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**Source: Nokia, Nokia Shanghai Bell**

**Title:** **KI #2: New Sol:** **Store & Forward operation for Registration procedure in 5GS**

**Document for:** **Approval**

**Agenda Item: 19.1**

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Abstract of the contribution: The contribution proposes a solution to KI#2: Support of Store and Forward Satellite operation

# Introduction

This contribution proposes a solution for UE registration feature in 5GS for KI#2: Support of Store and Forward Satellite operation.

# Discussion

SA1 TR 22.865 (Study on satellite access Phase 3) clauses 5.1 and 5.2 describe scenarios and service requirements for MO and MT use cases using the store and forward satellite operation. In the context of this study, it is an operation mode of a 5G system with satellite access where the 5G system can provide some level of service (in storing and forwarding the data) when satellite connectivity is intermittently/temporarily unavailable, e.g. to provide:

MO communication service for UEs under satellite coverage without a simultaneous active feeder link connection to the ground segment.

MT communication service for UEs via satellite having a feeder link connection and is expected to provide coverage in the future to UE(s).

The proposed solution defines how control plane operations of the UE and specifically the registration procedure in 5GS can be realised in a S&F scenario.

In addition, the proposed solution defines a new network function (and/or a new network function service) in the 5GC, “UE Reachability Estimator” (URE). URE abstracts all details related to UE reachability and its calculation from other TNFs (Terrestrial NFs) and provides UE reachability information to other TNFs as needed. The provided UE reachability information includes: a) the time and duration (time window Tw1) at which NTNF(s) (capable of) serving a given UE is reachable (contactable via feeder link), b) a subsequent time window (Tw2) through which the UE is reachable by this NTNF(s) (when the UE has satellite coverage).

# Proposal

A solution is proposed for KI#2 for incorporation in the FS\_5GSAT\_ARCH\_Ph3 TR23.700-29.

\*\*\* Start of changes (all new text) \*\*\*

## 6.X Solution #X: AMF Split Architecture to support Control plane procedure for S&F

### 6.X.1 Key Issue mapping

This solution aims to resolve the Key Issue #2, " Support of Store and Forward Satellite operation ".

### 6.X.2 Description

As agreed in KI#2, The Store and Forward Satellite (S&F) operation in a 5G system with satellite access is intended to provide some level of communication service for UEs under satellite coverage with intermittent/temporary satellite connectivity (e.g. when the satellite is not connected via a feeder link or via ISL to the ground network) for delay-tolerant communication service.



Figure 6.X.2-1: AMF split architecture for Store and Forward operation

In regenerative architecture, the RAN will be placed in Satellite. In the Store & Forward (S&F) scheme, the AMF is at Satellite will be responsible for providing Store and forward feature. AMF in satellite is represented as AMF-NT (non-terrestrial) in the above figure. Let’s assume the time T1 is between 10:00-10:20 and T2 is 10:40-11:00. The satellites will have ground station coverage when hovering over Rennes and Orleans but not when crossing Le Mans.

At time T1, the black satellite covers Le Mans, and the white satellite provides coverage to Rennes. At T2, the black satellite will be in Orleans, and the white satellite will cover Le Mans.

At time T3, the white satellite will sync up with the AMF-NT at Orleans.

### 6.X.3 Procedures

#### 6.X.3.1 5GS Architecture enhancement to support S&F

As agreed in KI#2, the delay tolerant/non-real time services can be served via S&F Satellite operation.



Figure 6.X.3.1-1: AMF split architecture for Store and Forward operation for 5GS

The key difference between the 3GPP Rel-18 and the proposed method is the buffering of MO and MT data on the NF in the orbit and buffering of MT data on the NF on the ground. The AMF role is split between peer AMF entities on the ground and onboard satellite.

For 5GS, the peer AMF entities hide the store-and-forward functionality from the other NFs. In this document, the AMF on the ground as AMF-T (for Terrestrial). The corresponding peer entities on board satellite are called AMF-NT (for Non-terrestrial).

UE registration and the related security procedures are assumed to have taken place earlier. It is foreseen that the target UEs would be under direct coverage at least occasionally and thus, the registration and mobility updates can be either via terrestrial network or when satellite cell has got ground station connectivity. The store and forward procedures shown in this document can be used for small data transmission when the UE is served by satellite cell that at least occasionally loses its ground station connectivity. The need to use store and forward operation can be detected at registration or mobility update or periodic update time.

In this solution, the following aspects are considered:

1. AMF instance (AMF-T) on the ground interfaces AMF instance on board (AMF-NT)
2. AMF-T has access to satellite orbital data.
3. AMF-T is aware of satellite coverage in terms of feeder link availability.
4. AMF-T supports the AMF's role towards the other NFs on the ground.
5. AMF-T supports an implementation-specific interface with delay-aware satellite-specific AMF functionality.
6. AMF and UDM store the “Store-and-forward indication” in UE context in AMF at UE registration time.
7. AMF-T discovers the next AMF-NT that can reach the UE.

#### 6.X.3.2 Registration Procedure in 5GS in S&F scenario



Figure 6.X.3.2-1: Registration procedure in S&F

1. UE to (R)AN: AN message (AN parameters, Registration Request (Registration type, SUCI or 5G-GUTI or PEI)

The Registration type indicates if the UE wants to perform an Initial Registration, a Mobility Registration Update, a Periodic Registration Update, an Emergency Registration.

The NAS message container shall be included if the UE is sending a Registration Request message as an Initial NAS message and the UE has a valid 5G NAS security context and the UE needs to send non-cleartext IEs. If the UE does not need to send non-cleartext IEs, the UE shall send a Registration Request message without including the NAS message container.

If the UE does not have a valid 5G NAS security context, the UE shall send the Registration Request message without including the NAS message container. The UE shall include the entire Registration Request message (i.e. containing cleartext IEs and non-cleartext IEs) in the NAS message container that is sent as part of the Security Mode Complete message.

2. (R)AN to AMF-NT-1: N2 message (N2 parameters, Registration Request (as described in step 1).

If the AMF-NT-1 do not have connectivity to the ground when receiving Registration Request, it will store the Registration Request message.

3. AMF-NT-1 to UE via (R)AN: Sends DL NAS transport with temporary UE identifier (Interim GUTI). Here assuming all the AMF-NT in all satellite in the constellation will have unique AMF ID, thus creating non-colliding GUTI allocations. (GUTI = PLMN ID+AMF Region ID+ AMF Set ID+AMF ID+TMSI).

UE will remember this temporary identifier (Interim GUTI) for future transactions. AMF may also provide validity time for this temporary identifier to UE.

NOTE 1: UE needs to maintain a NAS sub-state (e.g. Registration-on-going) to enable itself to process paging using temporarily assigned GUTI. It is up to stage 3 to define this new UE NAS sub-state. The RAN shall make the UE RRC-Idle before moving out of coverage or UE can autonomously go to RRC-idle when it detects loss of coverage.

4. AMF-NT-1 to AMF-T: When Satellite containing RAN-1 and AMF-NT-1 moves away from the UE and gets connected to ground station, the AMF-NT-1 shall forward the stored Registration Request message along with the Interim GUTI to AMF-T.

5. The AMF-T may decide to initiate UE authentication by invoking an AUSF. In that case, the AMF-T selects an AUSF based on SUPI or SUCI.

If the AMF-T is configured to support Emergency Registration for unauthenticated SUPIs and the UE indicated Registration type Emergency Registration, the AMF skips the authentication or the AMF accepts that the authentication may fail and continues the Registration procedure.

6. If authentication is required, the AMF requests it from the AUSF; Upon request from the AMF, the AUSF shall execute authentication of the UE. The authentication is performed as described in TS 33.501. The AUSF selects a UDM and gets the authentication data from UDM.

7. When the AUSF returns the authentication data to AMF-T, the AMF-T shall store it against the interim GUTI received from AMF-NT onboard the satellite.

AMF-T will now determine the next probable satellite which can reach the UE location next.

NOTE 2: One such determination mechanism is described in clause 6.X.3.3

8. AMF-T to next probable satellite’s AMF-NT-2: Namf\_N1N2MessageTransfer (containing Authentication Request NAS message and interim GUTI). AMF-T shall also provide the last known location of UE.

9. Either the UE comes back after seeing the new cell (RAN-2) or AMF-NT-2 pages the UE using the interim GUTI. When the UE gets connected to RAN-2; RAN-2 shall send initial UE message (containing service request)

10. The AMF-NT-2 sends the authentication request message to UE received in step 9.

11. UE sends the authentication response message (including HXRES\*) to AMF-NT-2. As the AMF-NT-2 do not have connectivity to the ground when receiving authentication response, it will store the authentication response message.

12. When AMF-NT-2 comes in contact with ground station (moves away from the UE as well), forwards the authentication response to AMF-T.

13. AMF-T validates (HXRES\*=XRES\*) sends the Authentication Request to AUSF.

14. AUSF sends authentication response with KSEAF to AMF-T.

15. AMF-T to AMF-NT-3: Since the NAS security context do not exist, the NAS security initiation is performed by sending Namf\_N1N2MessageTransfer (containing both security mode command for the UE) & (registration request message received at step 4) & interim GUTI. AMF-NT-3 stores the information until reaches the coverage area of the UE. (AMF-T finds the suitable AMF-NT-3 based on the criteria discusses in step 8). AMF-T shall also provide the last known location of UE.

16. AMF-NT-3 tries to reach UE via paging using the interim GUTI or UE tries to establish RRC connection using service request with interim GUTI. Then AMF-NT-3 sends the NAS security mode command to UE.

17-18. UE enables the security and acknowledges it to AMF-NT-3.

19. AMF-NT-3 upon receiving security mode command ack from UE stores it till it regains the ground station connectivity again and then sends the security mode command ack to AMF-T.

20. AMF-T does the steps 13, 14, 15 described in clause 4.2.2.2.2 in TS 23.502. AMF-T at this stage may determine, whether UE is allowed to be served in S&F scenario or not.

21. AMF-T then selects suitable candidate satellite which is going to serve the UE next. The selection criteria can be as per description in step 8. AMF-T sends the Registration accept message to AMF-NT-4 via N1N2MessageTransfer. AMF-NT-2 stores the Registration accept message. AMF-T shall also provide the last known location of UE.

22-23. When AMF-NT-4 reaches the UE serving area, it follows the steps mentioned in step 10. AMF-NT-4 sends the registration accept and shares the TMSI, security keys to RAN-4.

24-25. UE may respond with registration complete towards AMF-NT-4. Which AMF-NT-4 will store and forward until it reaches the ground connectivity again with AMF-T.

Editor's note: How to avoid/minimise DoS attack on AMF-NT while handling integrity protected messages from UE (as it lacks the NAS keys for decoding) is FFS.

Editor’s note: How to avoid/minimise fake base station attack when delivering plain text RRC message (message 3) is FFS.

Editor’s note: How to handle NAS timers due to extended delay in serving NAS transactions in S&F.

Editor’s Note: How to distribute the NAS key set and maintain SN across multiple AMF needs to be studied further.

Editor’s Note: It is FFS on the worst-case scenario for number of satellite change required to complete any C-plane procedure.

NOTE 3: The UE shall support storing interim GUTI and use it for responding to Paging or while sending any initial NAS request.

NOTE 4: AMF-NT should be able to create distinct interim GUTI (one assumption is to have distinct AMF pointer ID for each AMF in satellite).

NOTE 5: AMF-NT are not keeping any security material (both AS and NAS). Integrity and ciphering are to be done at AMF-T for every NAS message. This is to keep AMF-NT as light weight s/w as possible.

NOTE 6: The UE shall store the temporary NAS context till the validity time of the interim GUTI.

NOTE 7: How to create trust between AMF-T and AMF-NT is up to SA3.

NOTE 8: Due to the dependency on paging procedures (step 10, 17 and 23) to bring the UE into connected mode for DL signalling messages, the failure in paging will prolong the attach procedure.

#### 6.X.3.3 UE Reachability Estimation (Satellite Location/Coverage Information)

##### 6.X.3.3.1 UE reachability estimation

The URE is a new network function located on ground responsible for estimating which non-terrestrial network element can reach the UE, according to defined criteria, such as in shortest amount of time possible. The following figure shows a possible architecture, including the URE.



**Figure 6.X.3.3-1: Architecture 5GS including UE Reachability Estimator**

The UE reachability is a function of both:

1. UE location (and optionally trajectory and velocity, if available), and
2. Satellite (NTNFs) location, velocity, and ephemeris. This includes when there is a feeder link between the ground and a SAT and when there is Uu radio connectivity between the SAT and the UE

For a static UE, URE estimates reachability based on the satellite’s ephemeris. A precise “Reachability Schedule” (RS) can be calculated. This RS precisely contains the time and duration during which a UE is reachable by the satellite, through which the UE is reachable in each duration, and the latest time this satellite has reached the terrestrial core network before covering the UE.

For UEs in motion, if the trajectory and velocity of the UE are known, the URE takes these into account when constructing the RS. In this case, the RS may include reachability probabilities with each entry. The RS can also be more precisely constructed if the UE trip plan is known to the URE.

##### 6.X.3.3.2 URE-TNFs interaction and use-cases

A TNF that would like to know when a given UE is reachable queries the URE for this UE. The URE responds with the earliest possible “UE Reachability Time” and “UE Reachability Duration” and candidate Satellites. There can be several use cases where a TNF may interrogate the URE, for example:

1. to set a timer for a NAS procedure of a satellite-served UE,
2. to determine when to send messages (signalling, data, SMS) to the UE, or
3. during NAS procedures, the AMF may take “UE Reachability Time” into account when assigning the NAS timer values (such as Periodic Update Timer).

As a response to a TNF interrogation, the URE replies with the earliest possible “UE Reachability Time” and “UE Reachability Duration”. As an option, more than one alternative might be provided, e.g. “UE Reachability Time 1” and “UE Reachability Duration 1” via satellite 1, “UE Reachability Time 2” and “UE Reachability Duration 2” via satellite 2, etc.

Based on network configuration/policies and the interrogator TNF, the URE may include additional information in its response, such as the SAT-ID and/or the IDs of some or all NTNFs serving the UE during the provided reachability time and duration.

##### 6.X.3.3.3 Reachability Modes

The information provided in the URE response to the TNF varies, depending on a selected “Reachability Mode” (RM). The RM determines how the UE is reachable; for example, “Same SAT Mode” (SSM), “Any SAT Mode” (ASM) or “Fastest Reach Mode” (FRM) (via inter-SAT link).

“Same SAT Mode” (SSM) assumes that the same satellite that has received a request from a UE would be the same satellite to reply to the UE. It can also be assumed that the same satellite through which the UE registered to the network would be the satellite to use for MT signalling or MT data.

The “Any SAT Mode” (ASM), assumes that the UE will be reached by the first satellite that can cover this UE and that will have a feeder link to the terrestrial core network between the time of interrogation and before the satellite covers the UE.

The “Fastest Reachable Mode” (FRM) seeks to reach the UE and deliver the message in the fastest possible mean, including the utilisation of inter-satellite links for delivering the MT service.

If the user location is not available in the request to the URE, the URE service needs to determine the user location, e.g. by querying the UDM. The UDM provides an optional satellite constellation ID or satellite operator ID if the serving AMF of the UE has registered this information onto UDM. Assuming the last known TAI: registration area (set of TAI(s)) and gets also registered in UDM, for UEs registered via a S&F NTN RAT -Radio Access Type- (this may correspond to UE(s) with specific subscriptions that may benefit from satellite with S&F feature), the URE gets the location information from UDM.

Otherwise, the URE may need to fetch location information from AMF. If the user location is not provided by the UDM but only the registered AMF, URE queries the UE location from any AMF in the AMF set. This registration area will help in getting constellation/satellite information that is currently covering that region. The URE can query UE’s last registration area and Last TAI from any AMF, in AMF set which is currently reachable. NTNF AMF can also provide expected UE behaviour information (which is currently used for paging). URE can take that into consideration to assume UE’s current location.

The URE based on the satellite constellation ID or satellite operator ID, on the UE location (last known TA/ registration area) and on its knowledge of the satellite ephemeris determines:

* 1. The time and duration (time window TW1) at which NTNF(s) (capable of) serving a given UE is reachable (contactable via feeder link).
  2. A subsequent time window (TW2) through which the UE is reachable by this NTNF(s) (when the UE has satellite coverage).

Editor’s note: How does the URE obtains the UE trajectory or velocity, is FFS.

Editor’s note: How the ephemeris data on satellite movement is provisioned in URE is FFS.

### 6.X.4 Impacts on services, entities and interfaces

UE:

* NAS impact to handle larger delay due to S&F mode of operation.
* NAS impact due to new MM capability handling (S&F).
* NAS impact due to new interim GUTI allocation

AMF-T:

* Buffer/Store N2 messages for transmission towards the UE
* Determine when buffered N2 message should be transmitted to the relevant AMF-NT

Transmission (reception) of ciphered and plain text NAS messages to (from) AMF-TsAMF-NT:

* Buffer/Store N2 messages for transmission towards a ground station
* Determine when buffered N2 message should be transmitted to the AMF-T, once connected to a ground station.
* Transmission (reception) of ciphered and plain text NAS messages to (from) AMF-TsHandling of plain text NAS and NGAP messages on behalf of AMF-T

URE:

* New NF estimating when UE is reachable and by which non-terrestrial network element (i.e., satellite) according to request criteria.
* Provide/expose information about when a UE is reachable via a satellite, and also about the non-terrestrial network element (i.e., satellite) that can reach the UE.

NRF:

* New URE profile in NRF, including Constellations IDs supported

UDM:

* possible impact due to new subscription data

\*\*\* END of changes \*\*\*