The UE-to-Network Relay also receives the Remote User ID of the 5G ProSe Remote UE (CP-PRUK ID or UP-PRUK ID) from the Network during the UP or CP based security procedure as specified in clause 6.3.3.2.2 and clause 6.3.3.3.2 of TS 33.503[5].
2. The 5G ProSe Remote UE and the target 5G ProSe UE-to-Network Relay performs Direct Security Mode Command procedure as specified in UP based solution (step 5 of clause 6.3.3.2.2 TS 33.503[5]) or CP based solution (step 14-17 of clause 6.3.3.3.2 TS 33.503[5]). The messages exchanged between the Remote UE and the target 5G ProSe UE-to-Network Relay are sent within the U2N security container over secured PC5 transport messages via PC5 link of each hop.

Successful verification of the Direct Security Mode Command assures the 5G ProSe Remote UE that the 5G ProSe UE-to-Network Relay is authorized to provide the relay service. Successful verification of the Direct Security Mode Complete message assures the 5G ProSe UE-to-Network Relay that the 5G ProSe Remote UE is authorized to get the relay service.

* 1. After successful verification, PC5 security context is also set up between the Remote UE and the target 5G ProSe UE-to-Network Relay. The 5G ProSe UE-to-Network Relay responds a Direct Communication Accept message within U2N security container over secured PC5 transport messages via PC5 link of each hop. The U2N security container is protected by the PC5 security context between the Remote UE and the target 5G ProSe UE-to-Network Relay. Whether communication protection between Remote UE and U2N is activated is determined by the negotiated PC5 signalling security policy and the PC5 user plane security policies during UP/CP based security procedure as specified in clause 6.3.3.2.2 and clause 6.3.3.3.2 of TS 33.503[5].

9. When the conditions to send a Remote UE Report reach as specified in TS 23.304 [2], the target 5G ProSe UE-to-Network Relay shall send a Remote UE Report (Remote User ID, Remote UE info) message to the SMF of the 5G ProSe UE-to-Network Relay. The 5G ProSe Layer-3 UE-to-Network Relay shall include Remote User ID (i.e. UP-/CP-PRUK ID received in step 5 in the message.

10. If the mapping of the Remote User ID and the 5G ProSe Remote UE's SUPI is not available in the SMF of the 5G ProSe UE-to-Network Relay, the SMF of the 5G ProSe UE-to-Network Relay performs the procedure as specified in clause 6.3.3.2.2 and clause 6.3.3.3.2 of TS 33.503[5] to resolve Remote User ID procedure.

11. The Remote UE and the target 5G ProSe UE-to-Network Relay perform the rest of the UE-to-Network relay procedure.

The conclusion to KI#1 "Support of multi-hop UE-to-Network Relays" in TR 23.700-03 [1], related to communication and link establishment states the following principle: "Standalone discovery & link setup/management is considered and both Model A and Model B are supported". The 5G ProSe Direct Communication procedure defined in TS 23.304 [4] is reused for the Layer-2 link establishment between each pair of hops in the path. Step 0a, 0b in this solution aligns with the above principles therefore the solution is aligned to TR 23.700-03[1] conclusions.

### 6.4.3 Evaluation

The solution addresses key issue #1 and provides methods for security protection (confidentiality protection, integrity protection and replay protection, and mitigating trackability and linkability attacks) of multi-hop UE-to-Network Relay communication.

The solution proposes to perform PC5 link security establishment and sets up PC5 security context for each hop of multi-hop UE-to-Network Relay communication (e.g. between Remote UE and intermediate UE-to-Network Relay, between target UE-to-Network Relay and intermediate UE-to-Network Relay, or between two intermediate UE-to-Network Relays), reusing the methods as specified in TS 33.503[5]. For example, in case 5G ProSe Intermediate UE-to-Network Relay(s) are out of coverage, the security procedure specified in clause 6.2 is used to establish a secure PC5 link for each hop. If 5G ProSe Intermediate UE-to-Network Relay(s) are in-coverage, the CP-based/UP-based procedures as specified in clauses 6.3.3 of TS 33.503 [5] can be used.

Once hop-by-hop security for PC5 link establishment is established, the Remote UE and the target UE-to-Network Relay triggers authentication and authorization as well as e2e security context establishment between them, reusing the security methods (UP based or CP based solution) as specified in clause 6.3.3 of TS 33.503[5]. The signaling of the security context establishment between the Remote UE and the target U2N is overlay over the established PC5 security link of each hop.

The security context establishment between the Remote UE and the target U2N enables authorization between the two UEs. It can also enable signaling and traffic protection between the Remote UE and the target U2N if required by their PC5 security policy.

Furthermore, this solution also support security for Remote UE Report procedure. As output of UP or CP based security procedure between the Remote UE and the target U2N, the target U2N also obtains the Remote User ID (i.e. UP-PRUK ID or CP-PRUK ID) of the remote UE from the Network. When the conditions to send a Remote UE Report reach as specified in TS 23.304 [2], the 5G ProSe UE-to-Network Relay sends a Remote UE Report message with the received (UP-/CP-PRUK ID) to the SMF of the 5G ProSe UE-to-Network Relay. Thus, the existing Remote UE Report procedure can be reused.

This solution assumes hop-by-hop security establishment for the Multi-hop U2NW Relay path reuses the methods as specified in clause 6.6.3 of TS 33.503[5]. When mechanism without network assistance in 6.6.3.2 of TS 33.503 is used, the Remote UE is required to be provisioned with two sets of security materials (i.e. the Long-Term Credential and the CP/UP-PRUK). When mechanism with network assistance in 6.6.3.1 of TS 33.503 [5] is used, the solution only works when the Intermediate Relay in network coverage.

## 6.5 Solution #5: Security establishment for multi-hop UE-to-Network Relay

### 6.5.1 Introduction

This solution addresses Key Issue #1: Security for multi-hop UE-to-Network Relay, aiming to provide a method to establish security between UEs in the multi-hop UE-to-Network (U2NW) Relay scenario.



In this solution, each of the Intermediate Relay needs to establish secured PC5 link with the node (Intermediate Relay or the U2NW Relay) in the next hop before it can serve the Remote UE. This solution is based on the following terminologies and assumptions:

* The term ‘Intermediate Relay’ in this solution refers to the relays located between the Remote UE and the U2NW Relay, while the U2NW Relay is the node which connects to the network.
* The hops are counted based on the path from the Remote UE to the U2NW Relay, i.e. the Intermediate Relay that connects to the Remote UE is assumed as the first hop of the multi-hop connection, while the U2NW Relay locates at the last hop.
* The ‘next hop’ of a node (i.e. Remote UE, Intermediate Relay or U2NW Relay) refers to the neighbour node facing to the network side, while the ‘previous hop’ refers to the neighbour node facing to the Remote UE side.
* The Remote UE and the Intermediate Relay in this solution can locate of network coverage, the U2NW Relay in this solution is required to be covered by the network.

### 6.5.2 Solution details

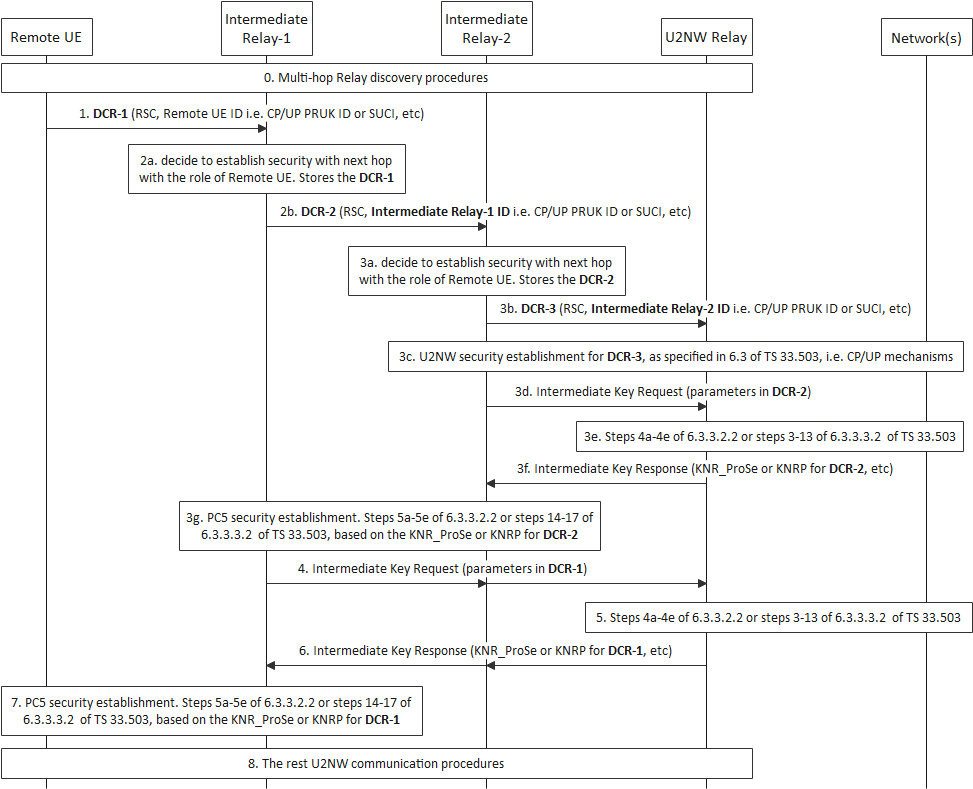


Figure 6.5.2-1: Example multi-hop U2NW Relay security establishment procedures

Each of the Intermediate Relay needs to establish secured PC5 link with the node (Intermediate Relay or the U2NW Relay) in the next hop before it can serve the Remote UE.

0. The multi-hop relay discovery procedure to discover the involvers, including the Remote UE, the Intermediate Relay(s) and the U2NW Relay.

1. After the multi-hop Relay discovery procedure, the Remote UE initiate the Direct Communication Request (DCR) message (i.e. DCR-1 on the figure) to request the security establishment between the intermediate relay in the next hop (i.e. the Intermediate Relay-1 on the figure), including the RSC, CP/UP-PRUK ID or SUCI of the Remote UE as defined in clause 6.3 of TS 33.503 [5].

2a-2b. The Intermediate Relay-1 receives the DCR-1 and temporarily stores the DCR-1. The Intermediate Relay-1 initiates another DCR (i.e. DCR-2 on the figure) to establish security establishment between the next hop node. If the path includes only a single Intermediate Relay, the next hop node is the U2NW Relay and step 2b is sent directly to the U2NW Relay.

When establishing the secured link between the next hop, the Intermediate Relay-1 takes the role of a Remote UE and the DCR-2 includes the RSC, CP/UP-PRUK ID or SUCI of the Intermediate UE as defined in clause 6.3 of TS 33.503 [5].

3. If only a single Intermediate Relay exists in the path, only step 3e is executed. The Intermediate Relay-1 and the U2NW Relay follow the procedures in 6.3 of TS 33.503 [5] to establish the secured PC5 link.

If multi-hop U2NW relay service using dedicated RSC value different from U2NW relay service, the Intermediate Relay’s UDM/PKMF checks whether the Intermediate UE is authorised to offer multi-hop U2NW relay service based on the RSC (including the authorisation of the Intermediate UE to get KNR\_ProSe/KNRP for DCR-1).

If more than one Intermediate Relays in the path, each Intermediate Relay needs to store the DCR message from its previous hop (step 3a in case of two Intermediate Relays) and establish secured link between its next hop (steps 3b and 3c for two Intermediate Relays). The parameters in the stored DCR message are sent to the next hop after the secured link is established (step 3d for two Intermediate Relays). The secured link is also used to receive security parameters from next hop to set up security with previous hop (steps 3f and 3g for two Intermediate Relays).

4-5. The Intermediate Relay uses the protected PC5 link established in step 3 to send intermediate key request message including the temporarily stored parameters in DCR-1. Based on the existing U2NW Relay security mechanism (i.e. steps 4a-4e of 6.3.3.2.2 or steps 3-13 of 6.3.3.3.2 of TS 33.503 [5]), the U2NW Relay uses the parameters in the Intermediate Key Request to interact with the network, in order to get the KNR\_ProSe/KNRP and freshness parameter to set up connection with the Remote UE.

If L2 connection is used to access to the U2NW Relay, the Intermediate Relay can send/receive steps 4 and 6 directly to the network as specified in clause 6.3 of TS 33.503 [5] (i.e. Relay Key Request/Response or Key Request/Response).

If L3 connection is setup using CP-based mechanism, the Intermediate Relay send/receive the Intermediate key request/response (i.e. the new PC5-S message in steps 4 and 6) to the next hop as show on the figure 6.5.2-1. All the NAS connection with the network will be sent to the U2NW relay’s AMF by the U2NW relay, instead of sending to the Intermediate Relay’s AMF by the Intermediate Relay.

If L3 connection is setup using UP-based mechanism, the Intermediate Relay send/receive Key Request/Response (i.e. step 4a/4b of clause 6.3.3.2.2 of TS 33.503 [5]) to the next hop using PC5 user plane.

6-7. The KNR\_ProSe/KNRP and freshness parameter are contained in the Intermediate Key Response and sent to the Intermediate Relay via the protected PC5 channel established in step 3. The Remote UE and the Intermediate Relay use existing mechanism to finish security link setup.

8. The rest multi-hop U2NW communication procedures.

### 6.5.3 Evaluation

This solution addresses the security requirements of key issue #1.

The secured link of a node with its previous hop is established after the security establishment with its next hop. The parameters in the DCR message from previous hop is sent protected via the secured PC5 link to its next hop node, and finally to the last hop (i.e. U2NW Relay). The security establishment, authentication and authorisation methods reuse the existing mechanisms (i.e. either UP-based or CP-based as specified in TS 33.503 [5]). Trackability and linkability are prevented by sending DCR parameters via secured PC5 link to the last hop.

This solution allows the Remote UE and the Intermediate Relay to locate out of network coverage.

The Intermediate Relay’s UDM/PKMF checks whether the Intermediate UE is authorised to offer multi-hop U2NW relay service based on the RSC in step 3, including the authorisation of the Intermediate UE to get/forward keys shared between other Intermediate UEs in the path. Intermediate Relay and U2NW Relay are considered as trusted entity after authentication and authorisation.

PC5 signalling confidentiality security policy is set to "REQUIRED" for the solution.

The CP-based and UP-based security procedures can be reused with the following adaptations:

* Intermediate U2NW Relay needs to temporally store the DCR message from its previous hop
* If L3 connection is setup using CP-based mechanism, new PC5-S message is needed (i.e. the Intermediate Relay Request/Response). The Intermediate Relay can decrypt the protected KNR\_ProSe/KNRP and freshness parameter in the hop-by-hop Intermediate Key Response and re-encrypt them to send to next hop in another Intermediate Key Responses, if the path includes more than one Intermediate U2NW Relays. Steps 4a-4e of 6.3.3.2.2 or steps 3-13 of 6.3.3.3.2 of TS 33.503 [5] need to be executed for each additional intermediate relay per Remote UE connection.

## 6.6 Solution #6: Security for multi-hop UE-to-Network Relay Communication

### 6.6.1 Introduction

This solution addresses security requirements for communication scenarios (as show in Figure 6-6) in Key Issue #1 (as defined in clause 5.1) .



Figure 6.6.1-1: Example scenario of multi-hop UE-to-Network Relay



Figure 6.6.1-2: High level security procedure for multi-hop UE-to-Network Relay Communication

1. Security procedure for each hop PC5 Link of multi-hop 5G ProSe UE-to-Network Relay Communication as described in clause 6.6.2.

2a. For the 5G ProSe Multi-hop Layer-3 UE-to-Network Relay Communication with N3IWF support, the 5G ProSe Remote UE establish security protection with 5G network as described in clause 6.6.3.

2b. For the 5G ProSe Multi-hop Layer-3 UE-to-Network Relay Communication without N3IWF support, as described in clause 6.6.4, the 5G ProSe Remote UE establish security protection with the UE-to-Network Relay to prevent eavesdropping attacks on the traffic of the 5G ProSe Remote UE.

2c. For the 5G ProSe Multi-hop Layer-2 UE-to-Network Relay Communication, the 5G ProSe Remote UE establish AS security with 5G network as described in clause 6.6.5.

### 6.6.2 Security procedure for each hop PC5 Link

The security procedure for 5G ProSe UE-to-Network Relay Communication as defined as defined in clause 6.3 of TS 33.503 [5] is used to establish a secure PC5 link between the Remote UE and the intermediate Relay, the intermediate Relay and the intermediate Relay, the intermediate Relay and the UE-to-Network Relay.

### 6.6.3 Security procedure for 5G ProSe Multi-hop Layer-3 UE-to-Network Relay Communication with N3IWF support

The 5G ProSe Layer-3 Remote UE selects N3IWF and performs the security procedures as specified in clause 7.2.1 of TS 33.501 [6].

### 6.6.4 Security procedure for 5G ProSe Multi-hop Layer-3 UE-to-Network Relay Communication without N3IWF support



Figure 6.6.4-1: Security procedure for 5G ProSe Multi-hop Layer-3 UE-to-Network Relay Communication without N3IWF support

1. The hop-by-hop PC5 security has been established as described in clause 6.6.2.

1. The Remote UE sends a Multi-hop Communication Request to the UE-to-Network Relay via one or more Intermediate Relay, which includes information about the selected path, the SUCI or UP-/CP-PRUK ID of Remote UE, RSC and freshness\_parameter\_1.

2. Upon receiving the Multi-hop Communication Request from the remote UE via one or more Intermediate Relay, the UE-to-Network Relay perform the security procedure with network assistance as specified in step 4 of clause 6.3.3.2.2 of TS 33.503 [5] or step 3 to step 13 in clause 6.3.3.3.2 of TS 33.503 [5].

NOTE 1: Whether UP based and CP based PC5 security procedures as specified in clause 6.3.3 of TS 33.503 [5] can be reused will be determined at the normative stage.

3. The 5G ProSe UE-to-Network Relay shall derive the session key from KNRP/KNR\_ProSe and then derive the confidentiality key (if applicable) and integrity key. The 5G ProSe UE-to-Network Relay shall sends a Authorization Check Request message to the 5G ProSe Remote UE via one or more Intermediate Relay. This message shall also include the freshness Parameter 2 and shall be protected by integrity key.

4. Upon receiving the Authorization Check Request message, the Remote UE shall derive the KNRP/KNR\_ProSe from UP-/CP-PRUK. It shall then derive the session key and the confidentiality key (if applicable) and integrity key and process the Authorization Check Request message. Successful verification of the Authorization Check Request message assures the Remote UE that the UE-to-Network Relay is authorized to provide the Multi-hop U2N Relay service.

5. The Remote UE responds with a Authorization Check Response message to 5G ProSe UE-to-Network Relay via one or more Intermediate Relay if successfully verified the Authorization Check Request message. The Authorization Check Response message shall be protected by integrity key and confidentiality key (if applicable).

6. Upon receiving the Authorization Check Response message, the UE-to-Network Relay shall verify the this message. Successful verification of the Authorization Check Response message assures the 5G ProSe UE-to-Network Relay that the 5G ProSe Remote UE is authorized to get the Multi-hop U2N Relay service.

7. After the successful verification of the Authorization Check Response message, the 5G ProSe UE-to-Network Relay responds a Multi-hop Communication Accept message to the 5G ProSe Remote UE via one or more Intermediate Relay to finish the Multi-hop Communication establishment procedures. The Multi-hop Communication Accept message shall be protected by integrity key and confidentiality key (if applicable).

NOTE 2: Whether the session key between the remote UE and U2N relay is used for security protection is left for normative phase.

NOTE 3: The Multi-hop Communication Request/Accept message and Authorization Check Request/Response message are transmitted between the Remote UE and the UE-to-Network Relay over hop-by-hop PC5 link.

### 6.6.5 Security procedure for 5G ProSe Multi-hop Layer-2 UE-to-Network Relay Communication

The 5G ProSe Remote UE and NG-RAN node shall establish AS security as specified in TS 33.501 [6].

### 6.6.6 Evaluation

For the 5G ProSe Multi-hop Layer-3 UE-to-Network Relay Communication with N3IWF support, this solution propose to reuse the security procedure as defined in clause 7.2.1 of TS 33.501 [6] to establish E2E security protection between the 5G ProSe Remote UE and 5G network to prevent eavesdropping attacks on the traffic of the 5G ProSe Remote UE.

For the 5G ProSe Multi-hop Layer-3 UE-to-Network Relay Communication without N3IWF support, this solution propose to reuse the security procedure for 5G ProSe UE-to-Network Relay Communication as described in clause 6.3 of TS 33.503 [5] to establish E2E security protection between the 5G ProSe Remote UE and the UE-to-Network Relay to prevent eavesdropping attacks on the traffic of the 5G ProSe Remote UE.

For the 5G ProSe Multi-hop Layer-2 UE-to-Network Relay Communication, this solution propose to reuse the AS security procedure as defined in TS 33.501 to establish E2E security protection between the 5G ProSe Remote UE and NG-RAN to prevent eavesdropping attacks on the traffic of the 5G ProSe Remote UE.

This solution assumes hop-by-hop security establishment for the Multi-hop U2NW Relay path reuses the methods as specified in clause 6.6.3 of TS 33.503[5]. When mechanism without network assistance in 6.6.3.2 of TS 33.503 [5] is used, the Remote UE is required to be provisioned with two sets of security materials (i.e. the Long-Term Credential and the CP/UP-PRUK). When mechanism with network assistance in 6.6.3.1 of TS 33.503 [5] is used, the solution only works when the Intermediate Relay in network coverage.

NOTE: Further evaluation is for normative phase.

## 6.7 Solution #7: Multi-hop UE-to-network Relay discovery security procedure

### 6.7.1 Introduction

This solution is proposed to address Key Issue #1, which provides a method by which the Remote UE can securely discover the UE-to-network Relay via one or multiple Intermediate Relays.

For the multi-hop UE-to-Network Relay discovery, in addition to protecting the discovery message by reusing the UE-to-network Relay discovery security mechanism defined in TS 33.503 [5], the involved UE also needs to ensure the trustworthiness of path information before updating the stored record or forwarding the discovery message.

This is because the attacker can launch the replay attack by re-sending the detected discovery message, which may distort the real path information maintained by the Remote UE and Intermediate Relay. For example, the discovery message is captured by the attacker at Time 1 in location A. The attacker can re-send this discovery message at Time 2 (Time 2 is sufficiently close to Time 1) in location B. Once receiving the discovery message, the UE in location B supporting multi-hop UE-to-network relay service can successfully verify this message and forward it to all the UEs in proximity in location B, resulting in the failure of multi-hop UE-to-network relay discovery.

The path information verification can be achieved by authenticating the UE sent the discovery message, i.e. only if the link can be securely established, the UE received the discovery message can trust the included path information and forward this message during the multi-hop UE-to-network Relay discovery.

### 6.7.2 Solution details

#### 6.7.2.1 Multi-hop UE-to-Network Relay Discovery security procedure with Model A

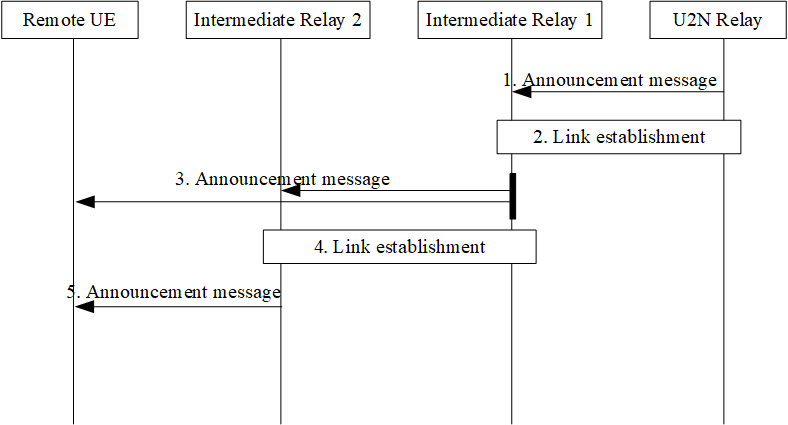


Figure 6.7.2.1-1: Security procedure for multi-hop UE-to-Network Relay Discovery with Model A

0. The discovery security materials provisioning procedure for 5G ProSe UE-to-network Discovery defined in TS 33.503 [5] is reused for multi-hop UE-to-network relay discovery.

The UE-to-network Relay obtains the discovery security materials associated with its HPLMN. The Intermediate Relay obtains the discovery security materials associated with its HPLMN, and multiple sets of discovery security materials associated with the HPLMN of potential UE-to-network Relay(s)/Intermediate Relay(s). The Remote UE obtains multiple sets of discovery security materials associated with the HPLMN of potential UE-to-network Relay(s)/Intermediate Relay(s).

1. The UE-to-network Relay broadcasts the announcement message, which is protected by the discovery security materials associated with the RSC and its HPLMN ID.
2. The Intermediate Relay1 verifies the announcement message by using the discovery security material associated with the PLMN ID of UE-to-network Relay and RSC.

If the verification is passed, the Intermediate Relay1 determines whether to broadcast the announcement message for multi-hop UE-to-Network Relay based on the following principles:

* Whether the criteria defined in TR 23.700-03 [1] can be met or not, e.g. if the Hop-count value is smaller than the Hop-Limit value or not, if the Hop-Count value is smaller than the stored value in the record or not, etc.
* Whether the secure link between the announcing UE and monitoring UE can be established or has been established, e.g. whether the Intermediate Relay1 can successfully establish the link with the UE-to-network Relay by reusing the link establishment procedure defined in TS 33.503 [5] when there is no connection.

1. If the above principles are met, the Intermediate Relay1 broadcasts the announcement message, which is protected by the discovery security materials associated with the RSC and its HPLMN ID.
2. The Intermediate Relay2 verifies the announcement message and determines whether to forward it as step #2. If there is no connection between the Intermediate Relay2 and Intermediate Relay1, the Intermediate Relay2 initiates the link establishment procedure as defined in TS 33.503 [5].
3. Once the link is securely established, the Intermediate Relay2 broadcasts the protected announcement message.
4. The Remote UE may select one of the Intermediate Relay based on the received announcement message. For the selected Intermediate Relay, the Remote UE initiates the link establishment procedure.

#### 6.7.2.2 Multi-hop UE-to-Network Relay Discovery security procedure with Model B

A diagram of a business process

Description automatically generated

Figure 6.7.2.2-1: Security procedure for multi-hop UE-to-Network Relay Discovery with Model B

0. The discovery security materials provisioning procedure for 5G ProSe UE-to-network Discovery defined in TS 33.503 [5] is reused for multi-hop UE-to-network Relay discovery.

The Remote UE, Intermediate Relay, and UE-to-network Relay obtains the discovery security materials associated with its HPLMN, and multiple sets of discovery security materials associated with the HPLMN of potential UE-to-network Relay(s)/Intermediate Relay(s).

1. The Remote UE broadcasts the solicitation message, which is protected by the discovery security materials associated with the RSC as specified in clause 6.3 of TS 33.503 [5].
2. The Intermediate Relay-1 verifies the solicitation message by using the discovery security material associated with its HPLMN ID and RSC. If the verification is passed, the Intermediate Relay-1 further broadcasts the solicitation message, which is protected by the discovery security materials associated with the RSC as specified in clause 6.3 of TS 33.503 [5].
3. The Intermediate Relay-2 verifies the solicitation message and further broadcasts the solicitation message.
4. The UE-to-network Relay verifies the solicitation message and sends the response message.
5. Once receiving the response message, the Intermediate Relay-2 verifies it by using the corresponding discovery security materials, and determines whether to forward the response message based on the following principles:

* Whether the criteria defined in TR 23.700-03 [1] can be met or not, e.g. if the Hop-count value is smaller than the Hop-Limit value or not, if the Hop-Count value is smaller than the stored value in the record or not, etc.
* Whether the secure link between the Intermediate Relay and UE-to-network Relay can be established or has been established, e.g. whether the Intermediate Relay1 can successfully establish the link by reusing the link establishment procedure defined in TS 33.503 [5] when there is no connection.

1. If the above principles are met, the Intermediate Relay-2 sends the response message, which is protected by the discovery security materials associated with the RSC and its HPLMN ID.
2. Once receiving the response message, the Intermediate Relay-1 verifies it by using the corresponding discovery security materials and determines whether to establish the PC5 link with Intermediate Relay-2.
3. The Intermediate Relay-1 sends the response message after the PC5 link between the Intermediate Relay-1 and Intermediate Relay-2 is established.

The Remote UE may select one of the Intermediate Relay based on the received response message. For the selected Intermediate Relay, the Remote UE initiates the link establishment procedure.

### 6.7.3 Evaluation

The solution fulfills the security requirements of Key Issue #1 for the multi-hop UE-to-network Relay discovery with Model A and Model B.

The UE-to-network Relay discovery procedure is reused for the multi-hop UE-to-network Relay discovery. By reusing the existing discovery mechanism, the Remote UE can securely discover the UE-to-network Relay via Intermediate Relay(s).

This solution ensures that the Intermediate Relay has been authenticated and established a connection to the network before serving the Remote UE (for discovery or connection), which is aligned with the SA2 conclusion.

In this solution, the Intermediate Relay needs to obtain the discovery security materials associated with its HPLMN and multiple sets of discovery security materials associated with the HPLMN of potential UE-to-network Relay(s)/Intermediate Relay(s).

The discovery solution for Model B is not aligned with the conclusion in TR 23.700-03 [1].

This solution does not address potential retransmission of protected discovery messages by an unauthorized entity.

If the Intermediate Relay and UE-to-Network Relay belong to different PLMNs, the Intermediate Relay needs to obtain multiple sets of discovery security materials associated with the HPLMN of potential UE-to-network Relay(s)/Intermediate Relay(s).

## 6.8 Solution #8: Multi-hop UE-to-network Relay security establishment procedure

### 6.8.1 Introduction

This solution is proposed to address Key Issue #1, which provides a method by which the Remote UE can securely establish the communication with the UE-to-network Relay via one or multiple Intermediate Relay(s).

In this solution, it is assumed that the security of each hop (i.e. the link between the Intermediate Relay1 and Intermediate Relay2, the link between the Intermediate Relay2 and UE-to-network Relay) has been established during the multi-hop UE-to-network Relay discovery procedure.

For establishing the security for multi-hop UE-to-network Relay communication, the DCR message is sent by the Remote UE and is transmitted over the secure link. Once receiving the DCR message, the UE-to-network Relay can perform the Remote UE report procedure as defined in TS 33.503 [5].

### 6.8.2 Solution details

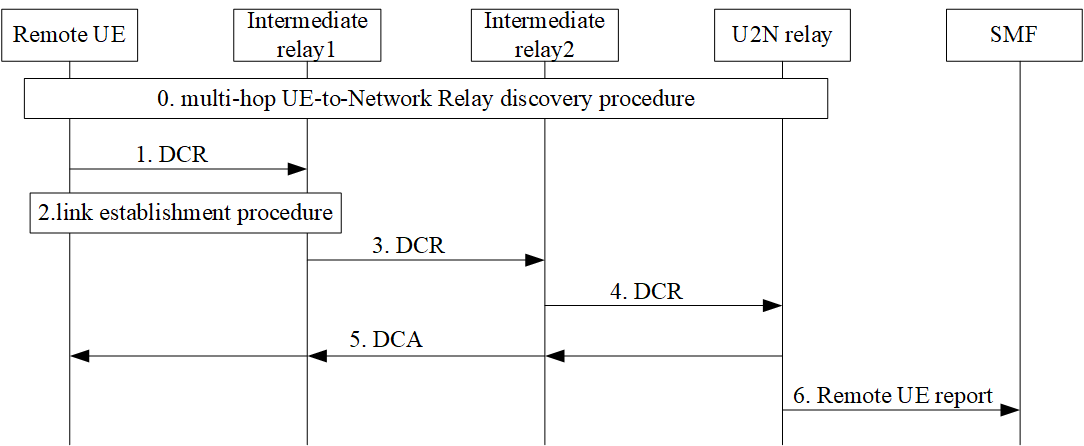


Figure 6.8.2-1: Security establishment procedure for multi-hop UE-to-network Relay communication

1. The Remote UE can securely discover the UE-to-network Relay by performing the multi-hop UE-to-network Relay discovery procedure.

It is assumed the final path selected by the Remote UE is Remote UE – Intermediate Relay1 – Intermediate Relay2 – UE-to-network Relay, and the security of each hop (i.e. the link between the Intermediate Relay1 and Intermediate Relay2, the link between the Intermediate Relay2 and UE-to-network Relay) has been established by reusing the existing procedure defined in TS 33.503 [5]. By reusing the existing link establishment procedure, the authorization of Intermediate Relay and UE-to-network Relay can be checked.

1. The Remote UE sends the DCR message to the Intermediate Relay1, which may include RSC, user info ID of Remote UE, etc.
2. Once receiving the DCR message, the Remote UE and Intermediate Relay 1 establish the PC5 link security connection by reusing existing link security establishment procedure defined in TS 33.503 [5].
3. The Intermediate Relay1 forwards the DCR message, which may include RSC, user info ID of Remote UE, etc. The DCR message is transmitted over the secure link between the Intermediate Relay1 and Intermediate Relay2.
4. The Intermediate Relay2 forwards the DCR message, which may include RSC, user info ID of Remote UE, etc. The DCR message is transmitted over the secure link between the Intermediate Relay2 and UE-to-Network Relay.
5. The UE-to-network Relay returns the DCA message to the Remote UE via the Intermediate Relay(s).
6. The UE-to-network Relay sends the Remote UE report to the SMF of Relay UE.

NOTE: Whether steps 3-6 are aligned with TR 23.700-03 [1] and TS 23.304 [4] will be determined at the normative stage.

### 6.8.3 Evaluation

This solution addresses the first security requirement of Key Issue #1 for the multi-hop UE-to-Network Relay communication.

In this solution, it is assumed that the security of each hop (i.e. the link between the Intermediate Relay1 and Intermediate Relay2, the link between the Intermediate Relay2 and UE-to-network Relay) has been established during the multi-hop UE-to-Network Relay discovery procedure.

This solution is for establishing the security between the Remote UE and Intermediate UE-to-Network Relay. The existing link establishment procedure is reused to support the multi-hop UE-to-Network service.

The Intermediate Relay can be assumed as a trusted node for forwarding the traffic between the Remote and UE-to-network Relay upon authentication and authorization are finished. Therefore, the E2E security between the Remote UE and UE-to-network Relay is not supported in this solution. The DCR message is for initiating the mutli-hop UE-to-Network Relay security establishment procedure with the selected Intermediate Relay(s) and UE-to-Network Relay, which is not aligned with TS 23.304 [4].

## 6.9 Solution #9: Multi-hop UE-to-Network Relay discovery security

### 6.9.1 Introduction

This solution addresses the first, second and fourth security requirements in the key issue #1 regarding the multi-hop UE-to-Network (U2N) Relay discovery. This solution proposes to reuse the security procedure for 5G ProSe UE-to-Network Relay discovery with Model A and Model B as specified in clause 6.3 of TS 33.503 [5]. In addition, it is proposed to mandate the integrity protection of discovery messages as the messages contain information related to path selection (e.g., hop count indicating the number of hops to reach the 5G ProSe UE-to-Network Relay). The proposed security procedure is based on the multi-hop UE-to-Network Relay discovery procedures in several solutions (e.g., solution #1, #2, and #7) of TR 23.700-03 [1].

### 6.9.2 Solution details

#### 6.9.2.1 Discovery with Model A

The security procedure for multi-hop UE-to-Network Relay discovery with Model A is shown in Figure 6.9.2.1-1.



Figure 6.9.2.1-1: Model A Discovery operation supporting multi-hop UE-to-Network Relay

0. The 5G ProSe Remote UE, Intermediate UE-to-Network Relay/5G ProSe UE-to-Network Relay is provisioned with the discovery security materials associated with an RSC from the 5G PKMF/5G DDNMF of 5G ProSe Remote UE/Intermediate UE-to-Network Relay/5G ProSe UE-to-Network Relay’s HPLMN based on the procedure specified in clause 6.3 of TS 33.503 [5]. The discovery security materials contain a Discovery User Integrity Key (DUIK) for the integrity protection of Relay Discovery Announcement.

1. The 5G ProSe UE-to-Network Relay protects a Relay Discovery Announcement using the discovery security materials associated with the RSC as specified in clause 6.3 of TS 33.503 [5]. Then, the 5G ProSe UE-to-Network Relay broadcasts the Relay Discovery Announcement.

2a. The Intermediate UE-to-Network Relay processes the received Relay Discovery Announcement message using the discovery security materials associated with the RSC as specified in clause 6.3 of TS 33.503 [5]. If the processing is successful and Intermediate UE-to-Network Relay does not have a PC5 link with the 5G ProSe UE-to-Network Relay, the Intermediate UE-to-Network Relay establishes a PC5 link with the 5G ProSe UE-to-Network Relay based on the PC5 security establishment for 5G ProSe UE-to-Network relay communication over User Plane specified in clause 6.3.3.2.2 of TS 33.503 [5].

2b. Once the PC5 link is established between the Intermediate UE-to-Network Relay and the 5G ProSe UE-to-Network Relay, the Intermediate UE-to-Network Relay updates the path information (e.g., hop count, Relay Info.) and protects the updated message using the discovery security materials associated with the RSC as specified in clause 6.3 of TS 33.503 [5]. The Intermediate UE-to-Network Relay broadcasts the updated message.

3. Upon receiving the Relay Discovery Announcement message from the Intermediate UE-to-Network Relay, the 5G ProSe Remote UE processes the received message using the discovery security materials associated with the RSC as specified in clause 6.3 of TS 33.503 [5].

#### 6.9.2.2 Discovery with Model B

The security procedure for multi-hop UE-to-Network Relay discovery with Model B is shown in Figure 6.9.2.2-1.



Figure 6.9.2.2-1: Model B Discovery operation supporting multi-hop UE-to-Network Relay

0. The 5G ProSe Remote UE, Intermediate UE-to-Network Relay/5G ProSe UE-to-Network Relay is provisioned with the discovery security materials associated with an RSC from the 5G PKMF/5G DDNMF of 5G ProSe Remote UE/Intermediate UE-to-Network Relay/5G ProSe UE-to-Network Relay’s HPLMN based on the procedure specified in clause 6.3 of TS 33.503 [5]. The discovery security materials contain a Discovery User Integrity Key (DUIK) for the integrity protection of Relay Discovery Solicitation and Relay Discovery Response.

1. The 5G ProSe Remote UE protects a Relay Discovery Solicitation using the discovery security materials associated with the RSC as specified in clause 6.3 of TS 33.503 [5]. Then, the 5G ProSe Remote UE broadcasts the Relay Discovery Solicitation.

2. The Intermediate UE-to-Network Relay processes the received Relay Discovery Solicitation using the discovery security materials associated with the RSC as specified in clause 6.3 of TS 33.503 [5]. If the processing is successful, the Intermediate UE-to-Network Relay updates the path information (e.g., hop count) and protects the updated message using the discovery security materials associated with the RSC as specified in clause 6.3 of TS 33.503 [5]. Then, the Intermediate UE-to-Network Relay broadcasts the message.

3. Upon receiving the Relay Discovery Solicitation from the Intermediate UE-to-Network Relay, the 5G ProSe UE-to-Network Relay processes the received message using the discovery security materials associated with the RSC as specified in clause 6.3 of TS 33.503 [5]. If the processing is successful, the 5G ProSe UE-to-Network Relay constructs a Relay Discovery Response and protects it using the discovery security materials associated with the RSC as specified in clause 6.3 of TS 33.503 [5].

The 5G ProSe UE-to-Network Relay replies to the Intermediate UE-to-Network Relay with the Relay Discovery Response.

4. Upon receiving the Relay Discovery Response from the 5G ProSe UE-to-Network Relay, the Intermediate UE-to-Network Relay processes the received message using the discovery security materials associated with the RSC as specified in clause 6.3 of TS 33.503 [5]. If the processing is successful, the Intermediate UE-to-Network Relay updates the path information (e.g., hop count) and protects the updated message using the discovery security materials associated with the RSC as specified in clause 6.3 of TS 33.503 [5]. Then, the Intermediate UE-to-Network Relay replies to the 5G ProSe Remote UE with the message.

5. Upon receiving the Relay Discovery Response from the Intermediate UE-to-Network Relay, the 5G ProSe Remote UE processes the received message using the discovery security materials associated with the RSC as specified in clause 6.3 of TS 33.503 [5].

### 6.9.3 Evaluation

This solution addresses the security requirements in the key issue #1 regarding the multi-hop UE-to-Network (U2N) Relay discovery by reusing the security procedure for single-hop 5G ProSe UE-to-Network Relay discovery with Model A and Model B.

The solution works when the intermediate relay and U2N relay belong to the same HPLMN.

This solution does not address potential retransmission of protected discovery messages by an unauthorized entity.

The solution is aligned with the conclusion in TR 23.700-03 [1] on the discovery procedure.

## 6.10 Solution #10: Multi-hop UE-to-Network Relay communication security

### 6.10.1 Introduction

This solution addresses the first, second and third security requirements in the key issue #1 regarding the multi-hop UE-to-Network (U2N) Relay communication. This solution proposes to reuse the security procedure over User Plane for PC5 security establishment for each hop among 5G ProSe Remote UE, Intermediate UE-to-Network Relay(s), and 5G ProSe UE-to-Network Relay as specified in clause 6.3.3.2 of TS 33.503 [5]. The proposed security procedure is based on the multi-hop UE-to-Network Relay communication procedures in the solutions (i.e., solution #1) of TR 23.700-03 [1].

### 6.10.2 Solution details

The security procedure for multi-hop UE-to-Network Relay communication is shown in Figure 6.10.2-1.



Figure 6.10.2-1: Security procedure for multi-hop UE-to-Network Relay communication

0. The 5G ProSe Remote UE, Intermediate UE-to-Network Relay, and 5G ProSe UE-to-Network Relay are provisioned with the discovery security materials associated with an RSC based on the procedure specified in clause 6.3 of TS 33.503 [5]. In addition, the 5G ProSe Remote UE and Intermediate UE-to-Network Relay are provisioned with UP-PRUK and UP-PRUK ID from 5G PKMF as specified in step 1 in clause 6.3.3.2.2 of TS 33.503 [5].

1a. During multi-hop UE-to-Network Relay discovery with model A procedure, the 5G ProSe UE-to-Network Relay broadcasts an Announcement message.

1b. If the Intermediate UE-to-Network Relay does not have an existing PC5 link with the 5G ProSe UE-to-Network Relay or an upstream intermediate UE-to-Network relay when it receives a valid discovery message (i.e., Announcement message in discovery model A), the Intermediate UE-to-Network Relay establishes a PC5 link with the 5G ProSe UE-to-Network Relay or the upstream intermediate UE-to-Network relay based on the PC5 security establishment for 5G ProSe UE-to-Network relay communication over User Plane specified in clause 6.3.3.2.2 of TS 33.503 [5].

1c. Once the PC5 link is established between the Intermediate UE-to-Network Relay and the 5G ProSe UE-to-Network Relay, the Intermediate UE-to-Network updates the path information (e.g., hop count) in the Announcement message and protects the updated message. Then, the Intermediate UE-to-Network Relay broadcasts the protected Announcement message.

2. After multi-hop UE-to-Network Relay discovery, the 5G ProSe Remote UE establishes a PC5 link with the upstream Intermediate UE-to-Network Relay based on the PC5 security establishment for 5G ProSe UE-to-Network relay communication over User Plane specified in clause 6.3.3.2.2 of TS 33.503[5] with the Intermediate UE-to-Network Relay taking the role of the 5G ProSe UE-to-Network Relay.

NOTE 1: It is assumed that an Intermediate UE-to-Network Relay is able to access to the 5G PKMF of its HPLMN.

### 6.10.3 Evaluation

This solution addresses the security requirements in the key issue #1 regarding the multi-hop UE-to-Network (U2N) Relay communication by reusing the security procedure over use plane for single-hop 5G ProSe U2N Relay communication.

This solution is based on hop-by-hop PC5 link security among Remote UE, Intermediate U2N Relay, and U2N Relay.

This solution is aligned with the conclusion in TR 23.700-13 when Model A based discovery is used.

## 6.11 Solution #11: Security establishment for multi-hop UE-to-UE Relay

### 6.11.1 Introduction

This solution addresses Key Issue #2: Security for multi-hop UE-to-UE Relay, aiming to provide a method to establish security between UEs in the multi-hop UE-to-UE (U2U) Relay scenario. In this solution, the existing mechanism to establish security in U2U scenario as specified in clauses 6.6.3 and 6.6.4 of TS 33.503 [5] is used as baseline. This solution is based on the following terminologies and assumptions:

* The term ‘Multi-hop UE-to-UE Relay’ in this solution refers to the relays located between the End UEs.
* The hops are counted based on the path from the source End UE to the target End UE, i.e. the Intermediate Relay that connects to the Source End UE is assumed as the first hop of the multi-hop connection, while the Target End UE locates at the last hop.
* The ‘next hop’ of a node refers to the neighbour node facing to the Target End UE side, while the ‘previous hop’ refers to the neighbour node facing to the Source End UE side.

### 6.11.2 Solution details

The mechanisms in clauses 6.6.3 and 6.6.4 are used as baseline of this solution, including mechanisms with and without network assistance. The solution addresses the multi-hop UE-to-UE relay security establishment for the scenarios of Ethernet and Unstructured PDU types.

#### 6.11.2.1 Security mechanism with network assistance

Both UP-based and CP-based procedures as specified in clauses 6.3.3.2 and 6.3.3.3 of TS 33.503 [5] are used as baseline to provide authentication, authorisation and security establishment within the Multi-hop U2U Relay scenario with the following modifications:

For security establishment between the Source End UE and the Multi-hop U2U Relay:

- The Remote UE is replaced by the Source End UE.

- The U2NW Relay is replaced by the Multi-hop UE-to-UE Relay.

For security establishment between the Multi-hop U2U Relays:

- The Remote UE is replaced by the Multi-hop U2U Relay close to the Source End UE side.

- The U2NW Relay is replaced by the Multi-hop U2U Relay close to the Target End UE side.

For security establishment between the Multi-hop U2U Relay and the Target End UE:

- The Remote UE is replaced by the Target End UE.

- The U2NW Relay is replaced by the Multi-hop U2U Relay at the previous hop of the Target End UE.

- Upon receiving the Direct Communication Request (DCR) message from the Multi-hop U2U Relay which includes an RSC and if the Network Assistance Security Indicator associated with the RSC indicates the security procedures with network assistance are required, the Multi-hop U2U Relay needs to make sure it is inside network coverage prior to initiating the security procedure with network assistance. If the Multi-hop U2U Relay is not in network coverage, it shall reject the DCR message.

- The steps 4-5d in clause 6.3.3.2.2 of TS 33.503 [5] and the steps 3-16 in clause 6.3.3.3.2 of TS 33.503 [5] are not triggered by the DCR from the Multi-hop U2U Relay. Upon receiving the DCR message from the Multi-hop U2U Relay which includes an RSC with the Network Assistance Security Indicator indicating the security procedures with network assistance, the Target End UE shall inform the Multi-hop U2U Relay to initiate the above steps with the message pair Direct Communication Security Request and Direct Communication Security Accept. The Direct Communication Security Request message shall include the SUCI or UP-/CP-PRUK ID of Target End UE, the RSC and freshness parameter. Upon receiving the Direct Communication Security Request message, the Multi-hop U2U Relay shall make sure it is inside network coverage prior to initiating the security procedures with network assistance. If it is outside network coverage, it shall reject the Direct Communication Security Request message.

- The RSC in the DCR sent by Multi-hop U2U Relay to Target End UE is protected using the security mechanism in clause 6.3.5 of TS 33.503 [5] by modifying Annex A.5 to generate a keystream of the length of the RSC. The Direct Communication Security Request message is protected by reusing the protection method defined in clause 6.3.5 of TS 33.503 [5].

#### 6.11.2.2 Security mechanism without network assistance

The security procedure in clause 6.2 of TS 33.503 [5] is used to establish a secure PC5 link, using mechanism without network assistance, between the End UE and the Multi-hop U2U Relay, and between Multi-hop U2U Relays with the following modifications.

- The RSC is included in the DCR message.

- The DCR message is protected based on the security mechanism defined in clause 6.3.5 of TS 33.503 [5] with a modification that the length of the UP-PRUK ID/CP-PRUK ID is set to zero in clause 6.3.5.2 of TS 33.503 [5].

### 6.11.3 Evaluation

This solution addresses the security requirements of key issue #2. The existing mechanism to establish security in U2U scenario as specified in clauses 6.6.3 and 6.6.4 of TS 33.503 [5] is used as baseline to provide authentication, authorisation and security establishment. Trackability and linkability are prevented by sending DCR/Direct Communication Security Request protected as specified in clause 6.3.5 of TS 33.503 [5].

For the network assistance mechanism in 6.11.2.1, there is risk of link establishment failure if any Intermediate Relay is not within network coverage.

The solution addresses the multi-hop UE-to-UE relay security establishment for the scenarios of Ethernet and Unstructured PDU types.

## 6.12 Solution #12: Solution of multi-hop UE-to-UE Relay Communication

### 6.12.1 Introduction

This solution addresses key issue #2.

For the use of multi-hop UE-to-UE relays, multi-hop UE-to-UE relays can be within or outside the 3GPP coverage range. When the multi-hop UE-to-UE relay is without 3GPP coverage, this solution provides a mechanism for the PC5 security setting process between the Source End UE or the Target End UE and the multi-hop UE-to-UE Relay.

### 6.12.2 Solution details

The security procedure in clause 6.2 is used to establish a secure PC5 link between the End UE and the 5G ProSe Layer-3 multi-hop UE-to-UE Relay and between multiple 5G ProSe Layer-3 multi-hop UE-to-UE Relays without network assistance with the following modifications.

- The RSC is included in the DCR message.

- The DCR message is protected based on the security mechanism defined in clause 6.3.5 with a modification that the length of the UP-PRUK ID/CP-PRUK ID is set to zero in clause 6.3.5.2.

### 6.12.3 Evaluation

## no evaluation is addressed in the present document 6.13 Solution #13: Solution of multi-hop UE-to-UE Relays Discovery Model B

### 6.13.1 Introduction

This Solution based on the solution #5 in TR 23.700-03 [1] and addressed the requirement of KI#2,

The 5G ProSe End UE are provisioned direct discovery security material associated with ProSe Code. The 5G ProSe End UE and U2U Relay are provisioned a set of discovery security material associated with RSC. The RSC related discovery security material is obtained from the HPLMN of discoveree 5G ProSe End UE.

The RSC related discovery security materials provisioning for Relay UE is between Relay UE and Discoveree End UE. The path information is protected by U2U RSC related discovery material.

### 6.13.2 Solution details



Figure 6.13.2-1 Security procedure for multi-hop UE-to-UE Relay Discovery Model B

1. The discoverer 5G ProSe End UE and discoveree 5G ProSe End UE are provisioned with the discovery security materials associated with a 5G ProSe Direct Discovery service based on the discovery security materials provisioning procedure for Restricted 5G ProSe Direct Discovery, as specified defined in clause 6.1.3.2.2.2.

The discoverer 5G ProSe End UE, discoveree 5G ProSe End UE and 5G ProSe UE-to-UE Relay are provisioned with the discovery security materials associated with a RSC based on the discovery security materials provisioning procedure for UE-to-Network Relay Discovery from the HPLMN of discoveree DDNMF, as specified in clause 6.1.3.2.2.2.

1. The discoverer 5G ProSe End UE shall construct a direct discovery set that contains two End UE discovery infos. Each End UE discovery info is protected using the discovery security materials associated with the 5G ProSe Direct Discovery service as specified in clause 6.1.3.2.3. The first protected End UE discovery info shall include User Info ID of the discoverer 5G ProSe End UE, the UTC-based counter LSB parameter, and a MIC IE. The second protected End UE discovery info shall include the and User Info ID of the discoveree 5G ProSe End UE, the UTC-based counter LSB parameter, and a MIC IE. Then, the discoverer 5G ProSe End UE shall include the above protected End UE discovery set and HPLMN id of the discoveree 5G ProSe End UE in the Solicitation message and protect the Solicitation message using the discovery security materials associated with RSC obtained from the HPLMN of discvoeree 5G ProSe End UE as specified in clause 6.1.3.2.3. The solicitation message is sent to the 5G ProSe UE-to-UE Relay 1.

NOTE 1: How can the discoverer End UE knows the HPLMN ID of discoveree End UE is left to the normative phase.

3. On receiving the 5G ProSe UE-to-UE Relay Discovery Solicitation message from the discoverer 5G ProSe End UE, the 5G ProSe UE-to-UE Relay 1 shall extract the PLMN id from the Discovery Solicitation message and process the received UE-to-UE Relay Discovery Solicitation message using the discovery security materials identified by extracted PLMN id. The discovery security materials is obtained from the HPLMN of discoveree 5G ProSe End UE~~.~~

If the verification is successful, the 5G ProSe UE-to-UE Relay 1 shall modify the UE-to-UE Relay Discovery Solicitation message to include User Info ID of the 5G ProSe UE-to-UE Relay 1.

The 5G ProSe UE-to-UE Relay Discovery Solicitation message is protected using the security materials associated with the RSC based on the extracted PLMN id as specified in clause 6.1.3.2.3.

Then, 5G ProSe UE-to-UE Relay 1 sends the message to the 5G ProSe UE-to-UE Relay 2 including the extracted PLMN id which is the HPLMN of discoveree DDNMF.

4.5. 5G ProSe UE-to-UE Relay 2…N repeat the step 3.

6. The discoveree 5G ProSe End UE shall extract the PLMN id and process the received UE-to-UE Relay Discovery Solicitation message using the discovery security materials associated with the RSC based on the extracted PLMN id which is the HPLMN of discoveree DDNMF,.

If the verification is successful, the discoveree 5G ProSe End UE shall extract the protected direct discovery set from the message and process the direct discovery set using the discovery security materials associated with the 5G ProSe Direct Discovery service as specified in clause 6.1.3.2.3.

The discoveree 5G ProSe End UE shall select a multi-hop relay path.

NOTE 2: Whether path selection procedure is aligned with TR 23.700-03 [1] and TS 23.304 [4] will be determined at the normative stage.

7. The discoveree 5G ProSe End UE shall construct a direct discovery set that contains two End UE discovery infos. Each End UE discovery info is protected using the discovery security materials associated with the 5G ProSe Direct Discovery service as specified in clause 6.1.3.2.3. The first protected End UE discovery info shall include User Info ID of the discoverer 5G ProSe End UE, the UTC-based counter LSB parameter, and a MIC IE. The second protected End UE discovery info shall include the and User Info ID of the discoveree 5G ProSe End UE, the UTC-based counter LSB parameter, and a MIC IE. Then, the discoveree 5G ProSe End UE shall include the above protected direct discovery sets and HPLMN id of the discoveree 5G ProSe End UE in the Solicitation message and protect the Solicitation message using the discovery security materials associated with the RSC based on the extracted PLMN id which is the HPLMN of discoveree 5G ProSe End UE’s DDNMF as specified in clause 6.1.3.2.3. The discoveree 5G ProSe End UE replies to the 5G ProSe UE-to-UE Relay N with the UE-to-UE Relay Discovery Response message.

8. On receiving the UE-to-UE Relay Discovery Response message from the discoveree 5G ProSe End UE, the 5G ProSe UE-to-UE Relay N shall extract the PLMN id from the Discovery Response message and process the received UE-to-UE Relay Discovery Response message using the discovery security materials associated with the RSC based on the extracted PLMN id which is the HPLMN of discoveree 5G ProSe End UE’s DDNMF.

If the verification is successful, the 5G ProSe UE-to-UE Relay N shall modify the UE-to-UE Relay Discovery Response message to include User Info ID of 5G ProSe UE-to-UE Relay N.

The UE-to-UE Relay Discovery Response message is protected using the security materials associated with the RSC based on the extracted PLMN id which is the HPLMN of discoveree 5G ProSe End UE’s DDNMF. Then, 5G ProSe UE-to-UE Relay N sends the UE-to-UE Relay Discovery Response message to UE-to-UE Relay 2.

Then, 5G ProSe UE-to-UE Relay N sends the message to the 5G ProSe UE-to-UE Relay 2 including the extracted PLMN id which is the HPLMN of discoveree DDNMF.

9. The 5G U2U Relay 2 repeat the step 8.

10. On receiving the UE-to-UE Relay Discovery Response message, the discoverer 5G ProSe End UE shall extract the PLMN id from the Discovery Response message and process the UE-to-UE Relay Discovery Response message using the discovery security materials associated with the RSC based on the extracted PLMN id which is the HPLMN of discoveree 5G ProSe End UE’s DDNMF.

If the verification is successful, the discoverer 5G ProSe End UE shall extract the protected direct discovery set from the UE-to-UE Relay Discovery Response message and process the protected End UE discovery infos using the discovery security materials associated with the 5G ProSe Direct Discovery service as specified in clause 6.1.3.2.3. If the verification of the first End UE discovery info is successful and the User Info ID of the discoverer matches, the discoverer 5G ProSe End UE processes the second End UE discovery info.

### 6.13.3 Evaluation

This solution addresses the provision of security material in discovery procedure of KI#2. This solution provides a method that the U2U discovery message between each pair of UEs in the path are protected by the security material provided from HPLMN of Discoveree End UE with the assumption that the U2U relays are in the same HPLMN with the Discoveree End UE.

NOTE: Further evaluation is for normative phase.

## 6.14 Solution #14: Multi-hop UE-to-UE Relay discovery security

### 6.14.1 Introduction

This solution addresses the first, third and fourth security requirements in the key issue #2 regarding the multi-hop UE-to-UE (U2U) Relay discovery. This solution assumes the architecture and procedures proposed in the solution #3 of TR 23.700-03 [1]. This means that 5G ProSe UE-to-UE Relays discover each other to form a 5G ProSe UE-to-UE Relay cloud, and 5G ProSe End UEs first discover nearby 5G ProSe UE-to-UE Relay and discover a target 5G ProSe End UE at IP layer (e.g., based on MANET routing protocol) via 5G ProSe UE-to-UE Relay cloud.

This solution proposes to reuse the security procedure for 5G ProSe UE-to-Network Relay discovery with Model A and Model B as specified in clause 6.1.3.2.2 of TS 33.503 [5]. That is, the discovery messages are protected based on the discovery security materials associated with an RSC for multi-hop UE-to-UE Relay.

### 6.14.2 Solution details

Based on the architecture and procedures in the solution #3 of TR 23.700-3 [1], this solution consists of two types of relay discovery: one for Relay discovery among 5G ProSe UE-to-UE Relays and the other one for Relay discovery between an 5G ProSe End UE and 5G ProSe UE-to-UE Relay.

1. Relay discovery among 5G ProSe UE-to-UE Relays

5G ProSe UE-to-UE Relays perform a Relay discovery to form a 5G ProSe UE-to-UE Relay cloud. For the provisioning of discovery security materials and discovery message protection based on the discovery security materials associated with an RSC for multi-hop UE-to-UE Relay, the security procedures for 5G ProSe UE-to-Network Relay discovery with Model A and Model B as specified in clause 6.1.3.2.2 of TS 33.503 [5] are used with the following changes:

- One 5G ProSe UE-to-UE Relay plays the role of a 5G ProSe Remote UE and the other 5G ProSe UE-to-UE Relay plays the role of a 5G ProSe UE-to-Network Relay.

2. Relay discovery between an 5G ProSe End UE and 5G ProSe UE-to-UE Relay

The 5G ProSe End UE performs a Relay discovery to discover a 5G ProSe UE-to-UE Relay that supports a multi-hop UE-to-UE Relay. For the provisioning of discovery security materials and discovery message protection based on the discovery security materials associated with an RSC for multi-hop UE-to-UE Relay, the security procedures for 5G ProSe UE-to-Network Relay discovery with Model A and Model B as specified in clause 6.1.3.2.2 of TS 33.503 [5] are used with the following changes:

- A 5G ProSe End UE plays the role of a 5G ProSe Remote UE and a 5G ProSe UE-to-UE Relay plays the role of a 5G ProSe UE-to-Network Relay.

### 6.14.3 Evaluation

This solution addresses the first, third and fourth security requirements in the key issue #2 regarding the multi-hop UE-to-UE (U2U) Relay discovery.

The solution reuses the security procedure defined for Rel-17 5G ProSe UE-to-Network Relay discovery for discovery among U2U relays and discovery between a Remote UE and U2U relay.

The solution is aligned with SA2’s conclusion when PDU type IP is used for multi-hop UE-to-UE Relay service.

## 6.15 Solution #15: Multi-hop UE-to-UE Relay communication security

### 6.15.1 Introduction

This solution addresses the first, second, and third security requirements in the key issue #2 regarding the multi-hop UE-to-UE (U2U) Relay communication. This solution assumes the architecture and procedures proposed in the solution #3 of TR 23.700-03 [1]. This means that UE-to-UE Relays establish a PC5 link with each other after the Relay discovery to form a 5G ProSe UE-to-UE Relay cloud, and a 5G ProSe End UE establishes a PC5 link with the 5G UE-to-UE Relay to discover a target 5G ProSe End UE and communicate with the discovered target 5G ProSe End UE at IP layer (e.g., based on MANET routing protocol).

For PC5 link security, this solution proposes to reuse the security procedure specified in clause 6.2 of TS 33.503 [5].

### 6.15.2 Solution details

Based on the architecture and procedures in the solution #3 of TR 23.700-3 [1], this solution consists of two types of PC5 link establishment: one for PC5 link establishment among 5G ProSe UE-to-UE Relays and the other one for PC5 link establishment between an 5G ProSe End UE and 5G ProSe UE-to-UE Relay.

1. PC5 link establishment among 5G ProSe UE-to-UE Relays:

After 5G ProSe UE-to-UE Relays perform a Relay discovery, they establish a secure PC5 link based on the security procedure for unicast mode 5G ProSe Direct Communication specified in clause 6.2 of TS 33.503 [5] with the following modifications:

- The RSC is included in the DCR message.

- The DCR message is protected based on the security mechanism defined in clause 6.3.5 with a modification that the UP-PRUK ID/CP-PRUK ID is not used in clause 6.3.5.2.

2. PC5 link establishment between an 5G ProSe End UE and 5G ProSe UE-to-UE Relay:

After the Relay discovery between an 5G ProSe End UE and 5G ProSe UE-to-UE Relay, the 5G ProSe End UE establishes a secure PC5 link with the 5G ProSe UE-to-UE Relay based on the security procedure for unicast mode 5G ProSe Direct Communication specified in clause 6.2 of TS 33.503 [5] with the following modifications:

- The RSC is included in the DCR message.

- The DCR message is protected based on the security mechanism defined in clause 6.3.5 with a modification that the UP-PRUK ID/CP-PRUK ID is not used in clause 6.3.5.2.

### 6.15.3 Evaluation

This solution addresses the security requirements of the key issue #2 regarding the multi-hop UE-to-UE (U2U) Relay communication by reusing the security procedure for unicast mode 5G ProSe Direct Communication defined in Rel-17.

This solution is aligned with SA2’s conclusion when IP PDU session type is used for multi-hop U2U Relay.

## 6.16 Solution #16: Multi-hop UE-to-Network Relay communication security after discovery with Model B

### 6.16.1 Introduction

This solution addresses the first, second and third security requirements in the key issue #1 regarding the multi-hop UE-to-Network (U2N) Relay communication. This solution proposes to reuse the security procedure over User Plane for PC5 security establishment for each hop among 5G ProSe Remote UE, Intermediate UE-to-Network Relay(s), and 5G ProSe UE-to-Network Relay as specified in clause 6.3.3.2 of TS 33.503 [5] after muti-hop U2N relay discovery with Model B. To this end, once an Intermediate UE-to-Network Relay receives a Direct Communication Request from a 5G ProSe Remote UE, it first performs the security procedure over User Plane for PC5 security establishment with the selected 5G ProSe UE-to-Network Relay based on the received path information. Then, the Intermediate UE-to-Network Relay continues the PC5 security establishment with the 5G ProSe Remote UE over user plane.

### 6.16.2 Solution details

The security procedure for multi-hop UE-to-Network Relay communication is shown in Figure 6.16.2-1.

Figure 6.16.2-1: Security procedure for multi-hop UE-to-Network Relay communication

0. The 5G ProSe Remote UE, Intermediate UE-to-Network Relay, and 5G ProSe UE-to-Network Relay are provisioned with the discovery security materials associated with an RSC based on the procedure specified in clause 6.3 of TS 33.503 [5]. In addition, the 5G ProSe Remote UE and Intermediate UE-to-Network Relay are provisioned with UP-PRUK and UP-PRUK ID from 5G PKMF as specified in step 1 in clause 6.3.3.2.2 of TS 33.503 [5].

1. The 5G ProSe Remote UE performs a multi-hop UE-to-Network Relay discovery with Model B procedure with the Intermediate UE-to-Network Relay and 5G ProSe UE-to-Network Relay.

2. After multi-hop UE-to-Network Relay discovery procedure, the 5G ProSe Remote UE initiates PC5 security establishment for 5G ProSe UE-to-Network relay communication over User Plane with the Intermediate UE-to-Network Relay by sending Direct Communication Request message.

3. If the Intermediate UE-to-Network Relay does not have an existing PC5 link with the selected 5G ProSe UE-to-Network Relay or an Intermediate UE-to-Network relay on the path to the 5G ProSe UE-to-Network Relay, the Intermediate UE-to-Network Relay establishes a PC5 link with the 5G ProSe UE-to-Network Relay or the intermediate UE-to-Network relay based on the PC5 security establishment for 5G ProSe UE-to-Network relay communication over User Plane specified in clause 6.3.3.2.2 of TS 33.503 [5].

4. The Intermediate UE-to-Network Relay, then, performs the Key Request/Response procedure with the 5G PKMF/DDNMF of Intermediate UE-to-Network Relay using the parameters received in step 2.

NOTE 1: It is assumed that an Intermediate UE-to-Network Relay is able to access to the 5G PKMF of its HPLMN.

5. The Intermediate UE-to-Network Relay performs Direct Security Mode Command procedure with the 5G ProSe Remote UE and completes the PC5 security establishment with the rest of procedures.

### 6.16.3 Evaluation

This solution addresses the security requirements in the key issue #1 regarding the multi-hop UE-to-Network (U2N) Relay communication by reusing the security procedure over use plane for single-hop 5G ProSe U2N Relay communication.

This solution assumes that hop-by-hop PC5 links among Remote UE, Intermediate U2N Relay, and U2N Relay are established after discovery with Model B, which is aligned with the conclusion in TR 23.700-03 [1].

Since the scope of this solution is per-hop PC5 link security establishments, Remote UE report procedure after PC5 links establishments is out of scope of this solution.

This solution describes how to perform a PC5 link security establishment for each hop among Remote UE, Intermediate U2N relays and root U2N relay in the path. The Remote UE and its upstream intermediate U2N relay are authenticated and authorized by network during PC5 link security establishment procedure. The direct authentication and authorization between Remote UE and root U2N relay are not the scope of this solution.

## 6.17 Solution #17: Multi-hop UE-to-UE Model A discovery security in non-IP scenario

### 6.17.1 Introduction

This solution proposes to follow the existing seucirty principle of single-hop UE-to-UE Relay in TS 33.503 [5], i.e. the Direct Discovery Set is End-to-End protected between End UEs, while other parameters in the discovery message are hop-by-hop protected between UE-to-UE Relay and End UE.

### 6.17.2 Solution details

For Model A discovery in non-IP Multi-hop UE-to-UE Relay scenario, the UE-to-UE Relay has discovered End UEs in proximity and obtains the Direct Discovery Set(s) from End UE(s) in proximity per RSC as specified in TS 23.304 [4] (e.g. via a previous 5G ProSe UE-to-UE Relay Discovery or via secure PC5 connection between 5G ProSe U2U Relay and 5G ProSe End UE). As per TS 23.304 [4], for each received Direct Discovery Set, the UE-to-UE Relay also gets paths information, hop count and optionally maximum number of hops.

Similar to the security principle of single-hop UE-to-UE Relay, the Direct Discovery Set is End-to-End protected between End UEs, while other parameters in the discovery message are hop-by-hop protected between UE-to-UE Relay and End UE:

1a. To provide End-to-End protection of the Direct Discovery Set, the existing discovery security material provisioning procedure as specified in clause 6.1.3.2.2.1 of TS 33.503 [5] is reused to provision the discovery security materials to the End UEs. The security materials are associated with 5G ProSe Direct Discovery service for Restricted 5G ProSe Direct Discovery.

1b. To offer hop-by-hop protection of discovery messages, the existing discovery security material provisioning procedure as specified in clause 6.1.3.2.2.1 of TS 33.503 [5] is reused to provision the discovery security materials to the End UEs and the UE-to-UE Relays. The security materials are associated RSC for the multi-hop UE-to-UE Relay Discovery. The monitoring End UE plays the role of Remote UE while the UE-to-UE plays the role of UE-to-Network Relay.

2. The announcing End UE protects the Direct Discovery Set, using the security materials as specified in clause 6.1.3.2.3 in TS 33.503 [5]. The protects the Direct Discovery Set is sent to UE-to-UE Relay using either by a previous UE-to-UE Relay Discovery procedure or via secure PC5 connection between to the UE-to-UE Relay.

3. Before announcing the Announcement message, the UE-to-UE Relay prepare the message including the protected Direct Discovery Set(s), and other discovery paremeters as specified in TS 23.304 [4], and protects the Announcement message using the discovery security materials in step 1b as specified in clause 6.1.3.2.3 of TS 33.503 [5]. The UE-to-UE relay needs to check the validity timer(s) associated with the protected Direct Discovery Set(s) as specified in clause 6.1.3.3.3 of TS 33.503 [5], only valid protected Direct Discovery Set(s) are included in the Announcement message.

4. On receiving the Announcement message from the UE-to-UE Relay, the monitoring End UE uses the discovery security material received in step 1b to process the message as specified in clause 6.1.3.2.3 of TS 33.503 [5]. If the verification is successful, the monitoring End UE processs the Direct Discovery Set(s) in the message using the discovery security materials in step 1a as specified in clause 6.1.3.2.3 of TS 33.503 [5].

### 6.17.3 Evaluation

This solution addresses the provision of discovery security material and discovery message protection of KI#2. This solution based on the procedure specified in TS 23.304 [4], reuses existing security material provisioning and discovery message protection mechansims in of TS 33.503 [5].

The solution addresses the multi-hop UE-to-UE relay Model A discovery security for the scenarios of Ethernet and Unstructured PDU types.

The validity timer wrap around scenario is not addressed by this solution.

# 7 Conclusions

## 7.1 Key Issue #2: Security for Multi-hop UE-to-UE Relay

The following statements are agreed as a basis for normative work:

For 5G ProSe Multi-hop UE-to-UE Relay discovery of IP PDU type:

* The security procedures for both relay discovery among 5G ProSe UE-to-UE Relays and relay discovery between an 5G ProSe End UE and 5G ProSe UE-to-UE Relay are based on solution #14.

For 5G ProSe Multi-hop UE-to-UE Relay communication traffic of IP PDU type:

* The security procedure for both PC5 link establishment among 5G ProSe UE-to-UE Relays and PC5 link establishment between an 5G ProSe End UE and 5G ProSe UE-to-UE Relay is based on solution #12 and solution #15.

For 5G ProSe Multi-hop UE-to-UE Relay discovery of non-IP PDU type (Ethernet or Unstructured):

* For discovery with Model B, the 5G ProSe End UE and 5G ProSe Multi-hop UE-to-UE Relay are provisioned with the discovery security materials associated with an RSC from the 5G PKMF/5G DDNMF in their own HPLMN, reusing the procedures specified in clause 6.1.3.2 of TS 33.503 [5].
* For discovery with Model B, the 5G ProSe End UE and 5G ProSe Multi-hop UE-to-UE Relay use the mechanisms as specified in clause 6.1.3.3 of TS 33.503 [5] as baseline for the normative work to protect the discovery messages.
* For discovery with Model A, the security procedures for both discovery between 5G ProSe UE-to-UE Relays and discovery between an 5G ProSe End UE and 5G ProSe UE-to-UE Relay are based on solution #17. How to address the validity timer checking upon validity timer wrap around is to be determined during normative phase.

For 5G ProSe Multi-hop UE-to-UE Relay communication traffic of non-IP PDU type (Ethernet or Unstructured):

* The security procedure specified in clause 6.2 is used as a baseline to establish a secure PC5 link for each hop among 5G ProSe End UDs and 5G ProSe UE-to-UE Relays.
* Both UP-based and CP-based security procedures specified in clauses 6.3.3.2 and 6.3.3.3 of TS 33.503 [5] can be used as a baseline for a secure PC5 link establishment for each hop among 5G ProSe End UEs and 5G ProSe UE-to-UE Relays if 5G ProSe UE-to-UE Relays are in-coverage.

## 7.2 Key issue #1: Security for multi-hop UE-to-Network Relay

The following statements are agreed as a basis for normative work:

For 5G ProSe Multi-hop UE-to-Network Relay discovery:

* The 5G ProSe Remote UE, Intermediate UE-to-Network Relay, and 5G ProSe UE-to-Network Relay are provisioned with the discovery security materials associated with an RSC from the 5G PKMF/5G DDNMF of 5G ProSe Remote UE, Intermediate UE-to-Network Relay, and 5G ProSe UE-to-Network Relay’s HPLMN respectively, based on the procedure specified in clause 6.1.3.2 of TS 33.503 [5].

NOTE 1: Which HPLMN provisioned the security material of the Intermediate UE-to-Network Relay is to be determined in normative phase.

* The discovery security materials contain a Discovery User Integrity Key (DUIK) for the integrity protection of discovery messages.
* The Intermediate UE-to-Network Relay processes the received discovery message using the provisioned discovery security materials associated with the RSC as specified in clause 6.1.3.2 of TS 33.503[5]. If the processing is successful, the Intermediate UE-to-Network Relay updates the path information (e.g., hop count, Relay Info.) and protects the updated message using the same security materials associated with the RSC as specified in clause 6.1.3.2 of TS 33.503 [5].

NOTE 1: Since the Intermediate UE-to-Network Relay and 5G ProSe UE-to-Network Relay are provisioned with a single set of discovery security materials from the 5G PKMF/5G DDNMF in their own HPLMN, it is assumed Intermediate UE-to-Network Relays and 5G ProSe UE-to-Network Relay belong to the same HPLMN during 5G ProSe multi-hop UE-to-Network Relay discovery.

* Both discovery with Model A and discovery with Model B are supported.
* For discovery with Model A, the Intermediate UE-to-Network Relay may (as specified in step 6 in clause 6.3.2.5.2 of TS 23.304 [4]) protect and send the Announcement message after a secure PC5 link establishment with the upstream Intermediate UE-to-Network Relay or the 5G ProSe UE-to-Network Relay.
* For discovery with Model B, the 5G ProSe Remote UE protects the discovery message (i.e., Relay Discovery Solicitation) reusing the procedures as specified in clause 6.1.3.2.3 of TS 33.503[5], i.e., using the discovery security materials associated with the RSC and HPLMN ID of the potential 5G ProSe UE-to-Network Relay.

For Key issue #1 on the support Security for multi-hop UE-to-Network Relay communication, the following principles apply:

1) For UE-to-Network Relay communication security following Model A discovery:

* The security establishment for each hop among 5G ProSe Remote UE, Intermediate UE-to-Network Relay(s), and 5G ProSe UE-to-Network Relay is based on CP-based/UP-based procedures as specified in clause 6.3.3 of TS 33.503 [5].

2) For UE-to-Network Relay communication security following Model B discovery, the existing CP-based/UP-based procedures as specified in the in clauses 6.3.3 of TS 33.503 [5] are used as baseline for the normative work with the following principles:

* To trigger the multi-hop U2NW Relay link security establishment, the Remote UE sends a DCR message as specified in the in clauses 6.3.3 of TS 33.503 [5] to the Intermeditate UE-to-Network Relay.
* The Intermediate UE-to-Network Relay plays the role of the Remote UE to establish secured link with the UE-to-Network Relay or with the next Intermediate UE-to-Network Relay, reusing the procedure as specified in the in clauses 6.3.3 of TS 33.503 [5], if the Intermediate UE-to-Network Relay does not have an existing PC5 link with the UE-to-Network Relay or the next Intermediate UE-to-Network Relay, and the next Intermediate UE-to-Network Relay is in-coverage.

NOTE 2: The next Intermediate UE-to-Network Relay are considered in-coverage if they have connection to the network.

NOTE 3: Void.

3) For authentication and authorization, the existing CP-based/UP-based procedures as specified in clause 6.3.3 of TS 33.503 [5] can be used as baseline for each hop during the normative work.

4) For Remote UE report procedure, the existing procedures for Remote UE Report as specified in clause 6.3.3 of TS 33.503 [5] can be used as baseline for the normative work.

NOTE 4: How the Remote User ID of the Remote UE is obtained by the 5G ProSe UE-to-Network Relay for the Remote UE Report procedure is to be determined during normative phase in coordination with SA2.

NOTE 5: For the security procedure over User Plane, it is assumed that an Intermediate UE-to-Network Relay is able to access to the 5G PKMF in its HPLMN (i.e., PC8 establishment via Intermediate UE-to-Network Relay(s) or UE-to-Network Relay).

Annex A (informative):  
Change history

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Change history** | | | | | | | |
| **Date** | **Meeting** | **TDoc** | **CR** | **Rev** | **Cat** | **Subject/Comment** | **New version** |
| 2024-04 | SA3#115 Adhoc-e | S3-241321 |  |  |  | Skeleton of TR33.743 | 0.0.0 |
| 2024-04 | SA3#115 Adhoc-e | S3-241618 |  |  |  | Included changes from S3-241558, S3-241619, S3-241620 and S3-241631 | 0.1.0 |
| 2024-05 | SA3#116 | S3-242521 |  |  |  | Included changes from S3-242072, S3-242156S3-242522, S3-242523, S3-242524, S3-242525, S3-242526, S3-242527, S3-242528, S3-242529, S3-242530, S3-242532S3-242650, S3-242651, S3-242652, S3-242653 | 0.2.0 |
| 2024-08 | SA3#117 | S3-243567 |  |  |  | Included changes from S3‑243663, S3‑243091, S3‑243560, S3‑243561, S3‑243562, S3‑243563, S3‑243564, S3‑243565, S3‑243566, S3‑243335, S3‑243336, S3‑243709, S3‑243568, S3‑243670, S3‑243569, S3‑243710, S3‑243706, S3‑243707, S3‑243332, S3‑243570, S3‑243571, S3‑243572, S3‑243708, S3‑243711, S3‑243669, S3‑243338, S3‑243339, S3‑243231, S3‑243248, S3‑243723, | 0.3.0 |
| 2024-10 | SA3#118 | S3-243831 |  |  |  | Included changes from S3-243965, S3-244372, S3-244374, S3-244377, S3-244481, S3-244496, S3-244497, S3-244498, S3-244513 | 0.4.0 |
| 2024-11 | SA3#119 | S3-245159 |  |  |  | Included changes from S3-245260, S3-245261, S3-245262, S3-245263, S3-245264, S3-245265, S3-245266 | 0.5.0 |
| 2024-12 | SA#106 | SP-241794 |  |  |  | Presented for information | 1.0.0 |
| 2025-02 | SA3#120 | S3-250971 |  |  |  | Included changes from S3-251037 and S3-251038 | 1.1.0 |