3GPP TSG RAN WG1 Meeting #104e R1-210XXXX

January 25th – February 5th, 2021

Agenda Item: 8.15.2

Source: Moderator (MediaTek)

Title: Summary #2 of AI 8.15.2 Enhancements to time and frequency

synchronization

Document for: Discussion and Decision

# Introduction

In RAN#86 meeting, a new Study Item was approved for IoT Non Terrestrial Network (NTN) [1]. In this meeting, company views on UL synchronization for IoT NTN are summarized and observations/proposals on identified issues are made. Observations and proposals in Company’s TDoc contributions are listed in the Appendix.

# Enhancements to time and frequency synchronization common to NR NTN and IoT NTN

ZTE mentioned similar to NR-NTN, UEs in IoT-NTN are assumed with GNSS capability [1]. Therefore, GNSS-assist UL pre-compensation methods proposed for NR-NTN should also be considered in IoT-NTN. There seems to be consensus on this view. OPPO, Huawei, CATT, Vivo, MediaTek, Intel, Spreadtrum, Sony, Ericsson, Asia Pacific Telecom, CMCC, Xiaomi, Samsung, Apple, Interdigital, Qualcomm mentioned in some form to re-use timing and frequency compensation mechanisms or principles for UL synchronization agreed in NR NTN in IoT NTN.

To avoid re-discussing every agreement on Enhancements to time and frequency synchronization, it is the view of the moderator that the related NR NTN agreements with no FFS should at least be included in a TP to TR 36.763. Agreements in NR NTN including FFS can also be included on the understanding that the FFS should first be discussed in NR NTN and revised in TR 36.763 timely. Companies may flag issues with a particular agreement if it needs to be revised for IoT NTN. Agreements in NR NTN containing FFS on options should not be included at this stage. The other way would be not to include these NR NTN agreements in the TR 36.763. It is not clear during a follow up WI phase for IoT NTN, which agreement in NR NTN WI would apply to IoT NTN and which would not, and where to find these agreements. This approach would increase the risk of re-opening discussions on the NR NTN WI agreements during an IoT NTN WI. The other way would be to reference the TR 38.821 in rel-16 NR NTN SI [2]. It is not clear for aspects such as UE pre-compensation using GNSS-acquire UE position and satellite ephemeris were not much discussed and further agreements were made in the normative phase in Rel-17. Hence, it is the view of the moderator to include NR NTN WI agreements in TR 36.763.

## TP#1 Proposal 1 for TR 36.763

***Initial Proposal Section 2.1:***

***Include in TR 36.763, the listed agreements on enhancements to time and frequency synchronization from NR NTN WI:***

***It is recommended that the following enhancements are considered for timing and frequency synchronization for UL transmission for normative phase:***

***An NTN UE in RRC\_IDLE and RRC\_INACTIVE states is required to at least support UE specific TA calculation based at least on its GNSS-acquired position and the serving satellite ephemeris.***

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

***An NR NTN UE in RRC\_CONNECTED states shall be capable of at least using its acquired GNSS position and satellite ephemeris to perform frequency pre-compensation to counter shift the Doppler experienced on the service link.***

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| **Company** | **Comments and Views** |
| ZTE | Fine to reuse the conclusion in NR-NTN for UL timing and frequency synchronization. But not sure whether to capture it in the TR at this stage given the solution is actually not complete yet. |
| Huawei | We are supportive to reuse the conclusion in NR-NTN for UL time and frequency synchronization but share a similar view with ZTE that the TP can wait a bit given the discussion is still ongoing and solution is not complete. |
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## TP#2 Proposal 1 for TR 36.763

***Initial Proposal Section 2.2:***

***Include in TR 36.763, the listed agreements on enhancements to time and frequency synchronization from NR NTN WI:***

***It is recommended that the following enhancements are considered for timing and frequency synchronization for UL transmission for normative phase:***

* ***In NTN, the network may broadcast*** 
  + ***A common timing offset value*** 
    - ***FFS details of the common timing offset***
  + ***FFS: A common timing drift rate***
* ***Before Msg1/MsgA transmission, the NR NTN UE in idle/inactive mode calculates its TA as follows:***

***where:***

***is derived from the User specific TA self-estimation***

***is derived at least from the common timing offset value if broadcasted by the network. The granularity of and whether is indicated as a Timing Advance or as a Timing Offset value [unit] are FFS. Upon resolving the FFS, one of the X in the equation will be removed.***

***depends on band and LTE/NR coexistence and is specified in TS 38.213 section 4.2.***

***is specified in TS 38.211 section 4.1.***

* ***Note: UE will not assume that the RTT between UE and gNB is equal to the calculated TA for Msg1/Msg A.***

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| **Company** | **Comments and Views** |
| ZTE | Same concern as in initial Proposal Section 2.1. Moreover this part is still under discussion. |
| Huawei | See comments on Initial Proposal Section 2.1: |
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## NR NTN WI time and frequency synchronization issues

Several companies contributed aspects on issues of time and frequency synchronization that are still under discussion in NR NTN [3]. It is un-desirable to have this approach unless there is a clear difference for IoT NTN for these aspects, which may lead to different conclusions. One exception is TA update in connected mode with autonomous TA adjustment by the UE (Issue#2), which could be one potential enhancement for long UL transmission

On GNSS accuracy requirements, MediaTek commented in [4] that the GNSS time reference in a typical GNSS chipset implementation can be guaranteed within a ±10 ns [5]. The GNSS position accuracy is in the order of ±3 m (=c\*t=3. 108 m/s \*10.10-9 s). GPS-enabled smartphones are accurate within a 4.9 m radius under open sky [6]. NTN use cases are targeted at outdoor coverage, where UE GNSS-based position should be always available. For LEO, the GNSS receiver on board of satellite is at least as accurate as GNSS receiver in device. The satellite position and UE position can be known with great accuracy in the order of 1 m - 3 m. The velocity can also be known with great accuracy since based on GNSS receiver in satellite and GNSS time can be accurate within ±10 ns. Eutelsat provided analysis showing that 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 [7].

On autonomous TA acquisition based on Timestamp, Nokia proposed timestamp method using time reference broadcast on SIB16 (in NR NTN, time reference is broadcast on SIB9) and make observations on the requirements for GNSS based time synchronization for the RACH preamble transmission. Nokia propose to evaluate whether GNSS based time frequency synchronization could be accurate for IoT cases with reduced number of receiver antenna, reduced power consumption, not covered by GNSS satellite (in this case consider a second synchronization solution). The moderator view is that the timestamp method does not require specification change. The timestamp on SIB16 has already been specified in Rel-15. A GNSS time reference to generate the internal clock in device will require tight integration between the GNSS module and NB-IoT/eMTC module to measure accurately the total satellite delay and determine the Doppler shift to apply for the UE pre-compensation. In effect, the timestamp method could be already used within the current specifications providing both the UE and eNB can be synchronized accurately to GNSS with impact on specifications mainly in RAN4. There could be limitation on using simultaneously the GNSS module and IoT module and high reliance of the device on GNSS to synchronize its internal clock to GNSS. This would require very accurate GNSS time acquisition and tracking. This seems to be higher requirement for GNSS accuracy than the approximate GNSS position with several hundred meters accuracy for UE pre-compensation based on GNSS-acquired position and satellite ephemeris. To the moderator understanding the GNSS antenna configuration and more generally GNSS module design is not specified in 3GPP and is an implementation consideration.

Specific aspects of use of GNSS module such as Half Duplex for UL, DL and GNSS reception, GNSS accuracy, UE capability, and UE power consumption are further discussed in section 4 and section 5.

***Working assumption Section 2.3:***

***The following aspects are still for further study in NR NTN WI and should not be prioritized for discussions in IoT NTN SI***

* ***Common timing offset with value X if broadcast by the network (Issue#1)***
* ***Common timing drift if broadcast by the network (Issue#1)***
* ***Autonomous TA acquisition based on Timestamp (Issue#1)***
* ***Indication of TA margin for over UE pre-compensation with autonomous TA (Issue#1-2)***
* ***Indication of common frequency offset pre-compensation and post-compensation at gNB side (Issue 3-2)***
* ***Serving satellite ephemeris format with orbital parameters or Position and velocity state vectors (Issue #5)***
* ***GNSS accuracy requirements (Issue#6)***
* ***UL time synchronization requirements (Issue#7)***
* ***UL time synchronization requirements (Issue#8)***

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| **Company** | **Comments and Views** |
| ZTE | We are supportive for the intention, but for some issue, e.g., Issue 7/8, difference between IoT and NR eMBB may be distinguished. |
| Huawei | This working assumption seems to be guidance to the overall discussion. We are fine with the list in general. We assume one of Issue#7 and Issue #8 should be “UL frequency synchronization requirements”. |
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# IoT NTN specific enhancements to time and frequency synchronization

It is noted that companies mainly avoided to re-discuss the same issues that were concluded in NR NTN and instead mainly contributed on IoT specific issues. This is very appreciated by the moderator, as it highly preferable to avoid re-discussing the same issue and potential designs that were concluded in NR NTN, unless there is a specific difference where these cannot apply to IoT NTN. Companies also contributed on the delta specific to IoT NTN to further refine the solutions within the agreements in NR NTN. We list the main differentiators of IoT NTN compare to NR NTN:

1. GNSS measurement window: ZTE mentioned GNSS search and data scheduling should be investigated to achieve a tradeoff between power saving and synchronization performance.
2. GNSS Position fix impact on UE power consumption: Ericsson proposed RAN1 should discuss whether GNSS positioning in RRC\_CONNECTED state is to be supported by IoT NTN UE and also proposed to study the impact of GNSS measurements on UE battery consumption prior to initial access and means to minimize the amount of GNSS measurements. Qualcomm proposed restricting alternate starting subcarriers for NPRACH transmissions to allow to correct for potentially large initial uplink frequency synchronization errors (e.g., up to 1 kHz) to save UE power with fewer GNSS fixes.
3. NTN SIB reading impact on UE power consumption: Qualcomm also proposed restricting alternate starting subcarriers for NPRACH transmissions to avoid frequent SIB reads (to acquire satellite ephemeris) required for UE pre-compensation to save UE power consumption.
4. Long UL transmission time: Huawei, ZTE, CATT, Vivo, MediaTek, Lenovo, Xiaomi mentioned this needs further discussions for UE pre-compensation.
5. DL synchronization: ZTE, CATT, Qualcomm, MediaTek [8] have proposed a new channel raster for DL synchronization. Ericsson also proposed to investigate DL synchronization. Qualcomm also proposed as a solution to include a portion of the ARFCN in the (NB-)MIB.

CATT proposed to study resource isolation mechanism for different users in UL signal transmission with 3.75 kHz sub-carrier spacing if UL frequency error is large. Consider the following:

* Huawei, Ericsson, and MediaTek have provided analysis and simulations using Eutelsat orbit data showing very good accuracy of UE determination of satellite Doppler shift and delay with an UL frequency error <10 Hz and UL time error < 0.10 us assuming propagation of orbital parameters or satellite position and velocity state vectors over 60 seconds (i.e. based on prediction of satellite position and velocity up to 60 seconds after reading serving satellite ephemeris on NTN SIB). This suggest that the accuracy of UE pre-compensation using GNSS capability can be sufficiently accurate.
* MediaTek mentioned in case of IoT NTN device with mobility ([4], section 4.1), acquiring position at most once per 10 seconds (@120 km/h would only result in a maximum UE position changes by ~300 m or 40 Hz worst additional Doppler (or per 30 seconds, it is 900 m or 120 Hz) which would still be well within the ≠0.1 ppm UL frequency error requirement.

A note in the Rel-17 IoT NTN SID states clearly that assumption of GNSS capability is that UE can estimate and pre-compensate timing and frequency offset with sufficient accuracy for UL transmission.

*NOTE: GNSS capability in the UE is taken as a working assumption in this study for both NB-IoT and eMTC devices. With this assumption, UE can estimate and pre-compensate timing and frequency offset with sufficient accuracy for UL transmission. Simultaneous GNSS and NTN NB-IoT/eMTC operation is not assumed.*

This would suggest that items (2) and (3) are out of scope of the Study Item, as it is not an objective to optimize UE power consumption to achieve sufficient accuracy.

While UE power consumption is not in scope of SID, it is reasonable and desirable to discuss this important aspect in the context of UE pre-compensation with GNSS capability assumption. Studying impact of GNSS use on IoT NTN power consumption and impact of NTN SIB reading could be considered to determine whether the GNSS accuracy would lead to un-acceptable impact on UE power consumption. This would need to be studied first before considering RACH enhancements, UL frequency correction, and sub-carrier isolation for UL transmission with sub-carrier spacing 3.75 kHz are needed and beneficial.

***Initial Proposal Section 3:***

***Do companies agree to at least study the following for UE pre-compensation based on GNSS capability and satellite ephemeris:***

1. ***GNSS measurement window***
2. ***GNSS Position fix impact on UE power consumption***
3. ***NTN SIB reading impact on UE power consumption***
4. ***Long UL transmission time***
5. ***DL synchronization***

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| **Company** | **Comments and Views** |
| ZTE | Agree to at least study these issues as a start point. |
| Huawei | We think this is an important topic and the impact to power consumption should be carefully studied. In order to facilitate the study, maybe it would be good clarify the above aspects and agree on a set of simulation assumptions for further evaluation. |
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# GNSS measurement window

Simultaneous GNSS and NTN NB-IoT/eMTC operation is not assumed. GNSS module always on is neither desirable nor necessary. In case UE is paged, the GNSS module can be switched on for GNSS position fix followed by NTN specific SIB read to obtain the serving satellite ephemeris for UE pre-compensation before UL transmission. A GNSS Time To First Fix (TTFF) typically take 1 second (hot fix if GNSS ephemeris known with last TTFF within 4 hours) or less than 5 seconds (warm start if GNSS Almanac known with last TTFF within 180 days). The time duration between the WUS and paging and UL transmission shown on the figure below should be sufficient for the GNSS TTFF. ZTE propose to study mechanism to trigger GNSS search when UE wakes up and UL transmission begins after GNSS receiving.

It is not clear whether there is specification change required or existing paging procedure can be used with adequate configuration of timer T3413. In cellular UE in extreme coverage, the MME initiated paging procedure can take several seconds as WUS then the NPDCCH on Common Search Space Type-1 needs to be received. The NPDCCH can be transmitted with up to Rmax=2048 repetitions. The paging message with many repetitions is then decoded before the UE initiates the Random access procedure. The RACH preamble may be transmitted with up to 1024 repetitions, followed by RAR, Msg 3, and Msg 4 with many repetitions for the RRC Connection request and RRC RRC Connection Request Complete.

The UE may autonomously stop receiving on NB-IoT module, switch on GNSS module for GNSS TTFF, then switch off the GNSS module, and switch on the NB-IoT module back to initiate the random access procedure. This should be fine as long as the timer T3413 is configured properly.

The moderator view is that RAN2 could first discuss this potential issue for configuration of T3413 and whether it is needed to enhance the paging procedure for IoT NTN.

***FL Recommendation Section 4:***

***Moderator view is that RAN2 could first discuss this potential issue of GNSS measurement window and whether configuration of T3413 and paging procedure need to be enhanced for IoT NTN.***



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| **Company** | **Comments and Views** |
| ZTE | Disagree. The GNSS measurement issue is related to the whole pre-compensation behavior, parallel discussion in RAN1 is also needed. |
| Huawei | We think the assumption of GNSS measurement window will have an impact on the overall synchronization procedure, data transmissions and UE power consumption. Maybe there is no need to wait for RAN2 conclusion. |
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# GNSS Position fix impact on UE power consumption

The moderator view is that the following issues are being discussed in NR NTN WI and should be de-prioritized in discussions in IoT NTN to avoid overlap between NR NTN WI and IoT NTN SI.

- GNSS accuracy requirements (Issue#6)

- UL time synchronization requirements (Issue#7)

- UL time synchronization requirements (Issue#8)

Studying impact of NTN SIB reading carrying the satellite ephemeris could be considered to determine whether the use of GNSS capability in device to get position TTFF for accurate UL time and frequency synchronization would lead to un-acceptable impact on UE power consumption. This would need to be studied first before considering whether enhancements for RACH, UL frequency correction, and sub-carrier isolation for UL transmission with sub-carrier spacing 3.75 kHz are needed and beneficial.

Huawei provided NB-IoT UE battery life analysis with GNSS fix with transmission of 50 bytes with 2 hours interval using GNSS signal reception with power consumption of 216 mW [9]. This shows that with a GNSS position fix of 2 seconds the reduction in battery life could be up to 50%. This assumes GNSS signal reception

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| **Protocol flow assumptions** | **Duration(ms)/each report** | **Power(mW)** | **Power consumption(mWh)** |
| **GNSS signal reception** | X | 216 | 216X/36e5 |
| **NPSCH(DL)** | 291 | 70 | 0.00566 |
| **NPBCH(DL)** | 10 | 60 | 0.00017 |
| **NPRACH(UL)** | 40 | 500 | 0.00556 |
| **NPDCCH(DL)** | 30 | 60 | 0.0005 |
| **NPUSCH(UL, 50bytes)** | 320(50bytes) | 500 | 0.04444 (50bytes) |
| **NPDCCH(DL)** | 30 | 60 | 0.0005 |
| **NPDCCH(DL)** | 30 | 60 | 0.0005 |
| **NPDSCH(DL)** | 100 | 60 | 0.00167 |
| **NPUSCH(UL)** | 40 | 500 | 0.00556 |
| **NPDCCH(DL)** | 30 | 60 | 0.0005 |
| **NPDCCH(DL, monitor)** | 120 | 60 | 0.002 |
| **Standby** | 7200000 | 0.015 | 0.03 |



MediaTek contributed on NB-IoT UE battery life analysis in [10]. Using same methodology and including GNSS power consumption of 30 mW (note that typical GNSS power consumption is 37 mW for acquisition and 27 mW for tracking [5]), it can be shown that over PSM typical cycle with GNSS ON for 1 to 2 seconds, the reduction in battery life is between -1% and -21%. Using same use case as Huawei with transmission of 50 bytes with 2 hours interval, the reduction in battery life is 21.47% assuming GNSS TTFF of 24 seconds or 4.09 % assuming GNSS TTFF o 2 seconds with coupling loss of 144 dB. This reduces to 13.31% and 3.77% assuming GNSS TTFF of 24 seconds with coupling loss 154 dB and 164 dB respectively. Much lower battery life reductions are shown in the table blow for larger packet size of 200 Bytes or more infrequent transmission – i.e. once a day.



Note that the Huawei and MediaTek analysis are worst case scenarios for IoT NTN. In practical IoT NTN deployment:

* Assuming a fixed IoT NTN device (e.g. sensor on a gas/petrol pipeline, heat temperature sensor), a GNSS position fix will be needed only once during set up phase and not be needed whenever a UE wakes up from DRX either via a timer setup via RRC configuration or via application layer.
* Assuming a moving IoT NTN device (e.g. used for vehicular tracking) would may require frequent GNSS position fix but may not be a problem if he IoT NTN device is connected to the vehicle battery via the dashboard or if embedded within the vehicle.
* IOT NTN devices will be typically left outdoors for a period greater than a year. They are unlikely to be in a protected environment where they cannot be damaged by the weather, people, or simply normal wear and tear.

Hence, it seems unlikely that the GNSS position fix for UE pre-compensation could be a serious concern for the battery life. Moderator views is that companies can contribute analysis based on rel-13 UE battery life methodology in [8].

***Initial Proposal Section 5:***

***Do companies agree to at least study the GNSS Position fix impact on UE power consumption based on Rel-13 NB-IoT battery life methodology with GNSS power consumption 30 mW.***

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| **Company** | **Comments and Views** |
| ZTE | Fine to reuse the Rel-13 NB-IoT battery life methodology. The GNSS searching time and the GNSS receiving frequency (e.g. periodic) will impact on UE power consumption, which needs to be investigated. W.r.t the 30 mW, it can be taken as one candidate value. |
| Huawei | We are fine to reuse the same methodology. However, it is important to settle down the assumptions on GNSS measurement window. The GNSS power consumption value can be FFS. |
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# NTN SIB reading impact on UE power consumption

The moderator view is that the following issues are being discussed in NR NTN WI and should be de-prioritized in discussions in IoT NTN to avoid overlap between NR NTN WI and IoT NTN SI.

- GNSS accuracy requirements (Issue#6)

- UL time synchronization requirements (Issue#7)

- UL time synchronization requirements (Issue#8)

Studying impact of NTN SIB reading carrying the satellite ephemeris could be considered to determine whether the use of GNSS capability in device to get position TTFF for accurate UL time and frequency synchronization would lead to un-acceptable impact on UE power consumption. This would need to be studied first before considering whether enhancements for RACH, UL frequency correction, and sub-carrier isolation for UL transmission with sub-carrier spacing 3.75 kHz are needed and beneficial.

A UE needs to prepare for UE pre-compensation on receiving paging or before initiating data transfer. This requires UE to synchronize on DL and obtain at least once the system information for RRC configuration when first accessing a satellite cell or waking up from long DRX. If UE re-selects a cell, the UE may read the MIB and SIB1, which contains indication on whether the system information needs to be refreshed.

MediaTek observed that it is not necessary for the UE to re-acquire the whole system information for RRC configuration for UE pre-compensation. Similarly to SIB9 in NR URLLC and SIB16 in LTE HRLLC that is acquired to get GNSS timestamp with low latency, the UE could acquire the serving satellite ephemeris Position and Velocity in an NTN-specific SIB. The SIB1 can indicate the scheduling of the new NTN-specific SIB carrying the satellite Position and Velocity. Once there is paging or UE needs to transmit data, the UE may need to acquire the NTN-specific SIB with the satellite position and velocity. This only requires the UE to decode 16 bytes every time it wakes up from DRX and is either paged or needs to transmit data.

Receiving and decoding small payload of 16 bytes on an NTN-specific SIB has no significant impact on power consumption as it is a small fraction of the processing and transmission power required by the device needs to transmit / receives Msg1, Msg2, Msg3, Msg4, Msg5 in the initial cell access procedure to transmit data and further messages to receive data.

Assuming UE power consumption figure for Rx in previous section, NTN SIB with 16 bytes transmitted in 10 ms for worst case of 50 Bytes every 2 hours, the impact on battery life of NTN SIB reading to acquire 16 bytes satellite ephemeris for UE pre-compensation if UE is paged or UE needs to transmit data is a negligible reduction of approximately 0.32%. The reduction will be expected to be smaller at lower coupling loss of 154 dB or 164 dB, or at larger packet size of 200 bytes.

***FL Recommendation Section 6:***

***Moderator view is that impact on battery life of NTN SIB reading to acquire 16 bytes satellite ephemeris for UE pre-compensation if UE is paged or UE needs to transmit small data packet is a not significant. Companies are encouraged to provide analysis on impact on NTN-specific SIB carrying satellite ephemeris for UE pre-compensation.***

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| **Company** | **Comments and Views** |
| Huawei | The satellite ephemeris has not been decided including the format and periodicity. We are fine to study this further but maybe no need to have the moderator view in the recommendation given there has not been much input yet. |
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# Long UL transmission

The long UL transmission in NB-IoT / eMTC are discussed for PUSCH and PRACH. The general issues related to the long UL transmissions and potential solutions should have high synergies between NB-IoT and eMTC.

## Long UL transmission on PUSCH

In IoT NTN, depending on the coverage class many repetitions may be needed. In NB-IoT, up to 1024 repetitions of NPUSCH Format 1 may be scheduled for UL transmission on data on the PUSCH. In the NB-IoT specification 36.211, the NPUSCH UL Compensation Gap (UCG) is used to allow UE to re-synchronize on DL during long UL transmission exceeding 256 ms. UCG definition is given as “*After transmissions and/or postponements due to NPRACH of time units, a gap of time units shall be inserted where the NPUSCH transmission is postponed. The portion of a postponement due to NPRACH which coincides with a gap is counted as part of the gap*.” When 2 HARQ processes are configured, the total maximum duration of both NPUSCH transmissions is not more than 256 ms, and any scheduling gap between the two NPUSCHs counts as part of the 256 ms as illustrated in an example in Figure 2.



The time drift in LEO @ 600 km is around 0.71 us in one RTD of 28.4 ms as given in TR 38.821. In a time duration of 256 ms, the total drift can be around 6.4 us which is larger than the Cyclic Prefix for UL transmission on NPUSCH. The Doppler shift variation can be 544 Hz/s. There are several solutions possible:

* Option 1: Use UE-specific TA calculation. The UE uses UE-specific TA calculation based on acquired GNSS position and satellite ephemeris for UE pre-compensation during long UL transmission. Similarly the UE can determine the UE-specific Doppler shift to apply for UE pre-compensation.
* Option 2: Use the timing drift rate. The UE can use knowledge of the timing drift rate to determine the UE-specific TA for UE pre-compensation during the long UL transmission
* Option 3: Use segmented pre-compensation. The UE can interrupt transmission, determine the UE-specific TA / Doppler shift for UE pre-compensation during long continuous repetition transmission.

Option 1: Supported by MediaTek, Spreadtrum

Option 2: Supported by Huawei, Lenovo

Option 3: Supported by ZTE, Vivo

***Initial Proposal Section 7.1:***

***Do companies agree to at least study the following options for UE pre-compensation during long UL transmission on NPUSCH:***

* **Option 1: Use UE-specific TA calculation.**
* **Option 2: Use the timing drift rate.**
* **Option 3: Use segmented pre-compensation.**

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| **Company** | **Comments and Views** |
| ZTE | Supportive for this proposal. Actually, from specification perspective, all these options are not exclusive, e.g., Option-3 can be results of Option 2 or Option-1. The only thing matter is to how to define the “segment”. |
| Huawei | Option 1 cannot be applied during long UL transmission when there is no gap for DL reception. Even with 40ms DL gap for each 512 UL transmission, the GAP may not long enough for acquiring a full information of satellite ephemeris according to the updating period of system information.  Option 2 can be combined with Option 1. The timing drift rate can be derived from the acquired GNSS position and satellite ephemeris and the indicated common timing drift rate. The UE specific TA can be calculated based on these information.  Option 3 seems to suggest the adjustment derived from Option 1 and Option 2 can be applied with segmented pre-compensation. |
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## Long transmission on PRACH

In NB-IoT, NPRACH may be transmitted with up to 2048 repetitions. The time drift in LEO @ 600 km in 2 seconds can be around 51.2 us. NB-IoT UE supports three CP lengths, 66.7us, 266.7us and 800us. Similarly to long transmission of NPUSCH, Option 1 and Option 2 could be considered. Segmented pre-compensation would require RACH interruption, which seems high impact on specifications and implementation.

***Initial Proposal Section 7.2:***

***Do companies agree to at least study the following options for UE pre-compensation during long UL transmission on NPRACH:***

* **Option 1: Use UE-specific TA calculation.**
* **Option 2: Use the timing drift rate.**

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| **Company** | **Comments and Views** |
| ZTE | Same comments as above for NPUSCH. Moreover, since the issue is similar we prefer to take same all Options including Option-3 also for NPRACH. |
| Huawei | Similar to the last comment, Option 1 cannot be applied during the UL transmission as not GAP is available during 64 times of preamble repletion. So, calculating the timing drift rate for the long UL transmission for ephemeris is needed. |
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# DL Synchronization

Eutelsat set 3 (234km) is very close to the maximum beam size that can be supported. Sateliot Set 4 (e.g. 1000km) beam sizes @Nadir point cannot be supported with current CS algorithms. Current Doppler maximum NB-IoT budget for 2.17GHz:

• ±50KHz: Half Tone raster for Initial Cell Search for NB-IoT

• ±10 ppm, ± 20 ppm: typical free running oscillator accuracy

• ± 1ppm : margin. E.g to account for overlapping coverage at beam edge.

• Doppler budget: ±50 kHz - ±11ppm (or ±20 ppm) \*2.17GHz = ± 26.13 kHz (or 6.6 kHz)

The nominal frequency of DL signal is not broadcast. It needs to be determined using a frequency grid with 100 kHz sync raster. If the uncertainty on DL raster is +/-Raster/2=+/-50 kHz, the UE can know exactly the DL frequency. It will first determine in which frequency grid the DL signal can be found, and then can synchronize with great accuracy on DL signal. If the uncertainty > +/-Raster/2, then the UE cannot know its DL frequency. If the UE does not know the DL frequency it does not have a DL synchronization source to use the right sampling rate and correctly generate the UL frequency. A new Channel Raster of 200 kHz could be potential solution to support beam diameter size with ±20 ppm. Another alternative is to broadcast the DL frequency, e.g. as part of the NTN SIB. Table below shows maximum Doppler shift at LEO 600 km for IoT NTN. There are two solutions that have been considered in companies contribution:

* Option 1: New Channel raster increased from 100 kHz
* Option 2: Include a portion of the ARFCN in the (NB-)MIB

Option 1: proposed by ZTE, CATT, Qualcomm, MediaTek

Option 2: proposed by Qualcomm

***Initial Proposal Section 8:***

***Do companies agree to at least study the following options for DL synchronization:***

* **Option 1: New Channel raster increased from 100 kHz**
* **Option 2: Include a portion of the ARFCN in the (NB-)MIB**

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| --- | --- | --- | --- | --- |
| Beam diameter size @Nadir point | 93 km | 234 km | 1000 km | 2000 km |
| 3dB Beam-width in degrees (2γ) | 8.86 deg | 22.03 deg | 77.7 deg | 111.5 deg |
| Elevation angle at beam edge | 85.15 deg | 77.93 deg | 46.63 deg | 25.26 deg |
| Maximum Differential Doppler @fc=2GHz | ± 3.89 kHz | ± 9.63 kHz | ± 31.63 kHz | ± 41.65 kHz |
| Maximum Differential Doppler @fc=2.17GHz | ± 4.22 kHz | ± 10.44 kHz | ± 34.32 kHz | ± 45.19 kHz |

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| **Company** | **Comments and Views** |
| ZTE | We are supportive for this proposal. Meanwhile, one important issue related to the synchronization performance degradation, e.g., PSS detection, DL timing/frequency offset estimation/maintenance should also be discussed. |
| Huawei | Agree with ZTE that the basic DL time and frequency synchronization performance should also be studied. The detailed solutions would be a second level discussion when problems are identified during the studied. |
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# Appendix

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| Contribution | Observation/Proposals |
| OPPO (R1-2100161) | Proposal 1: RAN1 shall decide if GNSS non-capable UE is in the scope of this release.  Proposal 2: For GNSS capable UE, reuse NR-NTN agreements for time and frequency synchronization. |
| Huawei (R1-2100234) | Observation 1: The UL time and frequency synchronization enhancement of NR NTN can be applied to IoT NTN.  Observation 2: RACH failure may happen for an NB-IoT UE since it may stay in the cell for a short time, which leads to increased power consumption.  Proposal 1: Reuse the UL time and frequency synchronization enhancement design and conclusions of NR NTN in IoT NTN.  Proposal 2: Study the effects of long UL transmission duration on UL time synchronization.  Proposal 3: The timing drift rate can be accounted for by the UE to compensate the timing offset during the long UL transmission.  Proposal 4: Study solutions for the possible RACH failure due to the insufficient time to stay in a given cell’s coverage. |
| ZTE (R1-2100249) | Observation 1: 100 kHz channel raster may not be large enough to avoid ambiguity in DL synchronization of IoT over NTN when multiple cells from different satellites could cover same UE.  Observation 2: Performance degradation will be experienced in IoT over NTN for different satellite parameters.  Observation 3: Performance degradation will occurs for the continuous transmission with larger repetition.  Observation 4: The NPRACH design can still work for UL synchronization in NTN scenario once the accurate UL pre-compensation is done.  Proposal 1: Channel raster should be enhanced in IoT over NTN when multiple cells from different satellites are allowed to cover same area.  Proposal 2: DL synchronization performance should be evaluated with potential enhancement for target scenarios.  Proposal 3: Scheduling of GNSS search and data transmission should be investigated to achieve a tradeoff between power saving and synchronization performance.  Proposal 4: Segmented pre-compensation for long continuous repetition transmission should be considered.  Proposal 5: Study PRACH format to improve UE density. |
| CATT (R1-2100266) | Observation 1: UE may have the maximum initial frequency error more than 50KHz contributed by oscillator, Doppler shift and anchor carrier offset in S band.  Observation 2: Except for format 4, preamble format needn’t be enhanced for GNSS-capable UE.  Observation 3: The accumulated timing error produced within a single transmission duration with multiple times repetition may exceed the tolerance of CP for NB-IoT and eMTC.  Proposal 1: Study the impact to channel raster configuration due to higher frequency error in IoT NTN.  Proposal 2: Reuse timing and frequency compensation mechanism of NR NTN to IoT NTN by taking into account UE power assumption.  Proposal 3: Defining specific requirement on synchronization accuracy for IoT NTN is needed.  Proposal 4: Study resource isolation mechanism for different users in UL signal transmission to guarantee UL transmission performance of NB-IoT NTN.  Proposal 5: RAN1 needs to study if Preamble format 4 is supported for eMTC NTN due to higher timing accuracy requirement.  Proposal 6: Further study the timing and synchronization issue in UL repetition transmission. |
| Vivo (R1-2100481) | Observation 1: TA information is out of date during NPRACH repetitions.  Observation 2: Frequency is out of synchronization during repetitions.  Proposal 1: Time synchronization can reuse relevant design and conclusions of NR NTN.  Proposal 2: The start time of RAR time window and Msg3 transmission should be redesigned.  Proposal 3: The update or re-calculation of TA information should be considered  Proposal 4: The extension of UL gap should be considered.  Proposal 5: Enhancement on UL gap and repetition number should be considered.  Proposal 6: Compensation methods of frequency synchronization in NR NTN can be applied to IoT NTN.  Proposal 7: For frequency synchronization, reduced duration of repetitions transmission could be considered. |
| MediaTek (R1-2100601) | Proposal 1: The value of X in shall be determined as:   * UL subframe and DL subframe timing aligned at the gNB: if X is expressed at a unit of Ts or if expressed as a unit of time * UL subframe and DL subframe timing aligned at the satellite: X = 0.   It is up to the network to configure the value of X.  Proposal 2: The common timing drift over the feeder link is broadcast.  Proposal 3: for UE with Autonomous acquisition of the TA, UE shall use one of:   * TA\_offset of half the cyclic prefix of PRACH preamble which is added to Timing Offset value X broadcast by the network when applying the TA pre-compensation. * Timing Offset value X including a margin TA\_offset broadcast by the network when applying the TA pre-compensation.   Observation 1: UE pre-compensation using satellite ephemeris can be applied to NR, NB-IoT, or eMTC with accuracy in the prediction of the serving satellite position and velocity in the order of a meter and 0.18 m/s respectively up to 10 seconds after reading the instantaneous serving satellite position and velocity state vectors broadcast on an NTN-specific SIB (i.e. corresponding to implicit reference time linked to the Downlink subframe where the SIB is broadcast).  Observation 2: The UE can autonomously determine its UE-specific TA support for UL time synchronization during continuous UL transmission up to 256 ms without need for more frequent UL Compensation Gaps for UL synchronization.  Proposal 4: For UE pre-compensation of satellite delay:   * An IoT NTN UE in RRC\_IDLE and RRC\_INACTIVE states is required to at least support UE specific TA calculation * An IoT NTN UE in RRC\_CONNECTED state is required to at least support UE specific TA calculation.   Proposal 5: For UE pre-compensation of satellite Doppler shift   * An IoT NTN UE in RRC\_IDLE and RRC\_INACTIVE states shall be capable of at least using its acquired GNSS position and satellite ephemeris to calculate frequency pre-compensation to counter shift the Doppler experienced on the service link. * An IoT NTN UE in RRC\_CONNECTED states is capable of at least using its acquired GNSS position and satellite ephemeris to perform frequency pre-compensation to counter shift the Doppler experienced on the service link.   Proposal 6: 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 7: Satellite Position and Velocity information field sizes broadcast on SIB with periodicity X   * The field size for position is 78 bits * The field size for velocity is 54 bits * Value of X – e.g. 200 ms, 500 ms, 1000 ms, 1500 ms, 2000 ms   Observation 3: UE pre-compensation is sufficiently accurate to fulfill the timing and synchronization requirements necessary for UL transmission as listed below:   * For TA update in RRC\_IDLE and RRC\_INACTIVE states, UE pre-compensation of satellite delay of PRACH transmission is within a timing error at the gNB corresponding to a satellite position error ΔU   + PRACH format 0, or * For TA update in RRC\_CONNECTED state, UE pre-compensation of satellite delay of UL transmission is within a timing error at the satellite corresponding to a satellite position error ΔU   + or . * For UE in RRC\_IDLE, RRC\_INACTIVE, and RRC\_CONNECTED states, accuracy of UE pre-compensation of satellite Doppler shift is within maximum UL frequency error of ± 0.1ppm.   Observation 4: The UE does not needed to read all the system information necessary to configure a device before accessing satellite cell. It is sufficient if the UE acquired at least once the system information with SIB1 to know the scheduling of NTN-specific SIB carrying the serving satellite ephemeris position and velocity state vector with a payload of around 16 bytes.  Observation 5: The device only needs to acquire the serving satellite ephemeris position and velocity state vector broadcast on SIB if it is paged or if it needs to transmit data. This is small additional SIB reading over the baseline where the System Information for RRC configuration is read when there is a change of system information when there is a change of cell or satellite. Receiving and decoding small payload of 16 bytes on an NTN-specific SIB has no significant impact on power consumption as it is a small fraction of the processing and transmission power required by the device needs to transmit / receives Msg1, Msg2, Msg3, Msg4, Msg5 in the initial cell access procedure to transmit data and further messages to receive data.  Observation 6: With sufficient accuracy of time and frequency for UE pre-compensation to achieve UL synchronization and broadcast with low latency of 16 bytes for serving satellite Position and Velocity on NTN-specific SIB, the legacy PRACH procedure and signals for NB-IoT and eMTC can be re-used to support Non Terrestrial Networks without enhancements. |
| Intel (R1-2100683) | Proposal 1:   * Accurate UL synchronization is achieved by using pre-compensation of delay and Doppler for UL transmission based on GNSS at the UE and satellite ephemeris broadcasted by the gNB   + Enhancements on PRACH and closed-loop UL frequency control are not needed   Proposal 2:   * Time and frequency offset introduced in service link is pre-compensated by the UE for UL transmission based on UE location (from GNSS) and satellite ephemeris (broadcasted by the gNB) * The following options are considered for compensation of time and frequency offset introduced in feeder link for UL transmission   + Post-compensation at the gNB side   + Pre-compensation at the UE side based on broadcast information from the gNB   Proposal 3:   * Enhancements for non-GEO satellite deployment with moving beams and frequency reuse should be discussed assuming existing features of eMTC and NB-IoT (e.g. multi-carrier operation and mobility)   + Increased number of anchor carriers for NB-IoT multi-carrier operation can be considered |
| Lenovo. Motorola Mobility (R1-2100763) | Proposal 1: A common timing offset (TO) and a TO drift rate for the propogation delay of feeder-link are broadcast in SIB.  Proposal 2: UE can calculate distance/delay for service link and update the distance/delay based on the satellite velocity.  Observation 1: For NPUSCH transmission with large number repetition, the TA adopted in the beginning is not suitable in the middle/end of the TB transmission.  Proposal 3: TA value drift during the repetitions should be considered in UL transmission in IoT on NTN. |
| Spreadtrum (R1-2100810) | Proposal 1: Reuse UL timing compensation mechanism of NTN WI in IoT NTN.  Proposal 2: Reference point for autonomous acquisition of the TA at UE is located at the satellite.  Proposal 3: Both open and closed control loops are supported in connected mode for IOT NTN.  Proposal 4: Reuse frequency compensation mechanism of NTN WI in IoT NTN.  Proposal 5: In IOT NTN, the reference point for frequency synchronization is located at the satellite.  Proposal 6: Updates on the pre-compensation value of time delay and frequency offset during the repetitions should be considered in UL transmission. |
| Sony (R1-2100875) | Proposal 1: RAN1 studies the following two methods for the UE determining timing advance:   * Option 1: Autonomous acquisition of the TA at the UE based on satellite ephemeris and knowledge of UE and eNB location   + Further refinement of TA can be signaled in the RAR message   + Distance from eNodeB to satellite may be signaled instead of eNodeB location * Option 2: Timing advance by network indication   + Network broadcasts a common TA to be applied in the cell   + Extended values of TA may be signaled in RAR   Proposal 2: The UE pre-compensates the frequency of its UL transmissions in order to mitigate for Doppler shift.  Proposal 3: The frequency compensation that the UE is to apply to UL transmissions is based on:   * UE GNSS receiver measurements of UE position and velocity * SIB signaling of either satellite ephemeris information or satellite position and velocity information   Proposal 4: RAN1 studies ways of mitigating PRACH congestion when IDLE mode UEs simultaneously transmit PRACH after receiving satellite position and velocity information. |
| Ericsson (R1-2100931) | Observation 1 As GNSS-equipped UEs can perform timing/frequency pre-compensation before MSG1 transmission, the existing (N)PRACH formats for NB-IoT/eMTC in TN are also sufficient for NTN scenarios.  Proposal 1 UE should pre-compensate its timing and frequency before transmitting MSG1.  Proposal 2 As a baseline, the time and frequency synchronization for eMTC and NB-IoT should follow the same principles as outlined in the NR NTN WI.  Proposal 3 RAN1 should investigate DL synchronization performance for NB-IoT and eMTC NTN.  Proposal 4 RAN1 should discuss whether GNSS positioning in RRC\_CONNECTED state is to be supported by IoT NTN UE  Proposal 5 Study the impact of GNSS measurements on UE battery consumption prior to initial access and means to minimize the amount of GNSS measurements. |
| Asia Pacific Telecom (R1-2100976) | Observation 1 A reference point for calculating UL transmission timing can be set on the ground, in the air, at the satellite, at the eNB, or a certain point on the service link or a feeder link.  Proposal 1 To guarantee the robustness of initial cell search with low complexity, e.g., one-shot detection, enhancement on time and frequency synchronization shall be considered.  Proposal 2 Evaluate the existing NPRACH formats and determines whether all of them can be reused in NTN.  Proposal 3 A reference point for UL transmission timing shall be set at the eNB, if needed.  Proposal 4 To maintenance UL frequency, any update of NW assistance information may need a signaling mean other than using system information. |
| Nokia (R1-2101028) | Observation 1: If GNSS based time synchronization is used for IoT over NTN, the entire cyclic prefix of the random access preamble should be able to cover multipath propagation delay as well as the inaccuracy imposed by the compensation algorithm based on the GNSS information.  Observation 2: the maximum doppler shift supported by current LTE NB-IoT/eMTC design is much lower than expected doppler shift in NTN scenario.  Observation 3: The power consumption and impact on timing and frequency accuracy for NB-IoT/eMTC UE with GNSS processing is unclear.  Observation 4: Using referenceTimeInfo-R16 and UE based understanding of GNSS time will suffer less from the satellite movement in terms of timing advance as the reference point is at a static location (the gNB).  Proposal 1: DL synchronization performance based on LTE NPBCH/NPSS/NSSS and LTE PBCH/PSS/SSS in NTN scenario should also be evaluated, like for SSB in Rel-15.  Proposal 2: If GNSS based time synchronization is used for IoT over NTN, the aggregate contribution of all sources of inaccuracy must not violate the limits imposed by the cyclic prefix of the random access preamble.  Proposal 3: 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.  Proposal 4: link budget of GNSS and IoT in NTN should be evaluated.  Proposal 5: it should be evaluated whether GNSS based time frequency synchronization could be accurate for following IoT cases  · With reduced number of receiver antenna  · With reduced power consumption  · Not covered by GNSS satellite  Proposal 6: how to compensate large doppler shift for IoT UE should be studied, where simplification of IoT UE processing could be considered.  Proposal 7: RAN1 and RAN4 should select one alternative of reference point to be working assumption and it is preferred that the selection should be also base line for IoT NTN scenario.  Proposal 8: power consumption should be studied for time/frequency sync in IoT over NTN when UE wake up and sync in UL gap, expecially with GNSS cold or warm starting.  Proposal 9: In case GNSS accuracy is not accurate enough or not always available, UL random access procedure should be studied, with baseline as NR over NTN solutions but power consumption and complexity/cost reduction should also be considered.  Proposal 10: it should be evaluated whether GNSS based time frequency synchronization could be accurate for IoT cases.  Proposal 11: Considering all issues on GNSS accuracy and GNSS fault for IoT UE with reduced antenna number, second synchronization solution should be studied, not based on GNSS or with less dependence on GNSS.  Proposal 12: Half duplex for UL, DL and GNSS reception should be studied considering GNSS accuracy and UE capability.  Proposal 13: in CONNECTED mode, power consumption and accuracy for NB-IoT/eMTC UE with GNSS processing should be studied.  Proposal 14: Network should be in control of the timing advance updates applied at the UE.  Proposal 15: If UE is performing autonomous update of timing advance during RRC\_CONNECTED mode, the network should know the details of such adjustments in advance.  Proposal 16: Self adjustement by the UE based on GNSS time and the time provided by referenceTimeInfo-R16 is a feasible solution and should be standardized as well.  Proposal 17: TA value changing during the repetitions should be configured by Node B for UL transmission in IoT over NTN. |
| CMCC (R1-2101070) | Proposal 1: To support NB-IoT and eMTC over satellite, the conclusions of NR NTN WI should be reused as much as possible with necessary enhancements focus on coverage, capacity, power consumption and complexity (cost).  Proposal 2: Broadcast instant position and velocity vector in system information, if indication of satellite ephemeris is needed.  Proposal 3: For GNSS capability assumption, at least a reference time and frequency can be derived.  Proposal 4: Potential enhancement to enhance the coverage for IoT should be studied. |
| Xiaomi (R1-2101105) | Observation 1: Existing NB-IoT/eMTC PRACH formats and preamble sequences can be reused with the assumption UE having GNSS capability.  Proposal 1: Pre-compensation on the Doppler shift for DL transmission should be considered.  Proposal 2: Reuse the UL time and frequency synchronization mechanism of NR NTN in IoT NTN while taking into account UE processing complexity.  Proposal 3: Study the effects of long UL transmission duration on UL time synchronization. |
| Samsung (R1-2101243) | Proposal 1: TA estimation should be supported for GNSS-capable UE at least for initial access.  Proposal 2: Common TA should be indicated to cover the roundtrip delay between Satellite and Gateway at least for position based TA estimation.  Proposal 3: Whether or not to support reporting of UE’s estimated TA should be further discussed.  Proposal 4: Frequency offset estimation should be supported by GNSS-capable UE for pre-compensation. |
| Apple (R1-2101369) | Proposal 1: IoT over NTN does not enhance PRACH formats and/or preamble sequences in release 17.  Proposal 2: In IoT over NTN, UE obtains UE specific TA based on its GNSS location and serving satellite ephemeris.  Proposal 3: In IoT over NTN, the timing reference point is set at satellite.  Proposal 4: UE calculates and pre-compensates the Doppler shift on service link based on its GNSS location and serving satellite ephemeris.  Proposal 5: Support network pre-compensates the frequency offset in downlink transmissions. |
| Interdigital (R1-2101402) | Proposal 1: The location-based timing compensation technique agreed in NR NTN is adopted for NB-IoT/eMTC.  Proposal 2: For UL frequency offset compensation, network indicates the required frequency offset to be compensated for UL transmission is supported for NB-IoT/eMTC. |
| Qualcomm (R1-2101513) | Observation 1: In S-band frequencies, the frequency error during initial downlink synchronization (initial cell access) can be up to 47.5 kHz + FO\_doppler.  Proposal 1: RAN1 to study enhancements to prevent an UE from locking on to an incorrect frequency corresponding to a (N)cell, such as increasing the raster size, or including a portion of the ARFCN in the (NB-)MIB.  Proposal 2: Support NB-IoT over NTN in standalone and in-band/guard-band with NR modes only.  Proposal 3: Include the first three symbols in a subframe as well as the REs corresponding to the 4 CRS ports for rate matching the NPBCH.  Proposal 4: RAN1 to study potential enhancements to (N)PRACH design, depending on the agreements on satellite location accuracy at the UE (including the frequency of SIB reads required to facilitate that accuracy).  Observation 2: Restricting alternate starting subcarriers for NPRACH transmissions allows to correct for potentially large initial uplink frequency synchronization errors (e.g., up to 1 kHz)   * Such a scheme may facilitate significant UE power savings by requiring less tight pre-compensation requirements in the form of relaxations in the frequency and accuracy of GNSS fixes and SIB reads (to acquire satellite ephemeris) required. |
| Fraunhofer (R1-2101692) | Observation 1: To the best of our knowledge, the performance of GNSS data for NB-IoT over satellite has not been subject to detailed investigations yet.  Proposal 1: The performance of GNSS data shall be evaluated in detail for NB-IoT over satellite by RAN1. The analysis shall be conducted with respect to the limited processing capability according to NB-IoT along with satellite IoT specific requirements such as strong limited power. |