3GPP TSG-RAN WG1 Meeting #103-e R1- 2009485

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Title: FL Summary on enhancements on UL time and frequency synchronization for NR NTN

Document for: Discussion

# Introduction

This feature lead summary document captures the issues related to UL synchronization in NR NTN. It contains a summary of the contributions under 8.4.2 at TSG-RAN WG1 #103-e. Discussions on uplink timing synchronization and uplink frequency synchronization are summarized in Section 1 and Section 2 respectively. Discussions on serving satellite ephemeris are summarized in Section 3. Discussions on accuracy of UE pre-compensation for UL synchronization are summarized in Section 4.

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# UL timing synchronization in NTN

## Issue#1: Initial acquisition of TA before PRACH preamble transmission

### Background

In Rel-17 NR NTN, for initial acquisition of TA, the UE needs to be assisted by its GNSS receiver and by the network.

It has been agreed at RAN1 Meeting #102-e to support at least UE which can derive based on its GNSS implementation one or more of:

• its position

• a reference time and frequency

and use these elements to assist UL synchronization.

According to the following agreements made at RAN1#102e, autonomous TA calculation by the UE using its GNSS can be based on either geometric calculations or measurements:

In case of GNSS-assisted TA acquisition in RRC idle/inactive mode, the UE calculates its TA based on the following potential contributions:

* The User specific TA which is estimated by the UE:
	+ Option 1: The User specific TA is estimated by the UE based on its GNSS acquired position together with the serving satellite ephemeris indicated by the network:
		- FFS: Details on serving satellite ephemeris indication
	+ Option 2: The User specific TA  is estimated by the UE based on the GNSS acquired reference time at UE together with reference time as indicated by the network
* The Common TA if indicated by the network:
	+ FFS: The need and details of Common TA indication

FFS: The TA margin, if needed and indicated by the network (in order to account for the TA estimation uncertainty)

Solution#1: Autonomous TA acquisition based on GNSS and serving satellite ephemeris

With this solution, autonomous TA calculation is performed by the UE using its GNSS and geometric considerations: The User specific TA is estimated by the UE based on its GNSS acquired position together with the serving satellite ephemeris indicated by the network.

The principle of the autonomous acquisition of the TA at UE with UE known location and satellite ephemeris can be summarized as follows:

* The UE is assisted by its GNSS receiver to acquire its position
* The UE is assisted by the Network to acquire the real-time position of the satellite:
	+ The network broadcasts the satellite ephemeris data in the SIB
	+ The UE derives current satellite location based on its last acquisition of the satellite ephemeris and some basic propagator model.
* The real-time propagation delay between the satellite and the UE; *t0* can be estimated with basic geometric formulas. The User specific TA is given by two times *t0.*

The figure below illustrates the TA components when the TA is acquired based on its GNSS-acquired position and the satellite ephemeris. For simplicity TA offset N TAoffset is not plotted:

TA = **UE specific TA** + **Common TA + (-TA margin)** = 2xT1 + 2xT0+**(-TA margin)**



Figure 1 TA first acquisition based on serving satellite ephemeris method

Solution#2: Autonomous TA acquisition based on Timestamp

With this solution, the UE can rely on the following procedure :

* The internal clock of the UE is readjusted based on GNSS reference time. This way, the UE has access to a very accurate reference of time.
* The propagation delay between the UE and the reference point is estimated by subtracting the current time given by the UE internal clock when the SIB is received to the reference time broadcasted inside the SIB.
* Doubling this propagation delay gives the RTT between the UE and the reference point.



Figure 2 TA first acquisition based on timestamp method

There are several proposals on the type of Network-assisted information to be provided to the UE for UL pre-compensation: Satellite ephemeris or Timestamp

|  |  |
| --- | --- |
| **Companies** | **Proposals** |
| Apple | Proposal 3: In case of GNSS-assisted TA acquisition in RRC idle/inactive mode, the UE calculates its TA based on the user specific TA, which is estimated by the UE based on its GNSS acquired position together with the serving satellite ephemeris indicated by the network. |
| CATT | Observation 1: Serving satellite ephemeris signalled from the network is more promising than the timestamp signalled.Proposal 1: Additional information signalled from the network should apply serving satellite ephemeris.Proposal 3: Initial TA acquisition based on GNSS and satellite ephemeris is supported. |
| Thales | Proposal 2. The usage of the UE GNSS implementation with the sole purpose of deriving its position shall be considered as baseline for Release 17 NTN. |
| Ericsson | Proposal 1: An NTN UE is required to support time offset estimation and pre-compensation based on UE position and satellite ephemeris.Proposal 2: Whether the measurement based method may optionally be used by the UE, in case the network broadcasts timestamps, is for further study. |
| CMCC | Proposal 1: All TA determination solutions can be supported and chosen can be left to deployment/ implementation.Proposal 2: Working mode for NTN is explicitly signaled in system information to eliminate potential confusion in terminology. |
| Sony | Proposal 1: Timing advance adjustment based on network indication of either satellite and gNB position or time-stamped reference times should be supported as baseline for GNSS-capable UEs. |
| Intel Corporation | Proposal 1: UEs without pre-compensation of time and frequency offset capabilities are not considered for the NTN WI |
| Panasonic | Proposal 1: Support UE autonomous TA acquisition based on location of UE and satellite. |
| InterDigital, Inc. | Proposal 1: UE-specific TA is estimated based on GNSS acquired UE position and satellite ephemeris (Option-1). |
| Spreadtrum Communications | Proposal 3: The UE specific TA is estimated by the UE based on its GNSS acquired position together with the serving satellite ephemeris indicated by the network. |
| MediaTek, Eutelsat | Observation 4: Timestamp method is suitable for satellite propagation delay only. It requires very accurate internal clock synchronized to GNSS with high impact on device hardware and architecture implementation and requires potential RACH design to support large satellite frequency offset. |
| LG Electronics | Observation 3. Both Option 1 and Option 2 can work properly for autonomous TA acquisition, but it is preferred that the one option should be down selected in order to reduce the UE implementation complexity in Rel-17 NTN. |
| ZTE | Proposal 4: For Option-2, additional indications, e.g., reference time information in PDSCH/PDCCH or time drift rate are needed to enable the TA calculation and maintenance. |

### Company views

Based on the above proposals, for uplink synchronization there is no objection that the UE can be assisted by the network by indicating the serving satellite ephemeris.

On the other hand, some companies arise some objection on the timestamp based method: several drawbacks were revealed about this method:

* Tight integration of GNSS receiver and NR module in the device are required for the device implementation.
* The maintenance of GNSS time or frequency reference may result in high power consumption in the device.
* A higher SIB periodicity could be required as a very accurate internal clock synchronized to GNSS will need to be maintained in the UE for the timestamp method.

Additionally, other companies observed that based on the UE implementation, both methods (satellite ephemeris based or Timestamp based) may be used in combination with each other..

Based on the above discussion, an initial proposal is made as follows. Companies are encouraged to provide views on the initial proposal.

Initial proposal 1-1:

**An NTN UE is required to support UE specific TA calculation based on its position and satellite ephemeris**

**FFS: Whether the Timestamp based method may optionally be used by the UE, in case the network broadcasts timestamps**

Companies are encouraged to provide their comments and views in the following table:

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| ZTE | 1. Fine to prioritize the geometric based solution. But additional aspect of this solution to achieve full TA compensation (i.e., handling the common TA part) should also be considered with unified framework.
 |
| MediaTek | Agree with proposal to prioritize UE specification calculation based on UE position and satellite ephemeris. We think the timestamp method should not be considered as an option for NTN. It does not require specification as already supported in Rel-16 SIB9. It is up to device implementation and RAN4 to define requirements and testing for this method (we provide further comments in Issue#3 FL recommendation 3-2. The UE specification calculation based on UE position and satellite ephemeris only requires UE to read the SIB from time to time. It’s sufficient to read it once in 10 seconds. In that time assuming UE is moving at around 120 km/h, the UE position only changes by 300 m which should still allow very accurate Doppler shift estimation in the order of 100 Hz. This solution to support UE pre-compensation could evolve without dependence on GNSS. For example, if an NTN-based positioning method is specified in rel-18 it could be used instead of GNSS to acquire UE position. The accuracy should be good enough for UE pre-compensation with an accuracy similar to OTDOA-based positioning. |
| Ericsson | We support the proposal. |
| Intel | We are fine with the proposal.  |
| Apple | Agree with the proposal. The satellite ephemeris information needs to be broadcast for UE to estimate the UE specific TA.  |
| OPPO | OK with the proposal |
| InterDigital | Support the proposal |
| Qualcomm | Support. |
| Huawei | Support the proposal. |
| Spreadtrum | Support the proposal. |
| Samsung | We support Proposal 1-1. The above-mentioned drawbacks for the timestamp-based method need to be investigated. |

### List of open issues

The following issues need to be further investigated:

* Issue#1-1: Serving satellite ephemeris format
* Issue#1-2: The need and indication of common TA
* Issue#1-3: The need and indication of TA margin
* Issue#1-4: TA command in RAR

### Issue#1-1: The need and indication of common TA

#### Background

The need of common TA is directly linked to the position of the reference point for time synchronization. The reference point (RP) is defined as the point where the timing alignment of uplink and downlink frames can be observed. The common TA is defined as the common component of propagation delay shared by all UEs within the cell coverage and corresponds to the Round Trip Delay (RTD) between the RP and the satellite; It is zero if the Reference Point is located at the satellite; or equal to NTN GW to satellite RTD if Reference Point is located at the NTN GW depending on the implementation.

There were 3 options considered for the common TA indication at RAN1#102e as summarized in moderator’s summary for UL synchronization in NR NTN in R1-2007290:

* RP OPTION 1: The RP is located at the gNB. Common TA indication shall be introduced.
* RP OPTION 2: The RP is located at the satellite. Common TA indication may be avoided.
* RP OPTION 3: The RP localization is not specified and left to the implementation, i.e. network. Common TA indication shall be introduced to support all the foreseen deployment scenarios.

A holistic view should be taken when deciding the Reference point localization . More specifically, RP OPTION 3 illustrated in the figure below, can be seen as a generic option that can be used to support all the foreseen deployment scenarios. Considering this option, the initial TA acquisition (before PRACH transmission) is computed as the sum of two distinct contributions:

- TA = UE specific TA + Common TA + (-TA margin) = 2xT1 + 2xT0+(-TA margin) As a consequence, the RTD experienced between the gNB and the RP shall be compensated by the network. It is masked to the UE from a synchronization point of view.



Figure 3 Reference Point (RP) OPTION 3

The following table recaps the proposals of the companies about the reference point for time synchronisation:

|  |  |
| --- | --- |
| **Companies** | **Proposals** |
| Ericsson | Proposal 4: The reference point for time and frequency in an NTN should be under control of the network and should at least support the option of having gNB as the reference point. |
| Qualcomm Incorporated | Observation 2: In NTN with transparent LEO satellites, it may not be feasible to have gNB as the reference point for time and frequency.Proposal 1: In NTN, the satellite is the time and frequency reference point of a UE, i.e., UE targets UL transmit time and frequency at the arrival of the satellite and does not autonomously compensate time delay and frequency errors introduced by the satellite transponder and the feeder link. |
| Nokia | Observation 12: The implementation of the synchronization reference point at the satellite or at the gNB are not transparent to the system, and both would require different support from the NTN specifications in terms of messages to be broadcast. Proposal 3: RAN 1 to define one of the alternatives as the current working assumption, to minimize the specification effort and the sub-branches of work. |
| Apple | Proposal 1: Define common TA as the RTD between reference point and satellite.Proposal 2: The reference point is set at satellite. |
| Thales | Proposal 8. Consider the satellite as the reference point for TA acquisition and maintenance. |
| MediaTek, Eutelsat | Observation 8: For RP option 1, the common TA drift needs to be indicated by the network. For RP option 2, common TA drift indication by the network can be avoided. |
| vivo | Proposal 1: The reference point needs to be clearly defined before NTN UL timing advance discussion. |
| Samsung | Proposal 4: Multiple reference points and common TA values should be considered for extremely large cells. |
| OPPO | Proposal 2: Consider RP option 3 as a baseline and FFS for detailed signaling design. |
| ZTE | Proposal 1: At least the full TA compensation at UE side to ensure the DL/UL frame boundary alignment at BS side should be supported. |
| Xiaomi | Proposal 1: Reference point and common TA definitions that are different to TR 38.821 should be clarified. Proposal 2: RP option 3 in FL summary should be supported. |
| Spreadtrum Communications | Proposal 2: Reference point for autonomous acquisition of the TA at UE is located at the satellite. |

#### Company views on the reference point position

Companies have different views on the position of the reference point. Many companies observed that at this stage we need to define one of the alternatives as the current working assumption, to minimize the specification effort and the sub-branches of work.

From UE perspective, all discussed options of Reference Point are equally acceptable as they clearly indicate the expected UE behaviour.

From gNB perspective: Some companies observed that the time-variant timing offset between the DL and UL frame timing may introduce much more complexities to the gNB in case RP is located at the satellite (RP Option 2). Considering the implementation complexity at gNB side, some companies proposed to adopt RP option 3 as baseline so that the delay compensated by the network can be a constant value instead of the feeder link RTD.

When it comes to specification effort, common TA indication by the network can be avoided when RP is located at the satellite (RP Option 2) as proposed by many companies.

There is a proposal stating that the RP should be under control of the network and having gNB as the reference point should always be possible.

From the above discussion and as mentioned earlier, a holistic view should be taken when deciding the Reference point localization. Initial proposal is made as follows:

Initial proposal 1-2:

The reference point for time synchronization in an NTN should be under control of the network and should at least support the option of having the gNB as the reference point.

Companies are encouraged to provide their preference/views in the following table:

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| ZTE | Supportive on this proposal. Reference point at gNB side is more typical/easy for implementation without additional cost. And it’s also aligned with existing NR with less spec impact |
| Mediatek | We have preference for reference point at satellite for time and frequency synchronization. We think that the reference point for frequency synchronize should not be assumed to be the gNB if this proposal is agreed. It should be clarified in the proposal that * UE does not autonomously compensate time delay introduced by the feeder link.
* Signalling of the delay over the feeder link to allow UE to apply full TA pre-compensation is supported with details for further study.
* Reference point for frequency synchronization is for further discussion.
 |
| Ericsson | We support the proposal |
| Intel | We agree with the proposal with an assumption that reference point for timing at the gNB does not mean that location of gNB is indicated to the UE. |
| Apple | We prefer the reference point is set at satellite, due to the following reasons:1). Reduce the signaling overhead of common TA; 2). Provide a unified design for transparent payload and regenerate payload; 3). Simplify the design in the inter-satellite scenario.  |
| OPPO | It is not very clear to us, with this proposal, what is the assumption of the RP from UE perspective? It seems that the proposal does not clarify the assumption.  |
| InterDigital | We support the proposal. |
| Qualcomm | We support to have reference point at satellite for it’s questionable how to have the timing reference point at gNB. In addition, timing and frequency should have the same reference point. |
| Huawei | Support. The locations of RP can be configured by the network. |
| Spreadtrum | We shared the same views with Apple. |
| Samsung | We support Proposal 1-2. One option for the reference point that has not been mentioned is the center of the spot beam from the satellite. |

#### Company views on Common TA indication

The following table recaps the proposals of the companies about Indication of Common TA:

|  |  |
| --- | --- |
| **Companies** | **Proposals** |
| Thales | Proposal 14. In NTN, indication of Common TA is not required, as the satellite is considered as the reference point for TA acquisition. |
| Huawei, HiSilicon | Observation 9: For GNSS UE, common TA related parameter(s) is needed regardless of whether gNB compensates for part of RTD.Proposal 4: A common TA indication is introduced to support all the foreseen deployment scenarios.Proposal 5: GNSS UE can obtain its TA based on calculated service link delay and indicated common TA. Proposal 3: The delay compensated by the network can be a constant value instead of the feeder link RTD, considering the implementation complexity at gNB side. |
| Ericsson | Proposal 5: The gNB may broadcast parameters giving TA offset and TA drift rate that the UE should apply at PRACH transmission. The value of these parameters should be configurable. They may be used for a common TA, including propagation delay observed on the feeder link and a margin determined by the maximum allowed estimation error of the RTT.Proposal 6: The UE should apply a TA at PRACH transmission comprising the estimated service link RTT and an additional offset based on broadcast information from the network.Proposal 7: The UE applies TA equal to (N\_TA+N\_(TA,offset)+N\_(TA,common) )×T\_c, where N\_TA is UE’s estimate of the service link RTT, N\_(TA,offset) depends on band and LTE/NR coexistence, and N\_(TA,common) is an offset derived from broadcast TA offset and TA drift parameters. |
| Qualcomm Incorporated | QC proposed to amend an existing agreement as belowProposal 2: * In case of GNSS-assisted TA acquisition in RRC idle/inactive mode, the UE calculates its TA based on the following potential contributions:
	+ The User specific TA which is estimated by the UE:
		- Option 1: The User specific TA is estimated by the UE based on its GNSS acquired position together with the serving satellite ephemeris indicated by the network.
		- FFS: Details on serving satellite ephemeris indication
		- Option 2: The User specific TA  is estimated by the UE based on the GNSS acquired reference time at UE together with reference time as indicated by the network
	+ FFS: The TA margin, if needed and indicated by the network (in order to account for the TA estimation uncertainty)
* The above replaces the earlier agreement on TA acquisition in RRC idle/inactive mode.
 |
| Apple | Proposal 5: Common TA is not indicated by network and UE does not calculate its TA based on common TA. |
| InterDigital, Inc. | Proposal 2: common TA (i.e., feeder link delay) is indicated by the network for UL timing sync and is broadcast in System Information. |
| vivo | Proposal 2: An offset associated with NTN scenarios can be added to NTA in RAR to indicate initial common TA |
| CATT | Observation 3: For common TA, it is more related to feeder link delay, which is not essential for UE TA compensation.Proposal 4: UE only needs to compensate for the UE-specific differential TA, and no common TA indication is needed. |
| Samsung | Proposal 3: A gNB signals residual common TA value to UEs such that UEs can derive common TA by adding to minimum common TA value, which can be obtained by UE from the satellite ephemeris (or altitude) information. |
| Sony | Proposal 2: RAN1 should support TA compensation with configuration of the common TA.Proposal 3: RAN1 should agree the maximum functional altitude of an NTN UE and use this as the altitude of the reference point for calculating the common TA.Proposal 4: RAN1 should consider the impact of feeder link delay changes on the common TA. |
| LG Electronics | Proposal 1. Further discussion should be needed on which signals/channels to transmit additional information (e.g., Common TA, reference time, etc.) provided by gNB.Proposal 7.  At least for the case when the UE is in RRC idle mode and/or RRC inactive mode, it is reasonable to provide the additional information via semi-static signaling. In case when the UE is in RRC connected mode, it can be considered that the information is provided by dynamic signaling.Proposal 5. It can be considered that the common TA is calculated based on K\_offset in case when the UE cannot acquire the accurate TA. |
| ZTE | Proposal 3: Indication on the Common TA related parameters should be supported for a unified solution to enable both full and partial TA compensation. |
| Lenovo, Motorola Mobility | Proposal 2: Support indication from gNB to UE on the common feeder link delay. Do not support gNB broadcasting gateway position to UE.Proposal 3: For NTN based on transparent payload, support indication of an initial value and a change rate to the UE to calculate the feeder link delay. |
| ETRI | Proposal 1: In case of GNSS-assisted TA acquisition in RRC idle/inactive mode, the UE transmits PRACH with pre-compensation based on the estimated user specific TA of the service link regardless of the common TA indication of gNB for the service link. |
| CAICT | Proposal2: In case of multiple common TAs due to more than one reference points, it is suggested to build an association relationship between the common TA and SSB indexes or PRACH resources, such that the network or UEs can apply the common TA according to associated the SSB indexes or PRACH resources. |
| Panasonic | Proposal 2: Cell specific TA offset should be supported in order to allow compensation of feeder link delay to some extent.  |
| CEWiT | Proposal 1: UE will apply full TA which includes UE specific TA and common TA for initial TA adjustment.  |
| Xiaomi | Proposal 3: In order to reduce impacts to UEs, common TA compensated by network is preferred. |
| CAICT | Proposal2: In case of multiple common TAs due to more than one reference points, it is suggested to build an association relationship between the common TA and SSB indexes or PRACH resources, such that the network or UEs can apply the common TA according to associated the SSB indexes or PRACH resources.Proposal4: It is suggested to adopt common TA pre-compensation without enlarging the UE’s transmission delay, otherwise it is suggested UE can report its TA to the network in case of UE-specific TA pre-compensation. |

Clearly the discussion on common TA indication is directly linked to the above discussion on reference point positions.

For some companies the indication of Common TA is not required as the reference point for TA acquisition is on-board the satellite. Moreover, one company proposed to amend the existing agreement on TA acquisition in RRC idle/inactive mode by removing the text related to common TA.

For other companies the indication of a common TA is required to support all the foreseen deployment scenarios

There are some proposals to broadcast the common TA value on the SIB together with a timing drift rate to account for the high variation of the RTD between the gNB and the RP. To derive the actual Common TA, the UE needs to consider both broadcasted common TA value and common TA drift rate.

Lastly, to derive the Common TA, there is a proposal that NTN should not support gNB broadcasting the NTN gateway position to the UEs.

By considering the above discussion, the following initial proposal is made:

Initial proposal 1-3:

**In NTN, the Network may broadcast a common TA value and common timing drift rate:**

* **Common TA corresponds to the RTD between the Reference point and the satellite**
* **Common timing drift rate corresponds to the RTD drift between the Reference point and the satellite**

Companies are encouraged to provide their comments and views in the following table:

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| ZTE | 1. Supportive on the main bullet.

W.r.t the sub-bullets, such restrictions are fine to enable the case with RP at gateway. But with consideration on the flexibility, it can be left to gNB’s implementation.  |
| MediaTek | Support main bullet in the proposal without the sub bullets. The common TA and common timing drift rate signalling will be needed to be broadcast in all 3 options for the reference point for time synchronization to allow UE to apply full TA compensation.  |
| Ericsson | We support the proposal.In addition, we also have the following proposal, where the reference point may or may not be the gateway. It is up to network to configure. In scenarios where it is acceptable to broadcast gateway position, the network can configure the reference point to be the position of the gateway. In scenarios where it is not acceptable to broadcast gateway position, the network can configure the reference point to be the “approximate” position of the gateway.Proposal: Support broadcasting a reference point of the feeder link and UE autonomous determination of the time and frequency offset of both the service link and the link between the satellite and the reference point of the feeder link. |
| Intel | OK with the proposal as assumption for RAN1 work, however, in the implementation it may be the case that common RTD drift is handled at the gNB by shifting UL timing. |
| Apple | Depending on the results of Proposal 1-2, we may not need common TA to be broadcast. Similarly, if the reference point is selected at satellite, then the common timing drift rate corresponding to the RTD drift between the reference point and the satellite does not need to be broadcast.  |
| OPPO | Support the proposal |
| InterDigital | Support the proposal |
| Qualcomm | Network should have the flexibility of broadcasting such a “common delay” or not. It should be handled by scheduling offset not as part of TA. Broadcast a common drifting rate of feederlink seem to be excessive. This would mean two drift rates are to be broadcasted: one for the service link (for UEs without GNSS in the future) and one for the whole or the feederlink. The benefit of having a reference point other than the satellite is not clear given that feederlink can be handled by the gNB in the form of timing relationship offset. We propose the following:**Proposal 1: Impacts of feeder link delay is to be handled by the gNB in the form of timing relationship offset(s).** |
| Huawei | Support |
| Samsung | We support Proposal 1-3. |

### Issue#1-2: The need and the indication of TA margin

#### Background

During the first acquisition of its UE-specific TA, the UE can either underestimate or overestimate the TA. i.e. the TA estimation error ε~[-$ TA\_{error}$,$ TA\_{error}$], where $TA\_{error}$ represents the maximum estimation error made by the UE.

In case of overestimation, the PRACH preamble will be received at gNB side in advance w.r.t. the PRACH occasion leading to unwanted interference with previous slot or PRACH occasion as shown in Figure 4

From RAN1#102e the support and need for TA margin indication is FFS.

W.r.t the TA margin the following open issues need to be discussed/solved:

* The need of TA\_margin to account for the TA estimation uncertainty
* Indication of the TA\_margin to the UE
* The value of TA\_margin



Figure 4 TA over-estimation by the UE



Figure 5 Pre-compensation of TA using TA-margin

To solve the issues above and based on the proposals submitted to RAN1#103e different solutions can be considered:

* **Solution#1-2-1**: No need for TA margin

TA does not include a margin for maximum TA estimation error. A bipolar TA command is needed in msg2. i.e support negative TA adjusting in RAR. But solution#1 does not solve the issue. Indeed, the TAC in RAR with negative value can correct the overestimated TA but it does not mitigate the interference issue mentioned above. If no TA margin is applied by the UE for its TA, the received PRACH timing error at gNB side ∈ [-$TA\_{error}$, +$ TA\_{error}$]

* **Solution#1-2-2**: TA includes TA margin but there is no need for TA margin indication

 The UE can derive this value by taking into account the maximum TA uncertainty ($TA\_{error}$).

The UE applies TA = $\left(N\_{TA}+N\_{TA, offset}+ N\_{TA,common}\right)×T\_{c}$ with $N\_{TA}= Estimated N\_{TA}-N\_{TA margin}$

Where NTA is UE’s estimate of TA minus a TA margin , $N\_{TA common} $corresponds to the Common TA and $N\_{TA Offset}$ [TS 38.213] depends on band and LTE/NR coexistence .

The TA margin is used to delay PRACH transmission, i.e. the received PRACH timing error at gNB side ∈ [-2$ TA\_{error}$,,0]

* **Solution#1-2-3**: TA includes TA margin, TA margin is indicated in SIB

The UE applies TA = $\left(N\_{TA}+N\_{TA, offset}+ N\_{TA,common}-N\_{TA margin}\right)×T\_{c}$

Where NTA,margin is a configurable parameter used as a margin to handle the UE’s estimation uncertainty.

With solution#3, the received PRACH timing error at gNB side ∈ [-2$ TA\_{error}$,0]

* **Solution#1-2-4**: TA margin is included within the Common TA. i.e.; Common TA configuration absorbs the maximum TA uncertainty , this could include any factors (including uncertainty on common TA indicated value) that the network may deem necessary.

In this case, the UE applies TA = $\left(N\_{TA}+N\_{TA, offset}+ N\_{TA,common}\right)×T\_{c}$

And the received PRACH timing error at gNB side ∈ [-2$ TA\_{error}$,,0]

Note that if the TA includes a margin for maximum TA estimation error (**Solution#1-1-2, #1-1-3 and #1-1-4)**, unipolar TA command in Msg2 is sufficient, i.e., bipolar TA command is not needed in Msg2.

* **TA margin value:**

Regarding the value to be considered for TA-margin in the cell, one must take into account the worst case UEs estimation accuracy. This is related to the UL time synchronization requirement that will be discussed in section 4.2

The following table is the recap of proposals from different companies:

|  |  |
| --- | --- |
| **Companies** | **Proposals**  |
| CATT | Observation 6: TA margin is needed in RRC idle/inactive mode in case of initial ephemeris information is not very accurate, and the maximum TA margin is 1/2 CP.Proposal 8: It is necessary to introduce a margin in the initial TA compensation to make up for TA estimation uncertainty in the initial access stage.Proposal 9: TA margin should not be used in RRC connected mode.  |
| Huawei, HiSilicon | Observation 10: Potential satellite position error may lead to inter-symbol interference (ISI) during preamble transmission.Proposal 6: Broadcast potential satellite position error to UE to avoid ISI. |
| MediaTek, Eutelsat | Proposal 4: for UE with Autonomous acquisition of the TA, UE shall use TA\_offset of half the cyclic prefix of PRACH preamble when applying the TA pre-compensation. |
| CMCC | Proposal 5: Further study TA refining at UE side, where User specific TA = raw TA of UE actual estimated – maximum UE’s estimation uncertainty.Proposal 6: There is no need to indicate TA margin by network. |
| OPPO | Observation 5: If RP option 2 or option 3 is adopted, TA margin can be absorbed in the signaled common TA. Observation 6: If RP option 1 is adopted, the gNB shall handle the feeder link TA anyway, the TA margin should be handled by the network. Proposal 3: decide RP option first before deciding the TA margin. |
| LG Electronics | Proposal 2. Within pre-defined set of TA offsets, the TA offset can be provided by gNB via higher layer signing (e.g., SIB or dedicated RRC signaling).  The TA offset can be independently corresponding to different ROs (or RO groups) |
| ZTE | Observation 3: When the basic accuracy requirements for autonomous pre-compensation is satisfied, the interference caused by TA uncertainty is negligible.Proposal 9: No need to introduce the TA margin for pre-compensation in the initial access stage. |
| Lenovo, Motorola Mobility | Proposal 4: There is no necessity to indicate the margin value, and it can be absorbed with larger initial value for feeder link delay indication. |
| ETRI | Proposal 2: After PRACH transmission, the UE starts a ra-ResponseWindow no earlier than ra-Offset after the last symbol of the PRACH occasion corresponding to the PRACH transmission. ra-Offset can be composed of the estimated user specific TA for the service link and common TA for the feeder link and TA margin. In this case, the common TA for the RTT of the feederlink can be broadcast by gNB. In addition, the ra-ResponseWindow can be started earlier by TA margin to reflect the estimation error for the estimated user specific TA. The TA margin may be broadcast or may be set in the UE. |
| Asia Pacific Telecom | Proposal 1 : The TA margin shall consider maximum timing advance compensated during initial access for different SCS. |
| Thales | Proposal 15. In NTN, TA margin indication by the network is needed. |
| Ericsson | Proposal 5: The gNB may broadcast parameters giving TA offset and TA drift rate that the UE should apply at PRACH transmission. The value of these parameters should be configurable. They may be used for a common TA, including propagation delay observed on the feeder link and a margin determined by the maximum allowed estimation error of the RTT. |

#### Company views

It is clear from the above proposals that the majority of companies agree on the necessity of the TA\_marin. But further discussion about how it should be indicated to the UE will be needed.

For some companies, the network shall indicate the TA-margin value whereas, for others, the TA margin can be absorbed in the signalled common TA value.

Furthermore, a company observed that when the basic accuracy requirements for autonomous pre-compensation is satisfied, the interference caused by TA uncertainty is negligible and therefore there is no need to introduce the TA margin.

The following initial proposal aims to anchor a baseline solution to account for the TA estimation uncertainty when applying the TA pre-compensation in initial access. The value of the TA\_margin can be further discussed when the required accuracy of UE pre-compensation is defined:

Initial proposal 1-4:

To account for TA estimation uncertainty when applying the TA pre-compensation in initial access, down-select one solution (Solution#1-2-1 to #1-2-4) as baseline:

|  |  |  |  |
| --- | --- | --- | --- |
| **Company** | **First preference** | **Second preference** | **Unacceptable solution(s)** |
| ZTE | Solution#1-2-1 (With well-defined requirements, the performance of newly introduced action, i.e., pre-compensation should be guaranteed. | Solution#1-2-4 (As mentioned for Initial proposal 1-3, it’s also beneficial for gNB to determine the value with some adjustment if it’s considered to be necessary at gNB side, e.g., assumption on the poor UE capability) | Solution#1-2-3 (Firstly, the inaccuracy pre-compensation should be avoided in case of solution develop. Otherwise, it will be contradict to the conclusion in SI. Then, if there are some corner case due to the UE implementation, it can also be handled by the “adjustment” for other parameter as defined in solution#1-2-4). |
| MediaTek | Solution# 1-2-4 (it is reasonable to assume small UE autonomous TA acquisition error over the access link and TA margin is included within the Common TA. i.e.; Common TA configuration absorbs the maximum TA uncertainty. | Solution#1-2-3 (but we think this could be specified and no need to broadcast the TA margin) | Solution#1-2-1 (a TA margin seems needed at least from RAN1 viewpoint depending on requirements for UE-autonomous TA error, RACH preamble format, and common TA error, common timing drift rate error. This could be left to RAN4 discussions) |
| Ericsson | Solution#1-2-4 | Solution#1-2-2, #1-2-3 | Solution#1-2-1 |
| Intel | Solution#1-2-2 | Solution#1-2-1 | Solution#1-2-3 |
| Apple | Option 1-2-1 | Option 1-2-2 | Option 1-2-3, Option 1-2-4. Since $TA\_{error}$ represents the maximum estimation error made by the UE, it is unclear how network could obtain TA margin from $TA\_{error}$.  |
| OPPO | Solution 1-2-3/1-2-4 if RP is on NTN satellite;Solution 1-2-1/1-2-2, if RP is not on NTN satelliteSolution 1-2-3 and 1-2-4 are in the same flavour and is indicated in SIB.Solution 1-2-1 and 1-2-2 are up to implementation: UE implementation (1-2-2) or gNB implementation (1-2-1). |  |  |
| Huawei | Solution#1-2-3 | Solution#1-2-4 | Solution#1-2-1 |
| Samsung | Solution#1-2-1There is no enough motivation to introduce TA margin for NTN. After pre-compensation and applying TA at the UE side, then the remaining thing can be done by network. | Solution#1-2-4 |  |

### Issue#1-3: TA command in RAR

#### Background

With concern on the accuracy on the self-calculated TA value at the UE side, both TA\_Margin (discussed above) and TA command (TAC) in the Random Access Response can be used for TA refinement in initial access:

* the TA\_margin can be used by the UE for pre-adjustment/pre-refinement of the autonomously acquired initial TA, even before mgs1 is transmitted
* and the TAC in RAR will be indicated by the Network for post-adjustment/post-refinement of the autonomously acquired initial TA.

W.r.t the TAC in RAR in NTN, there are essentially two issues that need to be discussed:

* Is there a necessity to extend the range of TAC in RAR?
* Shall TAC in RAR support negative values? i.e., bipolar TAC

In NR initial access, gNB derives the timing advance by detecting the received random access preamble and sends the value to UE via the Timing Advance Command field in MAC RAR. This field contains a 12-bit field of timing advance command. The TA range is recalled below:

|  |
| --- |
| *In case of random access response, a timing advance command [TS 38.321], , for a TAG indicates  values by index values of  = 0, 1, 2, ..., 3846, where an amount of the time alignment for the TAG with SCS of  kHz is . is defined in [TS 38.211] and is relative to the SCS of the first uplink transmission from the UE after the reception of the random access response* |

The maximum TA values depending on the numerology used on the UL after the reception of the random access response are presented in the following table:

Tableau 1 Maximal TA value depending on numerology

|  |  |
| --- | --- |
| **SCS** | **Max. Timing Advance**  |
| **15 kHz** | 2 ms |
| **30 kHz** | 1 ms |
| **60 kHz** | 0.5 ms |
| **120 kHz** | 0.25 ms |

In NTN, with large RTD and high differential delay within a cell and without TA pre-compensation, the TA range in RAR may not be enough and some changes on the RAR message will be needed.

But, with the self-calculated TA in NTN, the RAR field dedicated to TA should be used by the gNB to indicate the residual error on TA acquired autonomously by the UE.

Depending on the accuracy of autonomous TA, the existing TA range in RAR might be enough and the existing 12-bit field can be reused without any impact on the specifications. For example, if the requirement on the maximum UE’s estimation error on self-calculated TA is defined so that $TA\_{error}<250 $μs, which corresponds to the maximum TA value that can be encoded within the 12-bit field in case of SCS = 120kHz, then the existing Timing Advance Command field in MAC RAR does not need to be extended.

Furthermore, w.r.t to the bipolarity of the TA command, if the TA includes a margin for maximum TA estimation error (Solution#1-2-2, #1-2-3 and #1-2-4, as discussed in previous section), unipolar TA command in msg2 is sufficient, i.e., bipolar TA command is not needed in msg2.

The proposals and observations about the TA command in RAR are summarized in the following table:

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| Ericsson | Observation 3: If the TA includes a margin for maximum TA estimation error, unipolar TA command in Msg2 is sufficient, i.e., bipolar TA command is not needed in Msg2. |
| Apple | Proposal 6: If a UE autonomously acquires accurate UE specific TA and applies it in its PRACH transmission, then the TA command range in RAR does not need to be extended. Otherwise, study whether the TA command range in RAR needs to be extended. |
| CATT | Proposal 5: Reusing bit width of the TA command in NR is supported for NTN WI. |
| CMCC | Proposal 4: Support negative TA adjusting in RAR.Proposal 7***:***$ N\_{TA}$ for PRACH is determined as the UE calculated TA.Proposal 8:Two equivalent alternatives can be considered to update $N\_{TA}$ in case of random access response:* Alt 1: $N\_{TA}=N\_{TA}^{PRACH}+T\_{A}∙S\_{0}∙16∙{64}/{2^{μ}}$
* Alt 2: $N\_{TA\\_new}=N\_{TA\\_old}+T\_{A}∙S\_{0}∙16∙{64}/{2^{μ}}$

where $T\_{A}$ denotes TA command in RAR with negative value supported, and $S\_{0}$ denotes scaling factor to extending TA indication range. |
| LG Electronics | Proposal 6. Regarding TA command in RAR, support enhancement approaches to cover large cell coverage. Increase the step size of TA command field in RAR Support multiple reference points |
| Lenovo, Motorola Mobility | Proposal 1: There is no necessity to extend the range of bits of TA command in RAR and MAC CE command. |
| CAICT | Proposal3: In case of common pre-compensation, it is suggested to extend the TA indication value range in RAR by using more bits for TA indication in RAR, or implicitly by some modifications in the RAR detection procedure |

#### Company views

Two issues related to TA command (TAC) in RAR were discussed by some companies: the need of extended TAC range in RAR and support of negative/positive value of TAC in RAR.

For some companies, there is no need to extend the TA value range in msg2 with UE determining autonomously its TA based on its GNSS implementation. The need for negative TA in msg2 can be avoided by adding the TA\_margin in the autonomous TA applied before msg1 transmission.

There are few proposals to introduce enhancements to support larger cell coverage by increasing the step size of TA command field in RAR and to support negative TA adjustment in RAR.

To move forward, it is clear that with the self-calculated TA, the range of the timing advance command in MAC RAR message is depending on the associated accuracy of UE timing pre-compensation. To limit the impact on the specification, a target design would be to define the requirement on UL time pre-compensation so that the existing 12-bit field in msg2 can be reused without any extension. And the self-calculated TA shall include a margin for maximum TA estimation error so that the bipolar TA command is not needed in Msg2. i.e., only positive value of TAC are permitted.

Therefore, the following initial proposal is made

Initial proposal 1-5:

With the self-calculated TA in NTN, the initial Timing Advance Command range in msg2 shall not be extended.

TA shall include a margin for maximum TA estimation error so that the bipolar TA command is not needed in msg2 i.e. only positive value of TA command are permitted.

Companies are encouraged to provide their comments and views in the following table:

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| ZTE | This proposal is coupled with the discussion for Initial proposal 1-4. It can be taken later. But in general, it will be better to ensure the accuracy for pre-compensation with less spec impact during whole transmission regardless initial or connected mode. |
| MediaTek | We share same view as ZTE. This proposal can be postponed. First discuss proposal 1-4. With solution for TA margin in options 1-2-4 or 1-2-3 in proposal 1-4, we see no need for bipolar TA command. |
| Ericsson | We support the proposal. |
| Intel | OK with the proposal |
| Apple | If Option 1-2-1 in Proposal 1-4 is adopted, then the TA range may include negative values.If Option 1-2-2 in Proposal 1-4 is adopted, then the TA range does not need to be extended.  |
| OPPO | Reasonable to postpone  |
| InterDigital | Support the proposal |
| Qualcomm | Although the TA range in msg2 is believed enough for rel-17, forward compatibility should be considered. In the future, UEs without GNSS may be supported. |
| Huawei | Support  |
| Spreadtrum | Support the proposal. |
| Samsung  | Similar to ZTE, Mediatek, it is better to discuss later after discussion on Proposal 1-4. Depending on the cell (beam) size, we can consider and discuss whether/how range is needed to be extended. |

## Issue#2: TA update in connected mode

### Background

On TA maintenance, the following recommendation was made in Feature Lead summary at RAN1#**102e** based on company proposals and comments:

**RAN1 to further investigate the following enhancement on the maintenance phase of the timing advance:**

* **Enable autonomous TA update at UE side, taking into account:**
	+ **Common TA drift rate**
		- **Details on Common TA drift rate indication are FFS**
	+ **Self-estimated UE specific TA drift rate**
		- **Details on UE specific TA drift rate derivation are FFS**

In NTN, the radial velocity between the satellite and UE location can reach significant values especially in NGSO scenarios. As a consequence, the propagation delay changes quickly. In case of LEO transparent payload at 600Km for example the maximum NTN GW-UE delay variation as seen by the UE can be up to +/- 40 µs/sec.

In these conditions, the maintenance procedure based on MAC-CE may become rather challenging because the user-specific timing adjustment MAC-CE commands must be sent very often leading to critical DL signaling overhead.

For example, in case of a LEO scenario at 1200Km, for one-way delay of 20.89 ms, a timing control command sent by the gNB that is accurate at the time of its transmission can be outdated by 0.83 µs at the time of its arrival, which is larger than the CP duration for 120 kHz SCS, that is 0.69 µs

The following solutions were identified in the different contributions:

**Open loop method**: This solution has been already proposed during the previous SI. It consists in enhancing UE capabilities related to timing adjustment. In particular, it was foreseen to enable autonomous TA update at UE side based on the RTD (w.r.t the satellite) variation. This method relies on GNSS acquisition in RRC Connected mode this may need (or not) a GNSS measurement gaps (refer to 3.1).

With this solution the UE can autonomously adjust the TA based on the estimated propagation delay based on ephemeris and UE geo-location (.Solution #1: Open loop only) In complementary to the open loop TA adjustment, the legacy close-loop by MAC-CE Command can also be reused (.Solution #2: Combined Open and closed loop). Therefore, two solutions maybe considered:

* **Solution #2-1: Open loop only**

$$N\_{TA\\_new}=N\_{TA\\_old}+(T\_{d\\_new}-T\_{d\\_old})$$

* **Solution #2-2: Combined Open and closed loop**

$$N\_{TA\\_new}=N\_{TA\\_old}+(T\_{d\\_new}-T\_{d\\_old})+\left(T\_{A}-31\right).16.64/2^{μ}$$

Where $∆T\_{d}=(T\_{d\\_new}-T\_{d\\_old})$ is the propagation delay variation self-estimated by the UE and (TA-31) is the received TA command. The TA adjustment NTA is indicated in a TAC with 6 bits in MAC CE, where TA={0,1,2,…,63}.

Note that with Solution #2, the open loop is combined to the legacy control loop, how to avoid uncontrolled behavior between the two mechanisms shall be further discussed.

**Closed loop method**: keep relying on the legacy timing close control loop but to introduce a time drift correction indicated by the gNB. The drift indications shall be considered by the UE to update its TA before each new transmission. This way the signaling generated by the timing-advance commands may be reduced. Whether this drift is user specific or cell specific can be further discussed. Based on this principle, the gNB has full control over the timing adjustment behavior at UE side.

* **Solution #2-3: Closed loop only**

$$N\_{TA\\_new}=N\_{TA\\_old}+DriftRate∙∆t+\left(T\_{A}-31\right).16.64/2^{μ}$$

Where $DriftRate$ is the timing drift rate, $∆t$ is the time interval from last timing adjustment indication. And (TA-31) is the received TA command. The TA adjustment NTA is indicated in a TAC with 6 bits in MAC CE, where TA={0,1,2,…,63}.

FFS: Details on Common TA drift rate indication and details on UE specific TA drift rate derivation

When it comes to DriftRate indication: different options need to be discussed:

Another open issue to be tackled is the outdated TA value Command, in deed, TAC value may become outdated when it arrived at the UE in LEO.

The following is proposed by the companies w.r.t to TA update in connected mode:

|  |  |
| --- | --- |
| **Companies** | **Proposals** |
| MediaTek, Eutelsat | Observation 6: Autonomous adjustment of the TA before UL transmission by the UE avoids need for frequent TA update due to satellite time drift, which significantly reduces signalling overhead in connected mode.Proposal 5: The connected UE can autonomously adjust the TA to compensate the impact of the timing drift within specified maximum transmission timing error ±Te = ± 0.39 μs corresponding to a position error of ±117 m. |
| Qualcomm Incorporated | Proposal 4: In NTN, both UE autonomous and closed-loop time control are supported in connected mode. |
| vivo | Observation 3: The gNB needs to frequently send MAC CE to update common TA in NTN, which causes heavy signalling overhead.Proposal 3: Support to extend TA indication range in MAC CE for common TA adjustment in NTN. |
| CEWiT | Proposal 3: gNB should provide the set of instructions to refine the TA estimated by UE. |
| CATT | Observation 4: In LEO scenario, gNB has to frequently send TA commands to the UE if merely based on closed-loop TA adjustment, which will introduce huge signaling overhead.Observation 5: Open-loop TA compensation is necessary to relieve TA indication burden.Proposal 6: Both open-loop and close-loop methods should be supported for TA maintenance in UL transmission of NTN.Proposal 7: Supporting TA calculation and update autonomously based on GNSS and ephemeris information when UE being in connected mode is preferred.Proposal 10: UE compensates finer timing variation of symbol and sample point level of service link, and the network compensates that of feeder link. |
| OPPO | Observation 7: The legacy TN TA maintenance after RRC connection might suffer from unnecessary signalling overhead and it can be reduced by relying on open-loop TA maintenance.Proposal 4: NTN system should support open-loop TA maintenance by relying on UE autonomous TA adjustment. |
| Thales | Observation 9. In NGSO scenarios, the timing adjustment procedure may become challenging because the user-specific timing adjustment commands must be sent very often leading to critical DL signaling overhead.Proposal 16. RAN1 to investigate whether enabling GNSS-assisted TA update at UE side is a suitable solution for TA maintenance in NTN.Proposal 17. RAN1 to investigate whether time drift indications (assuming the UE can update its TA based on these indications) is a suitable solution for TA maintenance in NTN. |
| Ericsson  | Proposal 8: A UE supporting autonomous time correction for the service link in RRC\_CONNECTED state should apply a TA at UL transmission comprising the estimated service link RTT and an additional offset based on broadcast information from the network.Proposal 9: UEs are allowed to autonomously adjust its TA to seamlessly continue its RRC connection after the service link switch from one satellite to another.Proposal 15 NR NTN UE shall be capable of using an acquired GNSS position and satellite ephemeris to calculate pre-compensation of timing and frequency offset and apply the calculated values accordingly in RRC\_IDLE, RRC\_INACTIVE, and RRC\_CONNECTED states.Proposal 16 It is up to RAN4 to determine the need for supporting GNSS measurement gaps in RRC\_CONNECTED state.. |
| Apple | Proposal 7: UE autonomously updates its timing advance value based on timing drift rate. |
| Spreadtrum Communications | Proposal 4: Self-estimated UE specific TA drift rate should be supported for TA Maintenance procedure. |
| Xiaomi | Proposal 4: Open and closed loop mechanisms for TA adjustment should be supported in NTN.Proposal 5: TA Maintenance mechanism based DCI should be considered. |
| Huawei, HiSilicon | Observation 11: Timing drift rate is needed considering accuracy and timing tracking of feeder link.Proposal 7: The timing drift rate is indicated by the gNB.Observation 12: The TA value may become outdated when it arrived at the UE in LEO based NTN.Proposal 8: The network should pre-correct the indicated TA with the drifted parts when sending out the TA command. |
| Samsung | Proposal 5: The gNB signals common TA drift rate to enable autonomous TA update at UE.Proposal 6: The gNB can jointly signal common TA drift rate and Doppler shift such as the UE derives Doppler shift from common TA drift rate signaled by gNB or vice versa. |
| Sony | Observation 4: Inter symbol interference will be caused by out of alignment TA due to the movement of the satellite.Observation 5: Applying timing drift rate TA compensation can reduce the inter symbol interference.Proposal 5: RAN1 should support the signalling of TA drift rate information to the UEs in a beam specific manner. |
| ETRI | Proposal 3: For TA maintenance, the gNB can transmit a timing drift rate to the UE. The timing drift rate for the service link can be a UE-specific parameter. The UE can periodically perform the autonomous TA update according to the indication of the gNB. In the case of autonomous TA update of the UE, the gNB can indicate the reference time for TAold to the UE for TA ajustment. |

### Company views

All the 3 solutions mentioned above have been discussed by the different companies. Even though in some contributions there is some confusion between solution#1 and solution#2: It is not clear if the proposed open loop solution is referring to solution #1-Open loop only or solution #2-Combined Open and closed loop

Furthermore, a company is proposing to extend TA indication range in MAC CE for common TA adjustment in NTN.

And another company proposed to consider TA Maintenance mechanism based DCI.

There are few proposals regarding the drift rate indication:

a company is proposing tosupport the signalling of TA drift rate information to the UEs in a beam specific manner

For TA maintenance, the gNB can transmit a timing drift rate to the UE. The timing drift rate for the service link can be a UE-specific parameter

The gNB signals common TA drift rate to enable autonomous TA update at UE

The connected UE can autonomously adjust the TA to compensate the impact of the timing drift within specified maximum transmission timing error ±Te = ± 0.39 μs

Initial proposal 2-1:

For TA update in connected mode, down-select one solution as baseline:

* **Solution #2-1: Open loop only**
* **Solution #2-2: Combined Open and closed loop**
* **Solution #2-3: Closed loop only**

|  |  |  |  |
| --- | --- | --- | --- |
| **Company** | **First preference** | **Second preference** | **Unacceptable solution(s)** |
| ZTE | Solution#2-2 | Solution #2-3 (at least the closed loop mechanism can be used to ensure the baseline performance) |  |
| MediaTek | Solution#2-1 | Solution#2-2 (this seems reasonable that closed-loop can still be used, as autonomous TA error requirement for connected mode needs further discussion) | Solution #2-3 (assuming the baseline performance would require to heavily initiate the UL timing alignment procedure with RACH order) |
| Ericsson | Solution #2-2 |  | #2-1 and #2-3 |
| Intel | Solution#2-2 | Solution#2-1 |  |
| Apple | Solution 2-3 |  | Solution 2-1 and solution 2-2: In both options, UE may need to calculate the UE specific TA based on UE location and ephemeris information, before every UL transmission. |
| OPPO | Solution 2-2 |  | Solution 2-1 (it is not meaningful to preclude R15 functionality)Solution 2-3: we see serious issue if only relying on closed-loop |
| InterDigital | Solution 2-2 | Solution 2-1 |  |
| Qualcomm | Solution 2-2 |  |  |
| Huawei | Solution #2-2: the benefits of this solution is clear, it solve the issues of accuracy and overhead of solution #2-1 and solution #2-3, respectively |  | Solution #2-1 and #2-3 |
| Spreadtrum | Solution 2-2 | Solution 2-1 |  |
| Samsung | Solution #2-3 (closed loop only) | Solution #2-2 (combined open and closed loop) |  |

# UL frequency synchronization in NTN

* 1. Issue#3: UL Frequency adjustment for UE in RRC idle/inactive mode
		1. Background

During the last RAN1 meeting #102e, the following agreement was made.

Agreement:

In Rel-17 NR NTN, at least support UE which can derive based on its GNSS implementation one or more of:

* its position
* a reference time and frequency

And, based on one or more of these elements together with additional information (e.g., serving satellite ephemeris or timestamp) signalled by the network, can compute timing and frequency, and apply timing advance and frequency adjustment at least for UE in RRC idle/inactive mode.

* FFS: Details on additional information signalled from network

Then, it is up to RAN1 to identify the solutions to derive the frequency adjustments aforementioned as well as the network indications required to assist the UE in the process.

Solution #3-1: Autonomous frequency adjustment based on the GNSS-acquired UE position and the serving satellite ephemeris

One of the solution consists in enabling UE autonomous frequency compensation of the frequency error introduced by the Doppler effects experienced on the service uplink. The corresponding frequency adjustment can be derived by the UE based on the following elements:

* The GNSS-acquired UE position
* The serving satellite ephemeris
* The UE internal clock driven by the received DL signals

These elements can be used to derive the radial velocity between the UE and the satellite. Finally, the radial velocity is used to calculate the total Doppler (in ppm) experienced on the service links. This compensation shall be applied by the UE before PRACH transmissions.

The majority of the companies supported and explored this solution:

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| Thales | Proposal 2. The usage of the UE GNSS implementation with the sole purpose of deriving its position shall be considered as baseline for Release 17 NTN.Proposal 18. For UL transmissions, both Doppler shifts estimation and pre-compensation frequency adjustment should be conducted at the UE side.Proposal 19. NR NTN UE shall be capable of using an acquired GNSS position and satellite ephemeris to calculate pre-compensation of frequency offset and apply the calculated values accordingly.Observation 10. In case UEs cannot compensate for Doppler shifts experienced on both DL and UL service links, it is expected that UL frequency misalignments will be observed between the UL transmissions received at the gNB leading to critical performance losses. |
| Huawei | Proposal 1: For GNSS UE, UE-specific UL frequency compensation is conducted at the UE side.This frequency offset can be determined based on DL reference signals, UE location and satellite ephemeris |
| Vivo | Proposal 4: For UL frequency synchronization, UE can estimate and pre-compensate the doppler shifts.For UL frequency synchronization, if UE knows its location and satellite ephemeris information, the UL Doppler shift caused by satellite movement can be estimated and pre-compensated at UE side, which significantly reduces signalling overhead. |
| Apple | Proposal 8: UE pre-compensates the frequency offset in its UL transmissions, based on its calculated or indicated frequency offset. |
| MediaTek, Eutelsat | Proposal 6: The connected UE can autonomously predict and pre-compensate the Doppler shift drift before transmitting on the UL. |
| ZTE | Observation 2: UE is able to estimate UL Doppler through geometric formulas based on position and mobility information of UE and satellite. |
| Ericsson | Proposal 15 NR NTN UE shall be capable of using an acquired GNSS position and satellite ephemeris to calculate pre-compensation of timing and frequency offset and apply the calculated values accordingly in RRC\_IDLE, RRC\_INACTIVE, and RRC\_CONNECTED states. |

Solution #3-2: Autonomous frequency adjustment based on GNSS-acquired reference time/frequency

Another solution consists in enabling UE autonomous frequency compensation of the frequency error introduced on the service uplink but the corresponding frequency adjustment shall be derived by the UE at least based on a GNSS-acquired reference frequency.

With such solution, the need for additional elements such as :

• The GNSS-acquired UE position

• The serving satellite ephemeris

• The received DL signals

varies depending on the contributions:

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| Thales | Proposal 6. RAN1 to further clarify how GNSS-acquired reference time and frequency can assist UL synchronization and to identify the potential drawbacks of such approach (e.g. hardware constraints on the chipset architecture, power consumption, etc.)Observation 4. The acquisition of time and frequency references based on GNSS signals and their distribution towards the 5G chipset requires a strong level of integration between the 5G chipset and the GNSS receiver.Observation 5. The maintenance of GNSS time or frequency reference may result in high power consumption which can be much more significant than the consumption associated with the acquisition of a simple position |
| Huawei | For UE with GNSS capability, the local oscillator frequency from UE can be precisely corrected by GNSS signal, the remaining frequency offset at the gNB will be reduced to around 2‧FgNB, the value of which is negligible. |
| ZTE | Proposal 5: With reference time and frequency, for Option-2, one of following two approaches can be supported to UE for UL Doppler estimation: DL reference signal timing drift |
| Qualcomm | Autonomous Frequency Control: there are two options depending on if UE synchronized on GNSS.* Option 2: In this option, UL transmission clock is synchronized to GNSS. UE estimates the UL Doppler based on its own geolocation and ephemeris and applies the pre-compensation accordingly (i.e., UL clock is not driven by DL received signal).

Observation 3: There could be an UL frequency bias between Ues that are frequency synchronized with GNSS and Ues that are frequency synchronized using DL frequency. |
| Nokia | Through the detection of PSS/SSS in the DL, the UE can estimate the UE-specific frequency offset. For transmission of PRACH preamble in the UL, the UE should precompensate using this value to improve PRACH detection on the network side. Proposal 8: The UE-specific frequency offset estimated from PSS/SSS during nitial access is used to pre-compensate the PRACH transmission in the UL. |

### Companies views

The majority of the companies supported and explored this solution#3-1. Based on companies proposals the following initial proposal is made:

**Initial proposal 3-1:**

**NR NTN UE in RRC\_IDLE and RRC\_INACTIVE states shall be capable of using an acquired GNSS position and satellite ephemeris to calculate frequency pre-compensation to counter shift the Doppler experienced on the service link.**

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| ZTE | Supportive as the package for TA compensation based on the geometric calculation.W.r.t the solution#3-2, it can be taken together with the FFS part in Initial proposal 1-1 |
| MediaTek | Support the proposal.  |
| Ericsson | We support the proposal.  |
| Intel | Support the proposal 3-1 |
| Apple | Support the proposal |
| OPPO | OK |
| InterDigital | Support the proposal |
| Qualcomm | Support |
| Huawei | Support solution#3-1 as the baseline |
| Spreadtrum | Support the proposal |
| Samsung | Support in principle. We would like to clarify this proposal does not mean that RRC\_Idle/Inactive UEs keeps tracking the frequency offset. |

Few companies [Huawei, Qualcomm, ZTE] mentioned solution#3-2 as a valid option.

However, it has been observed [Thales] that this approach could have major drawbacks w.r.t. solution#3-1 such as :

* Strong level of integration between the 5G chipset and the UE GNSS receiver.
* Higher power consumption

Moreover, the compatibility between UEs implementing the solution#3-1 and #3-2 within the same cell has been questioned [Qualcomm].

**FL recommendation 3-2:**

**Companies are invited to provide feedback on whether solution #3-2 is a valid option. If yes, the following issues shall be addressed:**

* **What are the benefits of solution #3-2 if solution #3-1 is already supported ?**
* **How the constraints regarding the power consumption and the level of integration can be lifted ?**
* **How to avoid UL frequency bias between UEs implementing solution #3-1 and the ones implementing solution #3-2 ?**

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| ZTE | For the solution#3-2, it can be used to estimate the overall impact for transmission instead of only “LoS” assumption for solution#3-1. W.r.t the integration and power consumption, it’s really up the internal UE oscillator. With better performance for its own clock, the consumption can be minimized.The UL bias is up to the accuracy of estimation and compensation. It can be alleviated once good performance is ensured for both options. |
| MediaTek | We think solution #3-2 is not a valid option. As mentioned in issue #1-1 proposal 1-2, it does not require specification as already supported in Rel-16 SIB9. It is up to device implementation and RAN4 to define requirements and testing for this methodSolution #3-2 based on the timestamp method has significant drawbacks:* It requires the UE to read the SIB several times per second, which increases power consumption.
* It requires a new implementation in the UE to use GNSS to synchronize its internal clock using the 1 PPS pulse from GNSS receiver and maintain same timing in device as in gNB based on GNSS. This is needed to also determine the satellite Doppler shift for UE pre-compensation. We do not believe it is practically feasible to avoid this level of integration between GNSS module and NR module in the device in NTN. The DL RS cannot be used as it is not possible in the device to discriminate between the crystal error and the satellite Doppler shift.
* It requires significant effort for HW implementation and algorithm development for DL synchronization and AFC tracking. Assuming same device used for terrestrial and NTN, there will be compatibility issues with device needing to synchronize its internal clock using DL signals (scenario of indoor UEs) and device needing to synchronize its internal clock using DL signals for NTN. This has impact on specifications of procedures and testing.
* It requires high level of optimization, especially the accuracy of the method could be questionable in case of low C/N conditions when decoding of the SIB carrying the timestamp may occasionally fail and exact GNSS time reference cannot be guaranteed due to inaccuracy of internal clock in the device. The satellite Doppler shift estimation in the device may be quite challenging.
 |
| Ericsson | Solution #3-2 is not needed. |
| Intel | In our view the questions above are more related to implementation rather than standard. In our view for RAN1 work solution 3-1 can be prioritized while proposals which assume solution 3-2 can be submitted by companies. |
| OPPO | Agree with Intel |
| Qualcomm | Solution 3-2 should be deprioritized. |
| Huawei | The selection of solution #3-1 and #3-2 can up to UE implementation according to the hardware capability. Even with a single solution, UL frequency bias between UEs exists. |
| Samsung | We think, Solution#3-1 provides a better and exact solution. So, Solution#3-2 is not needed. |

### Issue #3-1 Reference point for UL frequency synchronization

#### Background

During the last e-meeting, the following FL recommendation was made:

* RAN1 to further clarify which reference frequency shall be considered by the UE when applying frequency adjustment.

It shall be further clarify what is the reference point to be considered by the UE when adjusting its UL TX frequency. In others words, it shall be clarified where in the system the UEs transmissions are expected to be frequency aligned.

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| Thales | Proposal 9. Consider the target UL reference frequency as the satellite RX frequency on the service link. |
| Mediatek | Proposal 1: The target requirements to achieve for UE uplink pre-compensation assuming access link is in S band are:• Timing error at the satellite < ± 50 µs • Frequency error at the satellite < ±0.02 ppm or ± 40 Hz at fc = 2 GHzIt is assumed that gNB does pre-compensation and post-compensation of Doppler shift over the feeder link |
| Ericsson | If the satellite is time and frequency reference point, then UL signals will be time and frequency aligned and received at nominal UL frequency at satellite RX. Then all time slots will be misaligned by twice the feeder link delay and the frequency will be affected by feeder link Doppler shift.Observation 2 Using satellite as reference for time and frequency requirements affects compatibility with existing rel-16 gNB.In our view, the reference point should be under control of the network. In case of autonomous access (i.e. time/frequency) offset determination, the UE should be responsible for determining the access offset required for time and frequency alignment at the satellite, while the network may configure additional time and frequency offsets that are signaled to the UE. The signaled offsets are determined by the gNB and may be used to move the reference point e.g. to the gNB.Proposal 4 The reference point for time and frequency in an NTN should be under control of the network and should at least support the option of having gNB as the reference point.Observation 5 If the position of a reference point of the feeder link and the UL and DL carrier frequencies of the feeder link are signaled to the UE, the UE can autonomously determine the time and frequency offset of both the service link and the link between the satellite and the reference point of the feeder link, which would simplify the time and frequency compensation procedures.Proposal 11 The gNB may broadcast a parameter giving an additional frequency shift that the UE should apply at PRACH transmission. The value of this parameter should be configurable. It may be used for compensating for the Doppler shift observed on the uplink of the feeder link.Proposal 12 The UE should apply a frequency shift at PRACH transmission compensating for the Doppler shift observed on the uplink. The frequency shift should be the sum of the Doppler shift of the service link, determined by the UE, and an additional frequency offset broadcast by the gNB.Proposal 14 Support broadcasting a reference point of the feeder link and UE autonomous determination of the time and frequency offset of both the service link and the link between the satellite and the reference point of the feeder link. |
| Qualcomm | Proposal 1: In NTN, the satellite is the time and frequency reference point of a UE, i.e., UE targets UL transmit time and frequency at the arrival of the satellite and does not autonomously compensate time delay and frequency errors introduced by the satellite transponder and the feeder link.Observation 2: In NTN with transparent LEO satellites, it may not be feasible to have gNB as the reference point for time and frequency. |
| CMCC | Proposal 15: Network compensate the doppler shift on the feeder link, which is transparent to UE. |

#### Companies views

Based on the companies contributions, it seems clear that the UE shall be responsible only for determining the frequency offset required for frequency alignment at the satellite. However, some companies mentioned the possibility for the network to signal additional offsets to be considered by the UE when adjusting its UL TX frequency. This enables the possibility to move the reference point. The following options have been proposed:

Option 1: The reference point for frequency in an NTN is located at the satellite.

The UE shall be responsible for determining the frequency offset required for frequency alignment at the satellite. The gNB shall manage the other sources of frequency error (e.g. satellite transponder, feeder links). However, it has been observed that using satellite as reference for frequency requirements affects compatibility with existing rel-16 gNB.

Option 2: The reference point for frequency in an NTN is located at the gNB:

The UE shall be responsible for determining the frequency offset required for frequency alignment at the satellite. However, the network shall configure additional frequency offsets that are signaled to the UE. The signaled offsets are determined by the gNB. These offsets are applied on top of the one determined by the UE.

Option 3 : The reference point for frequency in an NTN is under control of the network:

The UE shall be responsible for determining the frequency offset required for frequency alignment at the satellite. However, the network may configure additional frequency offsets that are signaled to the UE. The signaled offsets are determined by the gNB and may be used to move the reference point. This is the most flexible option.

Based on the above discussion FL recommendation would be:

**FL recommendation-3-3:**

**Companies are invited to provide feedback about the three listed options for regarding the reference point definition:**

* **Option 1: The reference point for frequency in an NTN is located at the satellite**
* **Option 2: The reference point for frequency in an NTN is located at the gNB:**
* **Option 3 : The reference point for frequency in an NTN is under control of the network:**

Companies are encouraged to provide their comments and views in the following table:

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| ZTE | It’s up to the solution for Doppler estimation. * If based on the geometric solution, Option-1 is more preferred to simplify the calculation since variation/assumption for Doppler calculation is different per service link and feedback link.
* If the timer based is used, either way is fine and just up to the implementation.
 |
| MediaTek | It is not necessary that reference point of UL time synchronization and reference point for frequency synchronization are the same. Option 1 is the only viable option for reference point for UL synchronization. The feeder link Doppler shift and transponder frequency error need to be pre-compensated with very high accuracy or NTN system will not work. The transponder frequency error alone could be several 10s of kHz, and Doppler shift over the feeder link several 100s of kHz. We have concern on viability of Option 2, as UE cannot estimate the Doppler shift over the feeder link and cannot estimate the transponder frequency error. In our view it is questionable to signal accurately the common Doppler shift and Doppler drift rate due to feeder link and also the transponder frequency error.Option 3 uses Option 1 or Option 2. But, with our concern on Option 2, then only option 1 will be used in the network. |
| Ericsson | We support Option 3.In addition, we also have the following proposal, where the reference point may or may not be the gateway. It is up to network to configure. In scenarios where it is acceptable to broadcast gateway position, the network can configure the reference point to be the position of the gateway. In scenarios where it is not acceptable to broadcast gateway position, the network can configure the reference point to be the “approximate” position of the gateway.Proposal: Support broadcasting a reference point of the feeder link and UE autonomous determination of the time and frequency offset of both the service link and the link between the satellite and the reference point of the feeder link. |
| Intel | In our view option 1 can be assumed for RAN1 work, there the indication of satellite location/speed is under control of the network. |
| Apple | Option 1, UE does not need to handle the frequency offset between satellite and gNB.  |
| OPPO | Option 1, we share the same view as MTK. The performance cannot be ensured if the network broadcast the Doppler shift over feeder link to the UE.  |
| InterDigital | Support Option 1. |
| Qualcomm | Support Option 1. Option 3 can be roughly implemented with Koffset. Both the benefit and feasibility of option 2 are unclear. |
| Huawei | Option1. At least the frequency offset introduced by feeder link part should be compensated by gNB to avoid large hopping of frequency compensation at UE side introduced by feeder link switch. In addition, signalling overhead can be avoided by Option 1 |
| Spreadtrum | Option 1 |
| Samsung | We think Option 1 or Option 3 feasible. We would like to discuss what the compatibility issues are for Option 1 and how it is critical.  |

**Initial proposal 3-4:**

**NR NTN UE should apply a frequency shift at PRACH transmission compensating for:**

* **The Doppler shift experienced on the service link.**
* **FFS: an additional frequency offset indicated by the network.**

Companies are encouraged to provide their comments and views in the following table:

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| ZTE | Supportive on this proposal. W.r.t the indication of frequency offset, the benefits should be further justified. |
| MediaTek | We can support the proposal. We however think the FFS is not needed. It is already addressed in the discussion on the reference point options as in proposal 3-3. |
| Ericsson | We support the proposal. We would also support it if the second bullet was not marked “FFS”. |
| Intel | Support the proposal |
| Apple | We support the proposal |
| OPPO | We support the proposal |
| InterDigital | Support the proposal |
| Qualcomm | Support. |
| Huawei | Support the proposal. For the FFS bullet, we think the additional frequency offset indicated from the network is not needed. |
| Spreadtrum | We support the proposal |
| Samsung | Agree  |

### Issue #3-2 Common frequency offset pre-compensation and post-compensation at gNB side

#### Background

During the last e-meeting, the following FL recommendations were made:

* RAN1 to further discuss:
	+ Whether indication of the pre-compensated Common Frequency Offset on DL transmissions is needed or can be transparent to the UE
	+ Whether in case of a Common Frequency Offset pre-compensation on DL transmissions by the gNB, the gNB shall perform post-compensation on UL transmissions.

As already concluded during the Study Item phase, there is a common agreement on the fact that the gNB may have to apply a common frequency offset pre-compensation on the DL transmissions to minimize the SSB searching space for the UE. As a consequence, it makes no doubt that common frequency offset pre-compensation shall be supported by the gNB.

However, it is not clear whether gNB post-compensation shall be supported as well. If it is the case, it should be clarified whether one can assume that gNB pre-compensation and post-compensation can be decoupled or not. To do so, the configuration to be supported among the ones summarized in the next table shall be identified.

**Table 1 : List of possible configurations for pre/post compensation implementation at gNB side**

|  |  |  |
| --- | --- | --- |
|  | gNB pre-compensation | gNB post-compensation |
| Configuration A | No | No |
| Configuration B | Yes | No |
| Configuration C | No | Yes |
| Configuration D | Yes | Yes |

Moreover, when pre-compensation and post-compensation are both implemented, should we assume that the same offset (normalized w.r.t. the reference frequencies on both DL and UL) is applied or should we consider that the offsets can be different.

Then, in case of pre-compensation, it shall be clarified whether the value of this common frequency offset shall be indicated by the network to the UEs. The majority of the companies are in favour of signalling the common frequency offset to the UEs. The reason invoked is that the pre-compensated frequency offset knowledge is needed by the UE. This is required for the UE to correctly adjust its UL frequency taking into account the residual Doppler affecting the RX DL frequency carrier on which its local oscillator is locked.

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| Huawei | For UL transmissions, frequency offset post-compensation can be applied at the gNB side. In this case, the frequency offset compensated at the gNB should be signaled to the UE so that the UE knows how much frequency offset should be pre-compensated. If post-compensated common frequency offset applied for UL is the same as the pre-compensated common frequency offset applied for DL, the indication can be avoided otherwise the indication should be introduced. |
| CATT | Proposal 11: UL common Doppler shift compensation information should be indicated to UE, which can be applied in handover case.  |
| CMCC | Proposal 9: For TA determining solution in Opt 1 (satellite ephemeris based), - Indication of the pre-compensated Common Frequency Offset on DL transmissions is needed, if UE only know its position;- Otherwise, pre-compensated Common Frequency Offset on DL transmissions can be transparent to the UE, if UE both know its position and frequency reference.Proposal 10: For TA determining solution in Opt 1 (satellite ephemeris based), it does not matter whether gNB perform post-compensation on UL transmissions or not.- If post-compensation is performed, the post-compensated Common Frequency Offset on UL transmission needs to be indicated by network.Proposal 14: Both pre-compensated and post-compensated Common Frequency Offset are applied on the service link. |
| MediaTek, Eutelsat | Proposal 7: In case the gNB pre-compensate the common Doppler shift on the access link w.r.t. center of the beam, the beam-specific common Doppler shift value is broadcast on the NTN SIB for earth-moving beam.Proposal 8: In case the gNB pre-compensate the common Doppler shift on the access link w.r.t. center of the beam, the beam-specific ECEF co-ordinates of a fixed Reference Point (RP) corresponding to the beam centre is broadcast on the NTN SIB for earth-fixed beam. |
| Intel | DL synchronization procedure may be more complex for NTN comparing to terrestrial networks due to larger frequency uncertainty. This frequency uncertainty and UE complexity for DL synchronisation can be reduced by applying pre-compensation of beam-specific or cell-specific frequency offset for DL transmission at the gNB side. For the UEs with pre-compensation of time and frequency offset for UL transmission it is assumed that UE synchronises internal clock to received DL carrier frequency measured from DL synchronization signals. For UL transmission such UEs applies additional frequency offset which corresponds to the projection of satellite velocity to UE-satellite direction.For the case where pre-compensation of frequency offset is done at the UE and compensation of common (beam-specific or cell-specific) frequency offset is done at the gNB the UL carrier frequency at the gNB receiver is aligned with the expected value. Thus, indication of frequency offset value pre-compensated for DL transmission at the gNB side is not needed for UL synchronisation.Observation 1: • Compensation of common frequency offset for DL transmission can be done in order to decrease UE complexity for DL frequency synchronizationo Indication of frequency offset value pre-compensated for DL transmission at the gNB side is not needed for UL synchronization |
| Xiaomi | Proposal 6: Both pre-compensation and post-compensation on the Doppler shift for DL and UL transmission should be supported.Proposal 7: Pre-compensation value on the Doppler shift for DL transmission should be signalled to UEs. |
| Asia Pacific Telecom | We prefer pre-compensation and post-compensation cannot be decoupled, e.g., it is not likely that NW only supports the pre-compensation for the DL, but not supporting the post-compensation for the UL.Proposal 2 Frequency post-compensation on UL transmission at the NW side shall be the baseline.If we assume the estimated DL Doppler shift can be applied to the UL transmission, then the post-compensation common frequency could be provided by indication of the pre-compensated common frequency on DL.Proposal 3 An indication of the pre-compensated common frequency on DL shall be the baseline. |
| Spreadtrum Communications | For the second bullet, if gNB performed post-compensation on UL transmissions, there is a need to indicate this post-compensated frequency shift value to the UE. Otherwise, the UE may over-compensate Doppler frequency shift on UL transmission, which may cause confusion. In our view, we should first clarify whether both pre and post compensation are needed at the same time.Proposal 5: Indication of the pre-compensated Common Frequency Offset on DL transmissions is not needed. |
| Ericsson | Proposal 10 If gNB applies frequency pre-compensation in DL, the gNB should broadcast a parameter giving the amount of pre-compensation. This parameter should indicate the TX frequency offset at the satellite transmitter relative to the nominal DL TX frequency of the service link. The amount of DL pre-compensation applied should be configurable but bounded by a maximum offset at the UE receiver to limit UE synchronization complexity. |
| Qualcomm | Proposal 3: Support optional network frequency pre-compensation of SSB or all DL signals and support the signaling of the compensated value if pre-compensation is applied. |
| Nokia | Proposal 7: The gNB or satellite pre-compensates in the DL a common frequency offset per beam/cell, caused by the Doppler shift from feeder and access link, to minimize the PSS/SSS searching space for the UE.Observation 12: For earth-moving cells the common frequency offset is constant per beam/cell.Observation 13: For earth-fixed cells the common frequency offset depends on the satellite location. |

#### Companies views

Several solutions have been already identified to indicate this pre-compensated Common Frequency Offset depending on the scenarios:

1. Indication of the absolute value of the offset in case moving beam scenarios
2. Indication of the reference point location on earth w.r.t which the common frequency offset is derived in case of earth fixed beam scenarios

However, some companies explicitly mentioned that such indication by the network is not needed at least in some scenarios such as :

* The scenario where pre-compensation and post-compensation are both implemented and the same frequency offset is applied [Intel, Huawei]
* The scenario where only pre-compensation is implemented but not post-compensation [Spreadtrum]

Finally, some companies also proposed to indicate the Common Frequency Offset post-compensated by the gNB instead or in addition to the Common Frequency Offset pre-compensated by the gNB.

Based on the above discussion and companies proposals the initial proposal is made:

**Initial proposal 3-5: NR NTN gNB shall be capable to pre-compensate a common frequency offset on DL transmissions.**

Companies are encouraged to provide their comments and views in the following table:

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| ZTE | Agree. Pre-compensation w.r.t the beam centre is basic assumption for SSB evaluation done in SI. Otherwise, the DL synchronization will be broken. |
| MediaTek | Agree with proposal |
| Ericsson | We are against the proposal. DL frequency offset pre-compensation capability should be up to gNB. We respectfully disagree with the statement by the FL above that a consequence of agreements in the SI is that “it makes no doubt that common frequency offset pre-compensation shall be supported by the gNB”. In 3GPP TS 38.821 it is stated that “for the LEO without pre-compensation of the frequency offset, additional complexity is needed at UE receiver to achieve robust DL initial synchronization performance based on Rel-15 SSB. No further enhancement on the SSB is needed.” but there is no conclusion that pre-compensation is required. Consider e.g. a GEO network, in which such pre-compensation is not needed. Rather, there should be a defined performance requirement for the UE. This should be discussed by RAN4. |
| Intel | gNB pre-compensation of common frequency offset on DL transmissions can be assumed by RAN1, however there is no need to specify it.  |
| Apple | We agree with the proposal |
| OPPO | Agree with the proposal |
| InterDigital | Agree |
| Qualcomm | gNB frequency pre-compensation does not have to be mandatory.  |
| Huawei | Support |
| Spreadtrum | Support |
| Samsung | We can discuss this after concluding Issue#3-1. We think this solution is not needed for Option 1.  |

**Initial proposal 3-6: If NR NTN gNB applies frequency pre-compensation in DL, the gNB should broadcast a parameter giving the amount of frequency pre-compensation. This parameter should indicate the TX frequency offset at the satellite transmitter relative to the nominal DL TX frequency of the service link.**

Companies are encouraged to provide their comments and views in the following table:

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| ZTE | Some merit can be found in this way, e.g., during handover/beam management. But it can be postponed once the general framework is consolidated. |
| MediaTek | Agree with proposal for earth-moving beams which all experience the same common Doppler shift due to satellite movement. For earth-fixed beams, since the beam is not moving the common Doppler shift cannot be broadcast at it varies rapidly as the satellite moves. It is preferable if it is derived at the device based on a reference point where the common Doppler shift compensation is applied by gNB– i.e. ECEF coordinates of centre of the beam is broadcast by gNB for earth-fixed beams. |
| Ericsson | We support the proposal.  |
| Intel | Agree with ZTE that it may be needed for handover/beam management. |
| OPPO | agree |
| InterDigital | Agree |
| Qualcomm | Support. |
| Huawei | If Solution#3-1 above is down selected, pre-compensation in DL can be indicated to assist UE to differentiate residual Doppler and local oscillator offset and compensated it for UL transmission  |

**FL recommendation 3-7: Companies are invited to provide feedback about :**

1. **The pre/post compensation configurations to be supported by the NR NTN gNB:**

|  |  |  |
| --- | --- | --- |
|  | gNB pre-compensation | gNB post-compensation |
| Configuration A | No | No |
| Configuration B | Yes | No |
| Configuration C | No | Yes |
| Configuration D | Yes | Yes |

1. **When pre-compensation and post-compensation are both implemented (configuration D), should we assume that the same offset (normalized w.r.t. the reference frequencies on both DL and UL) is applied or should we consider that the offsets can be different.**
2. **If NR NTN gNB applies frequency post-compensation in UL, is it required to indicate the amount of frequency post-compensated by the gNB ?**

Companies are encouraged to provide their comments and views in the following table:

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| ZTE | “Configuration A” can be the 1st choice and “Configuration B” is the 2nd one.The necessity for the indication on gNB post-compensation is not clear. With assuming that all UE under same beam will conduct the pre-compensation, the gNB is free to do any post-compensation according to the needs. Such operation is transparent to UE. |
| MediaTek | This discussion on pre/post compensation combinations can be postponed. First discussions on need and solution pre-compensation as in proposals 3-5 and 3-6 should conclude. |
| Ericsson | 1. All four configurations should be supported in the specification. Which configuration(s) to use should be up to gNB.
2. No. Different offsets should be supported in the specification. The chosen offset should be up to gNB implementation.
3. The specification should support indication of the amount of UL pre-compensation to be applied by the UE (if any). It is up to gNB to choose the indicated value.
 |
| Intel | Configuration D can be assumed with the same offset for UL/DL. The indication of post-compensated value is not required.  |
| OPPO | Agree that it would be better to have clearer understanding on the pre/post-compensation on gNB side, e.g. full feeder link or partial feeder link etc.  |
| Huawei | At least gNB pre-compensation should be supported to reduce the complexity of DL synchronization. If post-compensation is supported, the same offset should be assume to avoid extra signalling overhead. |
| Samsung | Similar to MediaTek, we think this discussion on pre/post compensation combinations can be postponed. |

* 1. Issue#4: UL Frequency adjustment for UE in RRC connected mode
		1. Background

RAN1 shall provide solutions to maintain correct frequency synchronization in RRC Connected Mode.

One solution consists in enabling autonomous frequency adjustment also in RRC connected mode. Another approach is to introduce a new control loop mechanism for frequency alignment as it is currently specified for timing advance.

Solution #4-1: Autonomous frequency adjustment based on UE GNSS implementation

Several companies proposed to support autonomous frequency adjustment in RRC Connected Mode based on UE GNSS implementation.

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| Thales | Proposal 7. RAN1 to further discuss the UE capabilities to perform GNSS acquisition in RRC Connected mode.Proposal 20. The feasibility for the UE to perform autonomous GNSS-assisted frequency adjustment in RRC Connected mode shall be further investigated. |
| Huawei | Observation 1: For GNSS UE, UE-specific frequency correction signaling can be avoided. |
| Ericsson | Proposal 15 NR NTN UE shall be capable of using an acquired GNSS position and satellite ephemeris to calculate pre-compensation of timing and frequency offset and apply the calculated values accordingly in RRC\_IDLE, RRC\_INACTIVE, and RRC\_CONNECTED states. |
| MediaTek | Observation 9: With GNSS capability, there is no need for UL frequency compensation indication if the UE pre-compensation of Doppler shift is done with sufficient accuracy for the transmission of RACH preamble and subsequent transmission of PUSCH and PUCCH. |
| Qualcomm | Proposal 5: In NTN, both UE autonomous and closed-loop frequency control are supported. |
| Nokia | During connected mode, precompensation of the UE-specific frequency offset is strongly recommended as well to mitigate inter-UE and inter-carrier interference caused by the loss of subcarrier orthogonality. Estimation can be done using DL reference signals. Considering that DL receptions and the associated UL transmissions typically take place within a very short time difference, it can be safely assumed that the frequency offset value remains constant and any value estimated by the UE from DL reference signals can be used for the UL precompensation. If needed, adjustment of frequency compensation value to the UL carrier frequency must be considered by the UE. Proposal 9: The UE-specific frequency offset can be tracked using DL reference signals and should be precompensated in the UL to avoid inter-user and inter-carrier interference. |

Solution #4-2 Control loop for frequency alignment

Several companies [Qualcomm, InterDigital, Apple] are also supportive of the introduction of closed-loop frequency control.

However, other companies clearly preferred to avoid specifying such solution since they considered that solution#2-1 is sufficient and the benefits of solution#4-2 is not sufficiently clear.

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| Thales | This will help decide whether it is reasonable to require autonomous frequency and timing adjustment at UE side in RRC Connected mode or whether relying on close loop mechanisms is the only reasonable option. |
| CATT | Observation 7: The benefit of close-loop UL frequency compensation is not clear.Proposal 12: Close-loop frequency compensation is not needed. |
| Apple | Proposal 8: UE pre-compensates the frequency offset in its UL transmissions, based on its calculated or indicated frequency offset. |
| Spreadtrum | In our view, for GNSS UE, both the estimation and UE-specific UL frequency compensation is conducted at the UE side and UE-specific frequency correction signaling can be avoided. |
| InterDigital | Proposal 3: for UL frequency offset compensation, network indicates the required frequency offset to be compensated for UL transmission is supported (Option-2). |
| Qualcomm | Proposal 5: In NTN, both UE autonomous and closed-loop frequency control are supported. Proposal 6: Support closed-loop frequency control commands by MAC-CE.Proposal 7: Consider group-common DCI for UL time and frequency control. |
| MediaTek | Observation 9: With GNSS capability, there is no need for UL frequency compensation indication if the UE pre-compensation of Doppler shift is done with sufficient accuracy for the transmission of RACH preamble and subsequent transmission of PUSCH and PUCCH. |
| Huawei | Observation 1: For GNSS UE, UE-specific frequency correction signaling can be avoided. |

* + - 1. Companies views

Based on companies proposals, the initial proposals are as follows:

**Initial proposal 4-1:**

**NR NTN UE in RRC\_CONNECTED state shall be capable of using an acquired GNSS position and satellite ephemeris to calculate frequency pre-compensation to counter shift the Doppler experienced on the service access.**

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| ZTE | Supportive. We need to support the unified UE implementation for pre-compensation regardless of UE status. This can be merged with the proposal for initial access. |
| MediaTek | Support proposal and agree with ZTE it can be merged with the proposal for initial access. |
| Ericsson | We support the proposal. |
| Intel | Support |
| Apple | Support |
| OPPO | Support |
| Qualcomm | Support |
| Huawei | Support |
| Spreadtrum | Support |
| Samsung | Agree  |

**Initial proposal 4-2:**

**NR NTN UE should apply a frequency shift at each UL transmission compensating for :**

* **The Doppler shift experienced on the service link.**
* **FFS: an additional frequency offset indicated by the network.**

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| ZTE | Support. We do only need one proposal to treat this issue regardless of UE status. It’s better to merged with **Initial proposal 3-4**; |
| MediaTek | Support proposal and agree with ZTE it can be merged with **Initial proposal 3-4**. We however think the FFS is not needed. It is already addressed in the discussion on the reference point options as in proposal 3-3. |
| Ericsson | We support the proposal. We would also support it if the second bullet was not marked “FFS”. |
| Intel | OK with the proposal |
| Apple | Support |
| OPPO | OK |
| Qualcomm | Support |
| Huawei | Support |
| Spreadtrum | Support |
| Samsung | Agree  |

**FL recommendation 4-3: RAN1 to further investigate whether closed-loop frequency control shall be supported as part of Rel. 17 for NR NTN.**

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| ZTE | No needed. With reasonable accuracy for pre-compensation, the performance for UL transmission can be ensured. Also, existing SCS/RS design is also available to handle certain errors. |
| MediaTek | Not needed. Same view as ZTE. |
| Ericsson | We support the proposal. |
| Intel | We don’t see the need for closed-loop frequency control assuming that autonomous UE pre-compensation is accurate enough. |
| Apple | We support the proposal. |
| OPPO | OK |
| Qualcomm | Support. There will always be some residual Doppler estimation error and there could be many reasons that the Doppler estimation error become significant. Note that this error is in addition to UE oscillator stability. For UEs without GNSS, closed-loop frequency control must be needed.  |
| Huawei | Not needed. |
| Samsung | We support FL recommendation 4-3. In particular, consider the closed-loop frequency control method in our Proposal 6:**Proposal 6: The gNB can jointly signal common TA drift rate and Doppler shift such as the UE derives Doppler shift from common TA drift rate signaled by gNB or vice versa.** |

# Serving satellite ephemeris

## Issue#5: Serving satellite ephemeris format

### Background

With Solution#1-1 and 3-1, UL timing and frequency synchronization relies on the (real-time) serving satellite ephemeris, in combination with the UE position. As a consequence, it should be possible to broadcast the serving satellite ephemeris under a standardized format.

Ephemeris can be expressed in an ASCII file using Two-Line Element (TLE) format. The TLE data format encodes a list of orbital elements of an Earth-orbiting object in two 70-column lines. The TLE format is an expression of mean orbital parameters "True Equator, Mean Equinox", filtering out short term perturbations.

From its TLE format data, the SGP4 (Simplified General Propagation) model is used to calculate the location of the satellite in True Equator Mean Equinox (TEME) coordinate. Then it can be converted into the Earth-Centered, Earth-Fixed (ECEF) Cartesian x, y, z coordinate as a function of time. The instantaneous velocity at that time can also be obtained.

It is assumed that the satellite orbit determination is performed through a proprietary solution (e.g. based on on-board GNSS measurements) at the NTN Control Center (NCC) and shared with the gNB such that the gNB can broadcast the satellite ephemeris parameters under the right format.

gNB can broadcast the serving satellite ephemeris based on:

* Orbital elements: e.g., (a, e, ω, Ω, i, M0)
* Or instant state vector: e.g., instance position and instance velocity (x, y, z, vx, vy, vz)

Propagation of satellite position and satellite velocity at the Gateway and at the UE can be used to predict what the satellite position and velocity at the moment of transmission on NTN SIB or at the moment of UL transmission respectively.

The accuracy of the time and frequency compensation performed by the UE depends to a large extent on the accuracy of the ephemeris data provided in the SIB. This accuracy and related proposals will be discussed in section 4.

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| Huawei, HiSilicon | Observation 13: The orbit element-based ephemeris format requires much less signalling overhead compared with PVT-based ephemeris format. Proposal 9: The orbit element-based ephemeris format shall be adopted. |
| Ericsson | Proposal 18 NTN UE should have the capability of satellite trajectory calculation based on a provided orbit representation at a reference time.Proposal 19 RAN1 to study the required accuracy of satellite ephemeris to support timing and frequency offset pre-compensation. |
| MediaTek, Eutelsat | Proposal 2: The base Station broadcast Position/ Velocity and implicit Time in each beam in the satellite cell:- Satellite location/velocity in ECEF coordinates- Validity Time is the end of SFN where SIB was transmitted (from the satellite)Proposal 3: Satellite Position and Velocity information field sizes broadcast on SIB with periodicity X- The field size for position is 84 bits- The field size for velocity is 60 bits- Value of X – e.g. 200 ms, 500 ms, 1000 ms, 1500 ms, 2000 ms |
| Apple | Proposal 4: The serving satellite ephemeris indicated by the network include satellite’s position and velocity. |
| CATT | Observation 2: The constellation ephemeris data signalled from network is more robust to be workable in different use cases, though Satellite position status vector is applicable in connected mode. Proposal 2: Constellation ephemeris data can be taken as the baseline for ephemeris format. |
| CMCC | Proposal 3: Broadcast instant position and velocity vector in system information, if indication of satellite ephemeris is needed. |
| Samsung | Proposal 1: A gNB signals the serving satellite ephemeris to UEs in system information, including the followings:• index to a pre-defined table of satellite altitude levels and altitude offset scaling factors, i.e., NTN type• satellite altitude offset• satellite position• satellite velocity• reference time for satellite position and velocity. |
| ZTE | Observation 1: Ephemeris, e.g. TLE based on satellite dynamic model, broadcast in NTN can be used to enhance the performance in both RAN1 and RAN2.Proposal 2: From physical layer perspective, either ephemeris or instant PVT is acceptable. |
| CEWiT | Proposal 2: Satellite ephemeris and velocity vector should be broadcasted to assist the UE specific TA estimation. |
| LG Electronics | Proposal 1. Further discussion should be needed on which signals/channels to transmit additional information (e.g., Common TA, reference time, etc.) provided by gNB. |
| Thales | Proposal 10. NTN SIB can include the satellite PV(T) in ECEF coordinates and the position in ECEF coordinates of the reference point considered for Doppler shift pre-compensation on DL transmissionsProposal 11. Broadcast NTN SI every few seconds. |

### Company views

From the above proposals, it is clear that companies have different views on the suitable format of the satellite ephemeris to be adopted.

Basically the two different forms of orbit representation can be translated to each other and both of them can be used to indicate the instantaneous satellite position and velocity to the UE. However, for some companies the instant state vector allows for straightforward calculation of propagation delay and Doppler.

When it comes to signalling overhead, for other companies, the orbit element-based ephemeris format requires much less signalling overhead compared with PVT-based ephemeris format.

Some companies observed that only instant orbital state vector format has the ability for implicit compatibility to support HAPS and ATG scenarios since orbit concept is meaningless in HAPS and ATG scenarios.

Further, there is a proposal that the UE should have the capability of satellite orbit propagation based on a provided orbit representation at a reference time and this may need to be captured in a proposal.

From the above discussion we need to make a trade-off between the two orbit formats (Orbital parameters/elements and instant state vector). The initial proposal is made as follows:

Initial proposal 5-1:

**gNB shall broadcast the serving satellite ephemeris based on:**

* **Option (1): Orbital elements: e.g., (a, e, ω, Ω, i, M0)**
* **Option (2): Instant state vector with implicit time: e.g., instance position and instance velocity (x, y, z, vx, vy, vz)**

Companies are encouraged to provide their preference/views in the following table:

|  |  |  |
| --- | --- | --- |
| **Company** | **First preference** | **Second preference** |
| ZTE | Option-2  | Option-1 |
| MediaTek | Option-2.Both Option-2 and Option-1 can be 16 bytes. Option-2 can be more easily propagated for UE pre-compensation. For satellite trajectory / next satellite fly by determination, device can translate satellite state vector to orbital parameters just once, then use its GNSS capability to determine epoch time and use is as input with orbital parameters to function f(t) to determine when next satellite fly by.  | Option-1Propagation for UE pre-compensation is more complex. There is no gain in signalling overhead.  |
| Ericsson | We have no strong preference. However, ephemeris is needed not only for the serving satellite but also for other satellites for different purposes including RRM measurements, idle/inactive measurements, handover, etc., which are expected to be discussed in RAN2. A unified format is preferred, even if not strictly necessary.  |  |
| Intel | Option 2 | Option 1 |
| Apple | Option 2 | Option 1  |
| Huawei | Obviously, more discussion is needed. We have a preference Option 1 since it requires much less signalling overhead compared with Option 2 and still can have enough accuracy. We also share with view that satellite ephemeris are also used for other purpose. Decision can be made later when the accuracy requirement for physical layer together with the requirement for other purpose is clear. |  |
| Samsung | Option (2) | Option (1) |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

On the UE capability of satellite orbit propagation, initial proposal is made as follows

Initial proposal 5-2:

**UE should have the capability of performing satellite orbit propagation based on a provided orbit representation at a reference time**

Companies are encouraged to provide their preference/views in the following table:

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| ZTE | It’s not proper to make such limitation for UE implementation. |
| MediaTek | We see no need for defining such UE capability. If device cannot do UE pre-compensation based on satellite ephemeris, then the other way is the timestamp method which is discussed in Proposal 1-1 and FL recommendation 3-2. Having both options supported in the network with both options supported in device implementation is not desired outcome of RAN1 discussions on UE pre-compensation.  |
| Ericsson | We support the proposal. |
| Intel | Agree in principle, however, there is no need to make such agreement since impact on RAN1 specification is not clear.  |
| Apple | It is unclear of specification impact.  |
| Huawei | Support.  |
| Samsung | We support Proposal 5-2. One point for further consideration is that NTN will focus on LEO and GEO scenarios, while de-prioritizing MEO scenarios. Since LEO and GEO orbits are not highly eccentric, this may simplify the calculations for satellite orbit propagation. |

# Accuracy of UE pre-compensation for UL synchronization

## Issue#6: GNSS accuracy requirement

### Background

W.r.t to GNSS usage for synchronization purposes, the following agreements were made in RAN1#102e:

* In Rel-17 NR NTN, at least support UE which can derive based on its GNSS implementation one or more of:
	+ its position
	+ a reference time and frequency
* And, based on one or more of these elements together with additional information (e.g., serving satellite ephemeris or timestamp) signalled by the network, can compute timing and frequency, and apply timing advance and frequency adjustment at least for UE in RRC idle/inactive mode.
* FFS: Details on additional information signalled from network

The GNSS performance has to be therefore considered when defining the UE pre-compensation accuracy. Several factors may degrade the GNSS positioning accuracy of the UE:

• The satellite configuration (orbital error, clock bias)

• The signal propagation (iono/tropospheric refraction, scintillation, …)

• The receiver noise (clock bias, antenna phase center variation, …)

• The receiver global location (geometrical distribution of the visible satellite, …)

• Local environment (RF noise, multipath, limited satellite visibility, …)

In order to characterize the positioning performance in the context of this WI, we can consider the performance metrics:

• Accuracy : Statistical characterization of the error in time and position.

• Availability : Percentage of time during which the outputs of interest are available to the UE.

GNSS accuracy requirement is being discussed in RAN4, some proposals on such requirement can be found in the following TDOCs submitted to RAN4# 97-e:

|  |  |
| --- | --- |
| **T-doc number** | **Company** |
| [*R4-2014875*](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_97_e/Docs/R4-2014875.zip) | MediaTek inc. |
| [*R4-2015946*](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_97_e/Docs/R4-2015946.zip) | THALES |
| [*R4-2016037*](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_97_e/Docs/R4-2016037.zip) | Ericsson |
| [*R4-2015730*](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_97_e/Docs/R4-2015730.zip) | Nokia, Nokia Shanghai Bell |
| [*R4-2014928*](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_97_e/Docs/R4-2014928.zip) | Eutelsat S.A. |

Another open issue is about the capability to perform GNSS acquisition when the UE is in RRC Connected mode. This issue shall be further discussed in particular in cases where the RF circuit is shared between the GNSS and NR chipsets. Then, the constraints related to the availability of the GNSS chipset in RRC Connected mode shall be further investigated to conclude on whether such solution is doable and whether GNSS measurement gaps shall be introduced.

Regarding this issue, it was observed in a Tdoc submitted to RAN4 [[R4-2016037](https://www.3gpp.org/ftp/TSG_RAN/WG4_Radio/TSGR4_97_e/Docs/R4-2016037.zip) ] that It is practically feasible to receive GNSS positioning signals without any measurement gap or interruption in 3GPP radio reception or transmission.

The proposals and observations about GNSS positioning accuracy of the UE are summarized in the following table:

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| Nokia | Observation 2: There are several sources of inaccuracy in estimating the time/frequency synchronization between UE and gNb by using GNSS information: lag of the ephemeris information, precision of the ephemeris data, GNSS inaccuracy, orbit perturbations and altitude modelling, delay on GNSS acquisition and information conversion at the UE and atmospheric delays. |
| Ericsson | Proposal 15: NR NTN UE shall be capable of using an acquired GNSS position and satellite ephemeris to calculate pre-compensation of timing and frequency offset and apply the calculated values accordingly in RRC\_IDLE, RRC\_INACTIVE, and RRC\_CONNECTED states.Proposal 16: It is up to RAN4 to determine the need for supporting GNSS measurement gaps in RRC\_CONNECTED state.Proposal 17: RAN1 to determine the relevance of the case of NTN coverage but no GNSS coverage. |
| OPPO | Proposal 1: RAN1 needs to decide if the case that GNSS-capable UE cannot ensure a requested TA pre-compensation error margin due to GPS service degradation should be addressed in Rel.17 NTN. |
| LG Electronics | Proposal 4. It is desirable to support the TA indication from gNB, because the accuracy of the GNSS can be degraded in specific scenario such as indoor, underground, etc. |
| Thales | Proposal 4. From RAN1 perspective, the UE position knowledge shall be considered available at UE side at any given time with acceptable accuracy.Proposal 5. It is up to the UE implementation to trigger new GNSS-based position acquisitions when the accuracy of UE positioning is no longer sufficient to meet the synchronization requirements.Proposal 7. RAN1 to further discuss the NR UE capabilities to perform GNSS acquisition in RRC Connected mode. |
| ZTE | Proposal 10: Further study on the case that poor GNSS function is experienced, can be considered once the main normative works are done. |
| Spreadtrum Communications | Proposal 1: GNSS-equipped UEs cannot perform timing and frequency pre-compensation for uplink synchronization should be deprioritized in this WI. |
| CEWiT | Observation 2: Definition of UE GNSS capability in terms of UE positioning accuracy and availability need to be defined to use it for TA pre-compensation. |

### Company views

W.r.t a possible GNSS unavailability, there is a proposal for RAN1 to decide whether the case where a GNSS-capable UE cannot ensure a requested TA pre-compensation error margin due to GPS service degradation should be addressed in Rel.17 NTN. And another proposal was made for RAN1 to determine the relevance of the case of NTN coverage but no GNSS coverage.

To move forward, a company proposed that further study on the scenarios where poor GNSS function is experienced, can be considered once the main normative works is done.

It was also proposed that from RAN1 perspective the UE position knowledge shall be considered available at UE side at any given time with acceptable accuracy.

W.r.t to GNSS positioning accuracy of the UE, it was observed that GNSS systems typically provide accuracy within a few meters. The impact of UE geolocation error is therefore negligible. The UE pre-compensation accuracy is mainly dependent on the accuracy of the position and satellite velocity signaled by the gNB and on the device propagation accuracy of this information.

W.r.t GNSS usage in connected mode, there is a proposal for RAN1 to further discuss the NR UE capabilities to perform GNSS acquisition in RRC Connected mode. And a company proposed that it is up to RAN4 to determine the need for supporting GNSS measurement gaps in RRC\_CONNECTED state.

Based on company proposals, the initial proposal is made as follows:

Initial proposal 6-1:

RAN1 to consider RAN4 defined requirements on GNSS positioning accuracy.

Further study on the case where poor GNSS function is experienced, can be considered once the main normative works is done.

It is up to RAN4 to decide whether interruptions or measurement gaps are required for GNSS measurements during NTN operation

Companies are encouraged to provide their comments and views in the following table:

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| ZTE | It’s not sure whether GNSS positioning accuracy is in the scope of 3GPP. The requirements for accuracy can only defined for the action for pre-compensation within consideration on the overall factors. |
| MediaTek | There is no need for this proposal. It is an on-going RAN4 discussion. GNSS position accuracy in the devise and satellite is very accurate.  |
| Ericsson | We support the proposal. |
| Intel | We are OK to use values provided by RAN4. |
| Apple | We are fine with the proposal.  |
| OPPO | OK |
| Huawei | Support |
| Samsung | We believe that the final NTN design should support GNSS-challenged scenarios (e.g. indoors, tunnels, situations where a UE has NTN coverage while lacking a LOS path to a majority of the GNSS satellites). |

## Issue#7: UL Time synchronization requirements

### Background

On UL time synchronization requirements , the following recommendations were made in Feature Lead summary at RAN1#102e based on company proposals and comments:

RAN1 to further discuss the requirements related to UL time synchronization.

RAN1 to further discuss the implication of UL timing alignment requirements on the expected accuracy of :

• The satellite position knowledge at UE side

• The UE position knowledge at UE side

The proposals about GNSS-assisted TA pre-compensation requirements are summarized in the following table:

|  |  |
| --- | --- |
| **Companies** | **Proposals** |
| Nokia | Proposal 1: The aggregate contribution of all sources of inaccuracy must not violate the limits imposed by the cyclic prefix of the random access preamble.Proposal 2: The GNSS-assisted pre-compensation solution used by the UE shall meet the demands of the preamble format chosen by the operator, i.e., UE must be prepared to fulfil all preamble format requirements. |
| Thales | Proposal 12. The UE shall be able to acquire its User specific TA with an accuracy better than ±min(CP/2,GP/2,(Minimal Relative Cyclic Shift Duration)/2 ), depending on the PRACH format and configuration.Proposal 13. The UE 3D positioning error ΔU and the satellite 3D positioning error ΔS shall accommodate the following requirement: ΔU + ΔS < c/2 \* min(CP/2,GP/2,(Minimal Relative Cyclic Shift Duration)/2) |
| MediaTek, Eutelsat | Proposal 1: The target requirements to achieve for UE uplink pre-compensation assuming access link is in S band are:• Timing error at the satellite < ± 50 µs • Frequency error at the satellite < ±0.02 ppm or ± 40 Hz at fc = 2 GHzIt is assumed that gNB does pre-compensation and post-compensation of Doppler shift over the feeder link For access link in other bands, the proposal above can be readily applied with Frequency error at the satellite < ±0.02 ppm of carrier frequency in these bands. |
| ZTE | Proposal 6: For geometric based solution, the accuracy of pre-compensated TA and Doppler shift should be evaluated with consideration on the errors of location information for both UE and BS.Proposal 7: For timestamp based solution, the accuracy of pre-compensated TA and Doppler shift should be evaluated with consideration on the errors of reference time and synchronization between BS and UE.Proposal 8: Reasonable requirements on the accuracy should be defined for pre-compensation to ensure the basic system performance. |
| Eutelsat | Proposal 1: The target requirements to achieve for feeder link and UE uplink pre-compensation are:• Time delay < 0.4 µs • Doppler shift < +/- 20 HzThese limits apply to a UE positioned at the center of a satellite beam. As UEs located elsewhere in the beam will receive the signal with a residual Doppler shift, the size of the beam will be determined by the maximum frequency shift tolerated by the UE.Proposal 2: The required accuracy of satellite position and satellite velocity broadcast by the Gateway is:

|  |  |  |
| --- | --- | --- |
| *Use* | *Position accuracy* | *Velocity accuracy* |
| *PVT info in SIB signaling for UE pre-compensation* | *< 120 m* | *< 1.5 m/s* |

 |

### Company views

All companies agreed that reasonable requirements on the accuracy should be defined for pre-compensation to ensure the basic system performance.

There is a proposal that the aggregate contribution of all sources of inaccuracy must not violate the limits imposed by the cyclic prefix of the random access preamble and UE must be prepared to fulfill all preamble format requirements.

For some companies the maximal tolerable error TA can be assumed as half of the CP of the configured PRACH.

A company proposed that the UE shall be able to acquire its User specific TA with an accuracy better than ±min(CP/2,GP/2,(Minimal Relative Cyclic Shift Duration)/2 ).

Another company proposed that the target requirement to achieve for UE uplink time pre-compensation to be defined as follows: timing error at the satellite < ± 50 µs

Based on company proposals, the initial proposal is made as follows:

Initial proposal 6-2:

**w.r.t to the acceptable TA error for initial access, down select one of the following options:**

**Option #1:**

**The UE shall be able to acquire its User specific TA with an accuracy better than min(CP/2,GP/2,(Minimal Relative Cyclic Shift Duration)/2) depending on the PRACH format and configuration.**

**Option#2:**

**The target requirements to achieve for UE uplink pre-compensation assuming access link is in S band are:**

**• Timing error at the satellite < ± 50 µs**

**• Frequency error at the satellite < ±0.02 ppm or ± 40 Hz at fc = 2 GHz**

**Option#3:**

**The target requirements to achieve for feeder link and UE uplink pre-compensation are:**

**• Time delay < 0.4 µs**

**Option#4:**

**Other requirements on the accuracy should be defined for pre-compensation to ensure the basic system performance.**

Companies are encouraged to provide their comments and views in the following table:

|  |  |
| --- | --- |
| **Companies** | **Comments and Views** |
| ZTE | It seems that these proposals are not comparable. I.e., option-1 is to define the general requirements. But option-2 is only for satellite self (seems to be for time stamp based solution). Option 3 is not clear w.r.t the feeder link part. More clarification is needed for this issue. And general, either one of following can be considered:1. Defining the overall requirement for pre-compensation including Doppler and TA directly without distinguish on the impact of each component;
2. Separately defining the requirement or indication on the uncertainty, e.g., PVT error.
 |
| MediaTek | Option 2 is same target timing error requirement of +/-50us as Option 1 for RACH transmission (CP/2 of smallest RACH format 0 in FR1). The UE pre-compensation can be much more accurate than 50us, but there is no need to specify new requirements for initial access. Frequency error is +/-40 Hz or 20% of +/-0.1 ppm UL frequency error in S band at 2 GHz.Option 3 is for the delay over the feeder link, whereas options 2 and 3 are for the access link.Option2, 3, and 4 could be combined to give overall requirement for timing error and frequency error at the gNB – i.e. CP/2 of smallest RACH format and maximum UL frequency error +/-0.1 ppm. |
| Ericsson | This is a delicate issue that requires careful coordination with RAN4. The UE transmission timing error can be found in TS 38.133, section 7.1.2, where it is stated: The UE initial transmission timing error shall be less than or equal to Te where the timing error limit value Te is specified in Table 7.1.2-1. This requirement applies:- when it is the first transmission in a DRX cycle for PUCCH, PUSCH and SRS or it is the PRACH transmission.The UE shall meet the Te requirement for an initial transmission provided that at least one SSB is available at the UE during the last 160 ms. The reference point for the UE initial transmit timing control requirement shall be the downlink timing of the reference cell minus . The downlink timing is defined as the time when the first detected path (in time) of the corresponding downlink frame is received from the reference cell. *N*TA for PRACH is defined as 0.We feel Options 1 – 3 are a bit ad hoc. For example, in option 1, CP serve other purposes such as handling time dispersion on the radio channel and should not fully be used for estimation inaccuracy. So, we suggest discussion along Option 4, with e.g. LS communications with RAN4 on this topic. |
| Intel | Option 1 with frequency error at the satellite < ±0.02 ppm |
| Qualcomm | These requires RAN4 coordination. Feeder link timing error should not be considered. It’s up to gNB.  |
| Huawei | It seems that different options are addressing different aspects. Overall, our preference is to identify which requirement would have an impact to RAN1 design first and consult RAN4 if necessary.  |
| Samsung | We think this issue should be discussed after determining TA/frequency offset compensation methods. |

## Issue#8: UL frequency synchronization requirements

### Background

During the last e-meeting, the following FL recommendations were made:

* RAN1 to further discuss the requirements related to UL frequency alignment.
* RAN1 to further discuss the implication of UL frequency alignment requirements on the expected accuracy of the satellite position and velocity and the UE position knowledge at UE side.

|  |  |
| --- | --- |
| **Companies** | **Proposals** |
| Thales | Proposal 4. From RAN1 perspective, the UE position knowledge shall be considered available at UE side at any given time with acceptable accuracy.Proposal 5. It is up to the UE implementation to trigger new position acquisitions when the accuracy of UE positioning is no longer sufficient to meet the synchronization requirements.Proposal 21. The UE shall be able to compensate the frequency offset due to the satellite mobility when generating its UL carrier frequency. The residual frequency error shall be sufficiently low such that it can be considered within the tolerated frequency error of 0.1 ppm already captured in the specification.Observation 2. In the NTN context (i.e outdoor conditions, open field environment, LoS predominance, …), the GNSS service can be roughly considered available at any time and the associated localization error (3D accuracy) can be roughly considered in the range from 1m to 20m. |
| Huawei | Observation 2: For GNSS UE, the UL frequency offset at gNB is negligible. |
| MediaTek, Eutelsat | The first order error of the Doppler formula ($\frac{f\_{Doppler}}{f\_{c}}=\frac{\left〈\vec{V\_{Sat}},\vec{U\_{Sat\_{UE}}}\right〉}{c\left‖\vec{U\_{Sat\_{UE}}}\right‖}$) is $$\frac{Δf\_{Doppler}}{f\_{c}}=\left〈∆\vec{V},\frac{\vec{U}}{c\left‖\vec{U}\right‖}\right〉+\left〈\vec{V},P\_{\vec{U}}^{¬}\frac{∆\vec{U}}{c\left‖\vec{U}\right‖}\right〉$$Where $P\_{\vec{U}}^{¬}$ is the orthogonal projection to $\vec{U}$. We have* Doppler error due to Velocity error : $\frac{1}{c}\vec{∆V}.\frac{\vec{U}}{\left|\vec{U}\right|}$
* Doppler error due to Position error :$\frac{1}{c}\vec{V}.P\_{\vec{U}}^{¬}.\frac{\vec{∆U}}{\left|\vec{U}\right|}$

Observation 2: UE pre-compensation of satellite Doppler shift within an accuracy of ±0.02ppm included in the total frequency error for UL transmission of ±0.1 ppm is sufficient for UL frequency synchronization. In term of satellite position accuracy (ΔU) and satellite velocity accuracy ΔV, this corresponds to  For LEO ∆U<±120m  ∆V<±1.5 m/sec For GEO ∆U< ±21 km  ∆V< ±2.7 m/secObservation 3: The UE pre-compensation accuracy is mainly dependent on the accuracy of the position and satellite velocity signaled by the Gateway and on the device propagation accuracy of this information.Proposal 1: The target requirements to achieve for UE uplink pre-compensation assuming access link is in S band are:• Timing error at the satellite < ± 50 µs • Frequency error at the satellite < ±0.02 ppm or ± 40 Hz at fc = 2 GHzIt is assumed that gNB does pre-compensation and post-compensation of Doppler shift over the feeder link For access link in other bands, the proposal above can be readily applied with Frequency error at the satellite < ±0.02 ppm of carrier frequency in these bands. |
| ZTE | Proposal 6: For geometric based solution, the accuracy of pre-compensated TA and Doppler shift should be evaluated with consideration on the errors of location information for both UE and BS.The Doppler is proportional to the relative speed between UE and air-/space-borne platform along the LoS path. Assuming that satellite velocity is known, the Doppler calculation error is mainly determined by the elevation angle difference of real path and obtained path. With fixed location error, the elevation angle difference is upper bounded by,where  is the height of air-/space-borne platform. Therefore, in order to ensure that the Doppler calculation error is lower than tolerable threshold, the location error should be smaller than,where  is the carrier frequency and  is the speed of air-/space-borne platform.Proposal 7: For timestamp based solution, the accuracy of pre-compensated TA and Doppler shift should be evaluated with consideration on the errors of reference time and synchronization between BS and UE. |
| Eutelsat | Proposal 1: The target requirements to achieve for feeder link and UE uplink pre-compensation are [8]:• Time delay < 0.4 µs • Doppler shift < +/- 20 HzThese limits apply to a UE positioned at the center of a satellite beam.Proposal 2: The required accuracy of satellite position and satellite velocity broadcast by the Gateway is:

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| --- | --- | --- |
| *Use* | *Position accuracy* | *Velocity accuracy* |
| *PVT info in SIB signaling for UE pre-compensation* | *< 120 m* | *< 1.5 m/s* |

Observation 1: LEO satellites are typically equipped with onboard GNSS receivers with position accuracy in the order of 10 meters and velocity accuracy in the order of 10 cm / s. Observation 2: Satellite position, Velocity, and Time (PVT) information can be transmitted to the gateway via an auxiliary channel in real-time in a typical report of size 28 bytes every 10 seconds.Observation 3: Satellite PVT report can be propagated by Gateway over a period of 2 hours with a position accuracy of < 1 m. |
| Qualcomm | Based on our best knowledge, without an on-board GPS receiver, the accuracy of LEO satellite’s geolocation available at UE side can range from several 100 meters to 10 km. Consider UL frequency control Option 1 that can have larger frequency error than Option 2. There are two main frequency error sources: UE residual frequency error after synchronized to DL signal, denoted by R in ppm. Estimation error of the Doppler of the service link, denoted by D in ppm.The UL frequency error in ppm after UE autonomous compensation with option 1 can be found asF\_e=R+2∆D (1)For a given location estimation error L, the maximal Doppler error occurs at a UE that is right underneath the satellite and can be found as∆D=v∆L/ch (2)where v and c are the speed of satellite and light, respectively, and h is the satellite height. From Eq. (2), it can be seen that every 1 km horizontal location error of the satellite at 600 km orbit translates to about 0.04 ppm in Doppler estimation error. From Eq. (1), we have the following observation.Observation 2: Unless satellite location accuracy at UE side can be less than 1 km, UE UL frequency error without network frequency control is non-negligible. |

### Companies views

Some companies [Thales, MediaTek] mentioned the requirement of 0.1 ppm captured in TR 38.101:

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| *6.4 Transmit signal quality**6.4.1 Frequency error**The UE basic measurement interval of modulated carrier frequency is 1 UL slot. The mean value of basic measurements of UE modulated carrier frequency shall be accurate to within ± 0.1 PPM observed over a period of 1 ms of cumulated measurement intervals compared to the carrier frequency received from the NR Node B.* |

It has been proposed to restrain the frequency error resulting of the imperfect satellite mobility compensation such that it can be considered included in this budget of 0.1 ppm. For instance, one can consider that 20% of this budget shall be allocated for this purpose. Then, the frequency compensation shall be sufficiently accurate such that the error induced on the RX frequency at the reference point is lower than 0.02 ppm. This target shall apply to all UEs inherently of their RRC state.

[ZTE] proposed to consider instead 10% of the SCS used for PRACH or PUSCH. Note that this requirement is more relaxed than the one aforementioned.

Only two companies[MediaTek, ZTE] proposed methods to derive the tolerated error on the satellite position and velocity based on the allocated budget for frequency error.

[MediaTek] provided the constraints on both the satellite position and velocity assuming the frequency error shall be lower than 0.02 ppm. The demonstration to derive the relation between the Doppler shift error and the satellite position and velocity error has been provided.

For LEO

 ∆U<±120m

 ∆V<±1.5 m/sec

 For GEO

 ∆U< ±21 km

 ∆V< ±2.7 m/sec

[ZTE] proposed another formula to derive the tolerated location error based on the maximal frequency error tolerated. Note that the error on the satellite velocity is not mentioned.

Finally, typical assumptions regarding the localisation performance of LEO satellites and the propagation of LEO orbits have been provided by [Eutelsat] :

Observation 1: LEO satellites are typically equipped with onboard GNSS receivers with position accuracy in the order of 10 meters and velocity accuracy in the order of 10 cm / s.

Observation 3: Satellite PVT report can be propagated by Gateway over a period of 2 hours with a position accuracy of < 1 m.

Based on the above discussion, the FL recommendation would be:

**FL recommendation 6-3:**

**RAN1 to further investigate the requirement related to UL frequency synchronization. Companies are invited to provide feedback on the proposed requirement:**

* **Option 1: 0.1 ppm w.r.t. to the reference RX frequency generated by the gNB. For instance, 20% of this budget can be allocated for the UE frequency compensation error.**
* **Option 2: 10% of the SCS used for PRACH or PUSCH**

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| **Companies** | **Comments and Views** |
| ZTE | This proposal is more aligned with the 1st alt as commented in Initial proposal 6-2. If the specific value is needed, the Option-1 can be taken as baseline, e.g., as recommendation from RAN1 perspective to RAN4. |
| MediaTek | Same view as ZTE |
| Ericsson | This is a delicate issue that requires careful coordination with RAN4. It is correct that the 0.1 ppm requirement is specified in 38.101. So, we suggest discussion along Option 1, with e.g. LS communications with RAN4 on this topic. |
| Intel | Both options are acceptable for us |
| Qualcomm | Requirements will be defined by RAN4. RAN1 can provide performance impacts. |
| Huawei | Not sure about the intension of the agreement. We should first identify how the requirement impact RAN1 design in what way then consult RAN4 if needed. |
| Samsung | Similar to the above, we propose to deprioritize this issue if there is no critical motivation on this for UL synchronization design for NTN. This can be done by RAN4. |

**FL recommendation 6-4:**

**Only 2 companies proposed a methodology to derive the tolerated error on the satellite position and velocity based on the allocated budget for frequency error. Companies are invited to propose other methods or share critical views w.r.t. the already proposed methods.**

Note that these mathematical relationships are essential for RAN1 to validate whether the NTN UE will be able to apply frequency compensation with sufficient precision.

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| **Companies** | **Comments and Views** |
| ZTE | All solution used are only as example, it should be aligned with the main target, e.g., to ensure the performance with implementation of pre-compensation. |
| MediaTek | Same viw as ZTE |
| Ericsson | This should be coordinated with RAN4. |
| Huawei | Further discussion is needed. |
| Samsung | Similar to the above, we propose to deprioritize this issue if there is no critical motivation on this for UL synchronization design for NTN. |

# Other issues

Some other issues reported by the companies:

TA reporting:

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| **Companies** | **Proposals** |
| InterDigital, Inc | Proposal 4: a PRACH resource set is configured per distance group from the UE to satellite and a UE determine a PRACH resource set for Msg1 transmission based on the distance group the UE belongs to. |
| Samsung | Proposal 2: UE’s estimated TA value is reported to gNB, if K\_offset is updated UE-specifically. |
| CEWiT | Proposal 4: UE should report the applied TA to the gNB for better control over UE behavior. |

The other proposals related to UL frequency synchronization are summarized below:

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| **Companies** | **Comments and Views** |
| CMCC | Proposal 15: Network compensate the doppler shift on the feeder link, which is transparent to UE. |
| Ericsson | Observation 5 If the position of a reference point of the feeder link and the UL and DL carrier frequencies of the feeder link are signaled to the UE, the UE can autonomously determine the time and frequency offset of both the service link and the link between the satellite and the reference point of the feeder link, which would simplify the time and frequency compensation procedures.Proposal 14 Support broadcasting a reference point of the feeder link and UE autonomous determination of the time and frequency offset of both the service link and the link between the satellite and the reference point of the feeder link. |
| Qualcomm | Proposal 7: Support SRS with multiple coherent symbols with configurable gaps.  |

# References

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4. R1-2009077 Considerations on Enhancements on UL Time Synchronization in NTN CAICT
5. R1-2007855 UL time and frequency compensation for NTN CATT
6. R1-2009292 UL time synchronization for NTN systems CEWiT
7. R1-2008011 Enhancements on uplink timing advance for NTN CMCC
8. R1-2009092 On UL time and frequency synchronization enhancements for NTN Ericsson
9. R1-2009016 Discussion on UL timing synchronization for NTN ETRI
10. R1-2008867 Satellite Position Accuracy Eutelsat S.A.
11. R1-2007570 Discussion on UL time and frequency synchronization enhancement for NTN Huawei, HiSilicon
12. R1-2008990 On UL time and frequency synchronization for NTN Intel Corporation
13. R1-2009117 On UL time/frequency synchronization for NTN InterDigital, Inc.
14. R1-2008923 Discussion on NTN TA indication Lenovo, Motorola Mobility
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24. R1-2009153 Consideration on enhancements on UL time and frequency synchronization Spreadtrum Communications
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26. R1-2007661 Discussion on UL time and frequency synchronization enhancements for NR-NTN vivo
27. R1-2009033 Discussion on UL time and frequency synchronization for NTN Xiaomi
28. R1-2008851 Discussion on UL synchronization for NTN ZTE