**3GPP TSG RAN WG1 Meeting #102-e R1-xxxxxx**

**E-meeting, August 17-28, 2020**

**Agenda Item: 8.3.4**

**Source: Moderator (Huawei)**

**Title:** **Feature lead summary#1 on propagation delay compensation enhancements**

**Document for: Discussion and Decision**

# Introduction

The revised IIoT / URLLC work item description for Rel-17 [1] has enhancements for time synchronization as one of its main objectives:

|  |
| --- |
| 1. Enhancements for support of time synchronization:
2. RAN impacts of SA2 work on uplink time synchronization for TSN, if any. [RAN2]
3. Propagation delay compensation enhancements (including mobility issues, if any). [RAN2, RAN1, RAN3, RAN4]
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This document summarizes the key issues discussed under agenda item 8.3.4 based on the views in [2][3][4][5][6][7][8][9], and aims to identify and discuss some high-level issues in RAN1#102-e.

# Requirements for time synchronization

The timing synchronization requirements between the clock grand master and the TSN end station are given in [10] and copied below. Please note that these requirements on the overall system level. The toughest numbers have to be achieved is 900 ns for motion control and control-to-control.

Table 1 - Clock synchronization service performance requirements for the 5G System

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| User-specific clock synchronicity accuracy level  | Number of devices in one Communication group for clock synchronisation | 5GS synchronicity budget requirement (note) | Service area  | Scenario |
| 1 | Up to 300 UEs | ≤900 ns  | ≤ 100 m x 100 m | * Motion control
* Control-to-control communication for industrial controller
 |
| 2 | Up to 300 UEs | ≤900 ns  | ≤ 1000 m x 100 m | * Control-to-control communication for industrial controller
 |
| 3 | Up to 10 UEs | < 10 µs | ≤ 2500 m2 | * High data rate video streaming
 |
| 3a | Up to 100 UEs | <1 µs | ≤10 km2 | * AVProd synchronisation and packet timing
 |
| 4 | Up to 100 UEs | <1 µs | < 20 km2 | * Smart Grid: synchronicity between PMUs
 |
| 5 | Up to 10 UEs | < 50 µs | 400 km | * Telesurgery and telediagnosis
 |
| NOTE: The clock synchronicity requirement refers to the clock synchronicity budget for the 5G system, as described in Clause 5.6.1. |

**Feature lead view**: From Table 1, there are different requirements for different use case. In order to make the discussion more focus, it would be good to select some representative use case for further discussion. Considering both the requirements and the difference of potential deployments, it seems use case 2 and use case 4 in Table 1 can be the representative use cases.

***Proposal 2-1****: Take the following use cases as the representative use cases for further study on propagation delay compensation enhancements in Rel-17.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| User-specific clock synchronicity accuracy level  | Number of devices in one Communication group for clock synchronisation | 5GS synchronicity budget requirement (note) | Service area  | Scenario |
| 2 | Up to 300 UEs | ≤900 ns  | ≤ 1000 m x 100 m | * Control-to-control communication for industrial controller
 |
| 4 | Up to 100 UEs | <1 µs | < 20 km2 | * Smart Grid: synchronicity between PMUs
 |

**Please provide your views on the above proposal 2-1, especially if you have different views on the selected representative use case.**

|  |  |
| --- | --- |
| *Company* | *View* |
| Nokia, NSB | Support the view. It could be good to be aligned on the assumptions of the SA2 work on these two representative use cases. Regarding the “Control-to-control” use case, it is out understanding that both a 5GS towards a single UE and the case where a TSC GM is connected to a device behind a UE also applied. But for the “smart grid” use case, it is our understanding that the TSC GM is the 5G GM and hence NOTE 6 from 22.104 does not apply. This means that the 1µs does only apply for one link (one Uu interface).  |
|  |  |

# Evaluation on the necessity of enhancements in RAN1 in Rel-17

In order to evaluate whether any enhancements needed in Rel-17 in order to meet the requirement discussed in section 2, we need the check the performance that can be achieved by Rel-16 mechanisms first.

## Summary of the evaluation and conclusion in Rel-16

ZTE gives a good summary of Rel-16 discussion. In Rel-16, RAN1 has analyzed the time synchronization accuracy of Uu interface for two cases, i.e. synchronization accuracy with and without UE propagation delay compensation. The maximum timing synchronization error results with UE propagation delay compensation are summarized in Table 2 below.

Table 2 – Summary of maximum timing synchronization error results with UE propagation delay compensation given in Rel-16

|  |  |  |  |
| --- | --- | --- | --- |
|  | 15kHz SCS | 30kHz SCS | 60kHz SCS |
| SourceR1-1900156  | 488ns | 357.5ns | 276.5ns |
| SourceR1-1901334  | 505ns | 371ns | 287.5ns |
| SourceR1-1900935  | 472.5ns | 338.5ns |  |
| SourceR1-1901252  | 536ns | 438ns | 357ns |

**Conclusion from the evaluation in RAN1 in Rel-16**:

|  |
| --- |
| RAN1 has performed analysis on the achievable time synchronization accuracy over Uu interface. A timing synchronization error between a gNB and a UE no worse than 540ns is achievable based on the RAN1 agreed evaluation assumptions for Rel-15 NR with 15kHz SCS. It is RAN1´s conclusion, that the synchronization accuracy is improved when using higher SCS. For small service areas with dense small cell deployments a propagation delay compensation by the UE would not be required. The propagation delay compensation needs to be applied by the TSN UEs for larger service areas with more sparse cell deployments (e.g. for inter-site distances >200m the gNB-to-UE timing synchronization accuracy without propagation delay compensation may be worse than 1us). |

In Rel-16, there is no any RAN1 specification work, and RAN2 has agreed that the reference timing information can be sent by SIB9 and dedicated RRC signaling with a granularity of 10ns was introduced to deliver the accurate reference time from the gNB to the UE in RAN2. More details can be found in TR 38.825.

**Feature lead view**: Although we already have the evaluation in Rel-16, some companies pointed out that different companies were estimating the accuracy differently in Rel-16, which can be seen from the values from different source as shown in Table 2 above. In Rel-16, it didn’t matter since the requirements were always fulfilled regardless which method was used. However, the situation is different in Rel-17, since different assumption would result in different conclusion on the necessity of the enhancements in Rel-17. Therefore, it is recommended to further evaluate the achievable time synchronization accuracy over Uu interface.

## Further evaluation on the achievable time synchronization accuracy over Uu interface

There are several aspects which have impact on the timing accuracy between UE and gNB. In order to do the evaluation, it would be good for us to discuss one by one. Note that there is commonality on the potential factors. However, it seems different companies use different name and/or different denotation in the contributions. Therefore, you might find that the name I use here different with what you used in your own paper.

The time synchronization between UE and gNB can be obtained basically through three steps, the first step is the reference time information (denoted by ) delivery, the second step is the downlink frame timing applied by UE, denoted by , and the third step is the estimation of downlink propagation delay, denoted by . The basic mechanism of time synchronization between UE and gNB can be expressed as the equation below. That is, the time clock of UE is equal to the received time clock of gNB plus the downlink propagation delay. A simple illustration of the basic mechanism can be found in Figure 1.



Figure 1: Illustration of time synchronization mechanism

### Error related to BS timing

The accuracy of is mainly impacted by two factors, i.e. one is the frame timing accuracy of BS transmitter and another is the indicating error associated to the indicating granularity of .

The frame timing accuracy of the gNB transmitter can refer to the Time Alignment Error (TAE) which is defined in TS38.104 as a requirement for the base station. This requirement applies to the frame timing in TX diversity, MIMO transmission, carrier aggregation and their combinations. And this requirement is defined due to the frames of the NR signals present at the BS transmitter antenna connectors or TAB connectors are not perfectly aligned in time, and the RF signals present at the BS transmitter antenna connectors or transceiver array boundary may experience certain timing differences in relation to each other. In a sense, the inaccurate frame timing of BS is caused by the misalignment of the BS transmitter timing in different antenna connectors or transceiver array boundary in different transmitting occasions. So the frame timing accuracy can be seen as same as the TAE.

According to the description in the TS38.104 as shown below, there is various requirement for the TAE under different cases.

|  |
| --- |
| 6.5.3.2 Minimum requirement for *BS type 1-C* and *BS type* 1-HFor MIMO transmission, at each carrier frequency, TAE shall not exceed 65 ns.For *intra-band contiguous carrier aggregation*, with or without MIMO, TAE shall not exceed 260ns.For *intra-band non-contiguous carrier aggregation*, with or without MIMO, TAE shall not exceed 3µs.For inter-band *carrier aggregation*, with or without MIMO, TAE shall not exceed 3µs.The time alignment error requirements for NB-IoT are specified in TS 36.104 [13] clause 6.5.3. |

**Question 3-1: What value should we assume for TAE for different representative use cases as given in section 2 (i.e. control-to-control and smart grid)?**

|  |  |
| --- | --- |
| *Company* | *View* |
| Nokia, NSB | TAE only applies if the respective feature is supported. We may assume that in the indoor scenario MIMO from different gNBs/TRPs or intra-band CA is supported and hence we have an inter-gNB error bounded by TAE of <65ns or <260ns. However, as we see it there are no TAE applicable for the smart grid scenario (unless we assume TDD band operation (<3µs). Therefore, we have to make an assumption on the maximum error between gNBs or at a single gNB. Our internal analysis suggests 400ns between gNB. This translates to a single gNB error between the time-stamping entity and the air interface SFN timing of: ±130ns for the indoor scenario and ±200ns for the smart grid scenario. |
|  |  |

It seems the indicating error would be associated to the indicating granularity of . According to what agreed in RAN2 in Rel-16, the granularity is 10 ns here.

### Error related to UE timing

The downlink frame timing at the UE receiver represents the arrival time of the downlink signal, and is obtained via detecting the downlink signal of the reference cell. The requirement of UE initial transmit timing error has been defined in TS 38.133 which is denoted by Te, and it represents the uplink transmission timing error of UE in a DRX cycle for PUCCH, PUSCH and SRS or it is the PRACH transmission. It mainly includes the detecting error of downlink signal by UE, and also includes the implementation error of UE due to the internal processing jitter. Both of these factors have impact on the final timing accuracy between UE and gNB. So basically the time error related to UE timing can be seen as same as Te.

According to the description in TS 38.133, Te has various values under different scenarios.



**Feature lead**: For the UE transmit timing error here, it seems we can take whatever defined in the RAN4 specification, and there should be no controversial views.

**Question 3-2: Do you agree that the value defined in TS 38.133 can be used directly for all the representative use cases?**

|  |  |
| --- | --- |
| *Company* | *View* |
| Nokia, NSB | Not agree. We do not agree that Te is applicable for this analysis as it only reflects the initial timing error. If we studied the worst cases, then OK, but here we have devices, which are not power limited and could be in RRC-CONNECTED all the time to receive (g)PTP messages. Instead we need to model the TA mechanism with the errors of the UE detection inaccuracy of the DL reference signal, applying the latest TA-C (noted TA-err or TA-adj). It is further our understanding that the UE transmitter chain is sufficiently simple, that that no mismatch exists between the UE timing understanding and the actual transmission on the air interface (hence no additional error (apart from a single sample maybe) at the UE transmitter chain. |
|  |  |

### Error related to DL propagation delay estimation

UE decides the downlink propagation delay according to the TA value obtained from TA command sent by gNB. According to the current TA mechanism, the TA command delivery is realized by implementation. That is, gNB decides, by realization, when to deliver the TA command to UE, and UE may re-obtain the TA value after the TA-alignment timer expires according to the specification. At worst case, the TA accuracy can be seen as about half of CP length since gNB may trigger the TA command delivery after one or several uplink demodulation failures. At best case, it can be assumed that gNB can deliver the TA command to UE in time and the accuracy relies on the detailed TA processing which is analyzed as follows. Since the TA command delivery belongs to the behavior which gNB has ability to control, **it is assumed that gNB can deliver the TA command in time at least to the UEs which have requirement of high accuracy time synchronization**.

#### Asymmetry between downlink and uplink channel

UE estimates the downlink propagation delay as half of the TA value obtained from gNB, which introduces error due to the asymmetry between downlink and uplink propagation delay. In TDD system, the downlink and uplink channel fading can be seen strongly correlated with each other while the time gap between them is short enough. And the asymmetry between downlink and uplink propagation delay is mainly due to the change of small scale fading. In FDD system, the situation is a little worse since the downlink and uplink signal are transmitted at different carrier frequencies. In general, devices in factory or electric system have low mobility, so it can be assumed that the downlink and uplink channel with time gap of dozens of milliseconds have the same large scale fading. Then the asymmetry is mainly caused by the change of multi-path distribution.

**Feature lead**: Based on the views in the contribution, it seems some companies assume there is no asymmetry between DL and UL. More views are needed.

**Question 3-3: Do we need to consider asymmetry between downlink and uplink channel? If yes, what value should we assume?**

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| --- | --- |
| *Company* | *View* |
| Nokia, NSB | No, we don’t need to consider asymmetry. The error introduced by asymmetry can be assumed to be quite small (if present). Asymmetry is only present if the second path is stronger and of a certain longer PD. In that case asymmetry is also only contributing by half to the inaccuracy introduced by PD estimation using TA. |
|  |  |

#### BS detecting error

BS decides the value of the TA for a certain UE by detecting the reference signal (e.g. SRS) sent by the UE, so the detecting error impacts the final accuracy of the time synchronization. However, it was observed in the contributions that the performance here would be impacted by some other factors also, e.g. the bandwidth of the signal.

**Question 3-4: What value should we assume here? Please provide your detailed analysis on how you achieve your value also.**

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| --- | --- |
| *Company* | *View* |
| Nokia, NSB | Based on simulations we have found that a value of 100ns for 15kHz and 92ns for 30kHz can be assumed. |
|  |  |

#### TA Indicating error

The indicating granularity of TA command causes additional error, i.e. the error can be as large as half of the indicating granularity. According to 38.213, the TA indicating granularity is , so the indicating error can be assumed as .

 for 15kHz

 for 60kHz

**Question 3-5: Do you agree with using**  **as the TA indicating error in the evaluation of the baseline performance? If you don’t agree, please provide your value and the corresponding analysis here also.**

|  |  |
| --- | --- |
| *Company* | *View* |
| Nokia, NSB | Agree |
|  |  |

#### Downlink frame timing error

The downlink frame timing error also impacts the accuracy of the estimation for downlink propagation delay . As shown in Figure 2, the estimated TA equals to correct TA plus Te without regard to other factors.



Figure 2: Te impacts the TA estimating accuracy

**Question 3-6: Do you have any other views on downlink frame timing error?**

|  |  |
| --- | --- |
| *Company* | *View* |
| Nokia, NSB | This assumption only applies when Te applies (i.e. the UE has been in DRX). We do not think this assumption applies for the scenarios related to this analysis. |
|  |  |

#### Overall error of the downlink propagation delay

In general, the error of TA estimation is composed of BS detecting error, TA indicating error and the downlink frame timing error. And the total error of TA estimation is calculated as:

Since the downlink propagation delay is gotten from the following equation sets:

So the downlink propagation delay is calculated as:

.

Then the error of the downlink propagation delay is:

**Question 3-7: Do you agree with the above method to calculate the error of downlink propagation delay? If your answer is No, please provide your suggestion here also.**

|  |  |
| --- | --- |
| *Company* | *View* |
| Nokia, NSB | We find the model insufficient as it does not capture the UE detection inaccuracy or the application error of timing advance. To estimate the PD the UE will use based on TA, the estimation will be as following (excluding TAE and TI as these error sources apply to the SFN timing (compared to R1-2006341)):tUE-SFN-TX-Timing = tUE-RX – ½TA1  = tUE-RX – (TO1 + TETA-C + TA0).The error then related to PD estimation becomes:TERAN-PD-estimation = ½TEUE-DL-RX + ½(dPD-DL - dPD-UL) - ½TEgNB-UL-RX - ½TETA-err - ½ TETA-C |
|  |  |

### 5GS Network time synchronization error budget

Nokia (R1-2006341) provides views on Network time synchronization error also.

|  |
| --- |
| **Network (NW) part** accounts for the time synchronization error caused by distributing the 5G GM to the gNB through the NW. When the 5G GM source is shared between the UPF and the gNB, the synchronization error involved in this, is also included in the network part. For the UE-UE synchronization scenario, the network part accounts for the relative synchronization error between the gNB providing the involved UEs with the 5G GM.5GS Network time synchronization error budget Based on the description above on the network part, we consider two general options for deployment of the 5G GM clock;1. A single 5G GM clock source (e.g. from aGNSS receiver or a TSC GM) is distributed to the gNB and UPF (NW-TT) with a (g)PTP framework.
2. Multiple 5G GM clock instances (of the same time-domain, e.g. from multiple GNSS receivers) are distributed in the scenario (e.g. one at each gNB and UPF).

We consider that Option A is relevant for the indoor factory scenario, where we assume that the 5G GM clock source, UPF and gNB are located within the same facility and potentially within the same rack. The connection between UPF (NW-TT) and gNB is assumed to span over maximum four (g)PTP capable hops relative to the 5G GM. According to The RAN3 LS in R3-187252 this can introduce an maximum error of TE<|4 ∙40ns|, corresponding to an error within ±80ns. For Option B, when multiple 5G GM clock sources (of the same reference) are provided throughout the scenario, the NW accuracy does not depend on the path between the 5GS components, but on the synchronization error between two 5G GM clock instances (e.g. GNSS receivers). Considering the 5G GM instance is provided by GNSS receivers, the maximum error between the GNSS receivers are 200ns according to R3-187252, which translates to a time synchronization error range of maximum ±100ns.  |

**Question 3-8: Do you have any different views on Network time synchronization error?**

|  |  |
| --- | --- |
| *Company* | *View* |
|  |  |
|  |  |

### Any other aspect that will have impact on the time synchronization?

If companies have some suggestion on additional factor that will have impact on the time synchronization, please indicate it here.

**Question 3-9: Any other aspect we need to consider also?**

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| --- | --- |
| *Company* | *View* |
| Nokia, NSB | Input from UE vendors on potential UE introduced timing errors would be good to get on the table now. |
|  |  |

### Overall error of the time synchronization

Once the factors that will have impact on the error of the time synchronization are set, we need some method to calculate the overall error of the time synchronization. It would be good if companies can provide some views here also.

One example is show as below (network time synchronization is not considered here):







It can be seen from the equation that the total error of the time synchronization is:

**Question 3-10: How to calculate the overall error of the time synchronization?**

|  |  |
| --- | --- |
| *Company* | *View* |
| Nokia, NSB | We agree with the principle of the analysis above, but on the the use of Te and would like to highlight that TAE and TI is not accounted for. The text below is copied from our t-doc [R1-2006341]:Starting at the air interface, (i.e. between two antennas), a reference signal is subject to propagation delay and detection errors at the receiver. The latter is subject to the bandwidth (fading conditions) and receivers sampling capabilities. So we may denote the antenna reception time at the UE to betSFN-UE-RX = tSFN-UE-TX + dPD-DL+ TEUE-DL-RX.As we use the SFN timing (tSFN-UE-RX) at the UE as our reference time for the timestamp received in referenceTimeInfo-r16, we need to account for the gNB introduced error for the transmission time and timestamp recording. This time error is denoted TETAE in this analysis and represents the gNB antenna port timing to the gNB timestamp used in referenceTimeInfo-r16 (providing the SFN timestamp. As mentioned in [4], there are no requirements on this in the specifications, but they can be derived from the RAN4 specifications of gNB TAE which captures the timing inaccuracy between two antenna ports. Further, there is a rounding error from the resolution of the referenceTimeInfo-r16 IE. Eventually, from an 5GS E2E perspective, the distribution of the 5G clock from the source of the clock to the gNB generating the timestamping, is also subject to errors denoted here as TETI. So we need to add the errors TETAE and TETI. The total accuracy error for cases without propagation delay compensation then becomesTERAN-Not-PD-Compensated = TEUE-DL-RX + dPD-DL + TETAE + TETI .We then consider the case where timing advance is applied for PD compensation. The UE UL transmission time is based on the UE’s DL reference timing, the latest TA command and the TA application error which is bounded by RAN4 (TETA-err) The expression becomes, assuming that TA is a positive numbertUE-TX = tUE-RX – TA0 + TETA-err . The gNB measures and compares the received signal time from the UE with the expected time and calculates the timing offset (TO). Again, the UL transmission is subject to air interface introduced errors such as propagation delay and receiver detection errors. The gNB may issue a new TA command to the UE, instructing it to adjust its UL transmission time with TO. This adjustment is subject to rounding error due to a limited TA adjustment granularity, which we denote TETA-C. The UE will add the new TA command adjustment to its previously applied TA and obtain the new and updated TA value. The applied TA by the UE can then be expressed asTA1 = TO1 + TETA-C + TA0 , where we note that the TETA-err is only considered when the UE adjusts its TA. So to not include it twice, it is not visible in this expression.We can then express the UEs best estimation of the transmission time of the SFN boundary by the DL reception time minus half the applied TA value tgNB-UE-Estimate = tUE-RX – ½TA1 . Putting it all together we get the following expression for the total time synchronization error when the TA procedure is used for PD compensation TERAN-PD-Compensated = ½TEUE-DL-RX + ½(dPD-DL - dPD-UL) - ½TEgNB-UL-RX - ½TETA-err - ½ TETA-C - TETAE + TETI .When, lets consider the case where the 5G clock timestamping entity is both a DS-TT, we need to consider the relative time difference at two UEs, which we express asTEUE0-UE1 = |tUE0 – tUE1| , wheretUE0 = tgNB0 + TEUE0-DL-RX + dPD-DL-gNB0-UE0 and tUE1 = tgNB1 + TEUE1-DL-RX + dPD-DL-gNB1-UE1The difference between transmission timing on the air interface on gNB0 gNB1, depends on the functional and hardware in the gNB architecture and whether components are shared in the synchronization chain to each UE. In this analysis we assume that the UEs are connected to two separate DUs but the same CU. |
|  |  |

In addition, it can be expected that the SCS will have impact on the final time synchronization also. To make the discussion more focus, it would be good for us to have some representative SCS for the representative use cases. Nokia pointed that 15 kHz can be considered for smart grid, while 30 kHz can be considered for control-to-control.

**Question 3-11: Do you agree that we can prioritize 15 kHz for smart grid and 30 kHz for control-to-control use case when evaluating the time synchronization?**

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| --- | --- |
| *Company* | *View* |
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|  |  |

If companies have some other views on how to evaluate the baseline performance here, please provide it here.

**Question 3-12: Any other view on how to evaluate the baseline performance on time synchronization?**

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| --- | --- |
| *Company* | *View* |
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|  |  |

# Potential enhancements for propagation delay compensation

At the moment, there is no consensus yet if enhancements are needed. However, it would be good if we in the group can already now get more understanding about the different candidate methods that are on the table. Based on the contribution review, it seems the following methods and their pros and cons are considered.

* **Option 1**: TA-based propagation delay (includes finer granularity of TA indication, TA adjustment error improvement, DL synchronization error improvement):
	+ Pro: mandatory feature, more UEs will support it.
	+ Con: Impact on legacy functions
* **Option 2**: RTT based delay compensation:
	+ Pro: Can achieve better accuracy than TA based delay compensation. Specified in positioning AI
	+ Con: Because positioning is optional, not as many UE will support it. Need to break out some part from positioning?
* **Option 3**: Finer delay compensation granularity:
	+ Pro: No impact on legacy functions and can achieve the same performance as a finer TA granularity.
	+ Con: New parameter that would need to be specified.

**Question 4-1: Do you have any suggestion on the formulation of the above three options? Any other option that need to be list here?**

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| --- | --- |
| *Company* | *View* |
| Nokia, Nokia Shanghai Bell | *We propose to split Option 1 into two:* Option 1a: Propagation delay estimation based on legacy Timing advance (potentially with enhanced TA-C granularity).Option 1b: Propagation delay estimation based on timing advanced enhanced for time synchronization (as 1a but with updated RAN4 requirements to TA adjustment arror and Te)*We also propose to split Option 2 into two:*Option 2a: Propagation delay estimation based on reusing the existing Rx-Tx based procedure from Positioning. Option 2b: Propagation delay estimation based on an RAN managed Rx-Tx procedure intended for time synchronization (FFS to expand or separate procedure to positioning). Option 3 is not clear at all. Is would assume that the gNB has a PD estimation acquired and signals this to the UE? But how does the gNB acquire this?We would like to highlight that if timing advance can be reused for the purpose of time synchronization, this should be preferred, as it will have a minimum of specification effort. Option 1b can quickly become overuse of TA for time synchronization, and have significant larger specification effort than Option 1a, therefore Option 1a should be the baseline method for PD estimation for time synchronization. That said, we believe that the accuracy can be further enhanced with Option 2a and 2b, but it is not in all cases that this is needed, and the corresponding overhead in configuring e.g. PRS and SRS and Rx-Tx measurements and reporting of these measurements, is significantly larger than for Option 1a and 1b. To avoid binding PD estimation together with a positioning UE capability, we prefer Option 2b over 2a. In summary, we propose to focus on Option 1a, but if time allows, study Option 2b as a supplementary procedure. |
|  |  |

# References

1. RP-201310, *Revised WID: Enhanced Industrial Internet of Things (IoT) and ultra-reliable and low latency communication (URLLC) support for NR* , Nokia, Nokia Shanghai Bell
2. [R1-2005378](file:///C%3A%5CUsers%5Cwanshic%5COneDrive%20-%20Qualcomm%5CDocuments%5CStandards%5C3GPP%20Standards%5CMeeting%20Documents%5CTSGR1_102%5CDocs%5CR1-2005378.zip) Other issues for Rel-17 URLLC vivo
3. [R1-2005435](file:///C%3A%5CUsers%5Cwanshic%5COneDrive%20-%20Qualcomm%5CDocuments%5CStandards%5C3GPP%20Standards%5CMeeting%20Documents%5CTSGR1_102%5CDocs%5CR1-2005435.zip) Discussion on propagation delay compensation enhancements ZTE
4. [R1-2005705](file:///C%3A%5CUsers%5Cwanshic%5COneDrive%20-%20Qualcomm%5CDocuments%5CStandards%5C3GPP%20Standards%5CMeeting%20Documents%5CTSGR1_102%5CDocs%5CR1-2005705.zip) Discussion on propagation delay compensation enhancements CATT
5. [R1-2006062](file:///C%3A%5CUsers%5Cwanshic%5COneDrive%20-%20Qualcomm%5CDocuments%5CStandards%5C3GPP%20Standards%5CMeeting%20Documents%5CTSGR1_102%5CDocs%5CR1-2006062.zip) Enhancement for Propagation Delay Compensation OPPO
6. [R1-2006143](file:///C%3A%5CUsers%5Cwanshic%5COneDrive%20-%20Qualcomm%5CDocuments%5CStandards%5C3GPP%20Standards%5CMeeting%20Documents%5CTSGR1_102%5CDocs%5CR1-2006143.zip) Discussion for propagation delay compensation enhancements Samsung
7. [R1-2006341](file:///C%3A%5CUsers%5Cwanshic%5COneDrive%20-%20Qualcomm%5CDocuments%5CStandards%5C3GPP%20Standards%5CMeeting%20Documents%5CTSGR1_102%5CDocs%5CR1-2006341.zip) Discussion on RAN1 involvement in propagation delay compensation Nokia, Nokia Shanghai Bell
8. [R1-2006803](file:///C%3A%5CUsers%5Cwanshic%5COneDrive%20-%20Qualcomm%5CDocuments%5CStandards%5C3GPP%20Standards%5CMeeting%20Documents%5CTSGR1_102%5CDocs%5CR1-2006803.zip) Enhancements for support of time synchronization for enhanced IIoT and URLLC Qualcomm Incorporated
9. [R1-2006930](file:///C%3A%5CUsers%5Cwanshic%5COneDrive%20-%20Qualcomm%5CDocuments%5CStandards%5C3GPP%20Standards%5CMeeting%20Documents%5CTSGR1_102%5CDocs%5CR1-2006930.zip) Enhancements for support of time synchronization Huawei, HiSilicon
10. TS 22.104 V17.3.0, “Service requirements for cyber-physical control applications in vertical domains”

# Appendix – Selected details from company papers and proposals

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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| R1-2005378, vivo | *vivo R1-2005378*Table 1: Timing error in clock synchronisation

|  |  |  |
| --- | --- | --- |
| **Factors** | **Timing error type** | **Requirement for different SCS (kHz) (unit: ns)** |
| 15 | 30 | 60 | 120 |
| 1 | Inaccuracy caused by downlink/uplink frame timing alignment |
| 1.1 | Time alignment error of gNB transmitter (TETAE) | 65 | 65 | 65 | 65 |
| 1.2 | Inaccuracy caused by UE detection (TEUE-DL-RX) | 260 | 260 | 163 | 98 |
| 1.3 | Inaccuracy caused by propagation delay when propagation delay is decided from TA. (1.3.1+1.3.2+1.3.3)/2 | 375 | 245 | 192.5 | 119 |
| 1.3.1 | Inaccuracy of UE transmitting (TEUE-DL-to-TX) | 390 | 260 | 228 | 114 |
| 1.3.2 | Inaccuracy of gNB detection (TEUL-RX) | 100 | 100 | 92 | 92 |
| 1.3.3 | Inaccuracy caused by TA indication (TETA-G) | 260 | 130 | 65 | 32 |
| 1.4 | Inaccuracy caused by propagation delay when considering 20km2 service area (TEPD) | 8410 | 8410 | 8410 | 8410 |
| 2 | Inaccuracy caused by time reference information delivery from gNB to UE (TERT) | 5 | 5 | 5 | 5 |
| 3 | Inaccuracy caused by the synchronisation between the gNB and external clock (TEEC) | 100 | 100 | 100 | 100 |
| Total error | Total inaccuracy for 20 km2 service area (with propagation compensation) = (2\*(1.1+1.2+1.3+2+3)) | 1610 | 1350 | 1051 | 774 |

**Proposal 1: NTA/2 is used for the propagation delay compensation of the reference time.****Observation 1: After the propagation delay compensation, the inaccuracy of 15/30/60 KHz SCS cannot fulfil the TSN clock synchronization requirements.****Proposal 2: RAN1 should discuss the potential enhancements for the propagation delay compensation:*** **More accurate DL signal detection (1.2)**
* **More accurate UL signal transmission (1.3.1)**
* **More accurate UL signal detection (1.3.2)**
* **Finer granularity of TA indication (1.3.3)**
 |
| R1-2005435, ZTE | * The gNB wants to transmit DL signal to the UE at t1. In fact, the DL signal is transmitted by the gNB at t2 due to the gNB transmitting time error (e1), where e1 is a negative error. It means that the gNB transmits the signal before the time that the gNB wants to transmits, i.e. t2 is before t1 as shown in Figure 1.
* After DL propagation, the DL signal arrives to the UE at t3, where t3-t2 is the DL propagation delay. Due to DL synchronization error (e2), the UE detects that the DL signal is received at t4, where e2 is a negative error so that t4 is before t3 as shown in Figure 1.
* When the UE performs UL signal transmission, the TA indicator error (e4) and TA adjustment error (e5) should be taken into account, which leads to the UE transmits UL signal at t6, where e4 and e5 are positive errors so that t6 is after t4 as shown in Figure 1.
* After UL propagation, the UL signals arrives to the gNB at t8, where t8-t6 is the UL propagation delay. t8-t7 is the unbalance between the DL and UL (i.e. e6), which is a positive error so that t8 is after t7 as shown in Figure 1. t7 is the time that the UL signals arrives to the gNB if we assume UL propagation delay is equal to the DL propagation delay.
* Due to UL synchronization error (e3), the gNB detects that UL signal arrives at t9, where e3 is a positive error so that t9 is after t8 as shown in Figure 1.
* In order to adjust the UE transmitting time such that the UL signals is aligned at the gNB, the TA should be 2PDL+e3+e4+e5+e6-e1-e2. Note: all the ex in the equation are the positive time duration value.

Figure 1 An example of time error The UE detects that DL signals arrives to the UE at t4. According to the UE-based method, the UE thinks t4 is reference timing plus half of the TA, i.e. t1+TA/2=t1+1/2\*(2PDL+e3+e4+e5+e6-e1-e2). However, the correct time of t4 is t1+PDL-e1-e2. Therefore, the timing synchronization error is 1/2\*(e1+e2+e3+e4+e5+e6). Note that the time error for the other cases are also given in the appendix. ***Observation 1:*** *Propagation delay compensation is performed by UE implementation in Rel-16.****Observation 2:*** *The time accuracy of Uu interface should be improved to meet the requirements in Rel-17.****Proposal 1:*** *It's better to achieve an aligned result on synchronization accuracy of Uu interface by aligning the calculation method and assumption before going further on the enhanced propagation delay compensation.****Proposal 2:*** *The maximum timing synchronization error with UE propagation delay compensation should be 1/2\*(e1+e2+e3+e4+e5+e6), where e1 is the gNB transmitting time error, e2 is the DL synchronization error, e3 is the UL synchronization error, e4 is the TA indicator error, e5 is the TA adjustment error, e6 is the unbalance between the DL and UL.* ***Proposal 3:*** *Further improvement on the accuracy for some of the factors can be considered.** + *TA indicator error is discussed in RAN1*
	+ *TA adjustment error and DL synchronization error should be discussed in RAN4.*

***Proposal 4:*** *The clock message transmission in UL link should be resolved in Rel-17.*  |
| R1-2005517, Ericsson | **Uncertainties related to UE determination of the downlink PD:*** (c) : The uncertainty associated with UE downlink frame timing detection. As a worst case, a UE synchronizes to the DL using Sync Signal Block (SSB) received within the last 160 ms, where SSB contains information identifying specific DL frame and slot numbering.
	+ If there are other DL reference signals available to the UE the uncertainty will be reduced compared to the worst case.
	+ This uncertainty covers (b) above and therefore (b) need not be considered as a separate source of uncertainty.
* (d) : The combined uncertainty associated with UE receive error and UE transmit time error, where a UE performs transmission of UL frames after acquiring DL sync per (c) and applying the most recently received TA information (i.e. this uncertainty = “Te”)
* (e) : The uncertainty with which a gNB acquires UL frame timing, which affects how accurately it determines the difference between when an UL sub-frame has been received and when that sub-frame should have been received if the UE was perfectly time aligned (i.e. this uncertainty affects the value the gNB sends within a TA command).
	+ Currently there is no accuracy requirement defined for (e) in RAN4 specification. It is expected that RAN4 will define some accuracy requirement for "gNB Rx – Tx time difference" (or similar) in in near future. Thus, no definite values are available for the analysis of propagation delay compensation before that.
* (f) : The uncertainty due to timing advance (TA) command granularity. Maximum value of this uncertainty is half of TA command granularity, i.e.,

 in the existing NR specification where µ represents the applicable SCS.* (g) : The uncertainty due to “Timing Advance adjustment accuracy” performed by a UE, see section 7.3.2.2 of TS 38.133.

**Determining Overall Uncertainty**The equation below is then used to determine the overall uncertainty introduced when a UE adjusts the value of the last received 5G reference time to take into account the downlink PD (= ½ the total of all TA adjustments it has made).* When using this equation it is assumed that no UL-DL RF channel asymmetry exists. Otherwise, UL-DL asymmetry is another error source.
* In addition, if using legacy methods to convey 5G reference time and TA information to a UE, it is assumed that the downlink PD applicable to when the UE receives 5G reference time information is the same as when it receives the TA command used to determine the value for downlink PD (i.e. it is assumed that no appreciable change in the downlink radio path occurs between reception of 5G reference time and a TA command).

**Determining Downlink PD Using an Enhanced RTT Method**An alternate procedure for allowing a UE to determine a value for the downlink PD is to make use of an enhanced RTT method that is based on the timing advance Type-1 measurement definition taken from LTE:

|  |
| --- |
| TS 36.214:Type1:Timing advance (TADV) type 1 is defined as the time difference  TADV = (eNB Rx – Tx time difference) + (UE Rx – Tx time difference),where the eNB Rx – Tx time difference corresponds to the same UE that reports the UE Rx – Tx time difference. |

**Proposal 1**: RAN1 to adopt a target uncertainty goal of no more than 200ns for each instance of 5G reference time relayed from a gNB to a UE. **Proposal 2:** Investigate whether the legacy RTT method or an enhanced RTT method is most suitable for determining the downlink propagation delay value, which is then used to adjust the 5G reference time value sent from a gNB to a UE. **Proposal 3:** For the selected RTT method, identify the sources of uncertainty involved and potentially requiring mitigation to reach the 200ns uncertainty target. |
| CATT, R1-2005705 | With the evaluation results in Rel-16, the gNB-to-UE timing synchronization error can be up to 540ns for 15kHz SCS. So that UE-to-UE timing synchronization error can be up to 1080ns which exceeds the 5GS synchronicity budget requirement of 900ns as shown in Figure 1.**Observation: 900ns 5GS synchronicity budget requirement may not be met for uplink time synchronization for TSN between two UEs.**Therefore, RAN1 should further study whether/how to improve UE-to-UE timing synchronization accuracy within 5GS.**Proposal: RAN1 further study whether/how to improve UE-to-UE timing synchronization accuracy within 5GS.** |
| Oppo, R1-2006062 | ***Observation 1: Propagation delay accuracy requirement cannot be met through current TA indication scheme for SCS=15kHz.******Observation 2: The granularity of RTT could meet accuracy requirement of propagation delay.******Proposal 1: Granularity for TA indication should be improved to satisfy accuracy requirement of propagation delay.******Proposal 2: RTT measurement and positioning could be decoupled and RTT measurement can be configured to compensate propagation delay only.*** |
| Samsung, R1-2006143 | *Samsung R1-2006143***Observation #1: For large service area, propagation compensation is needed.**Based on the study in Rel-16, the estimation errors are related to subcarrier spacing and mainly consist of the following parts: * **gNB transmit error** **(*Tgte*)**: Based on the definition in TS 38.104, the typical value of BS timing error caused by *Tgte* can be seen as within ± 65ns.
* **UE transmit timing error** **(*Te*)**: As defined in TS 38.133 Table 7.1.1-2, this error *Te* is about as ±12\*64\*Tc , ±8\*64\*Tc and ± 7\*64\*Tc for 15KHz, 30KHz and 60KHz respectively. This includes the error on DL timing estimation.
* **gNB estimation error (*Tge*)**: This error is introduced when gNB estimates UL channel/signals to obtain propagation delay. PRACH may not able to provide enough accuracy of time estimation. SRS/UL DMRS or PUSCH can be used. The estimation accuracy depends on occupied BW. The error about ~100ns can be assumed with 20MHz bandwidth.
* **TA (Propagation delay) granularity (*Tpd*)**: If using current TA granularity, i.e., , and the error is .
* **Timing Advance adjustment accuracy (*Tadj*)**: Based on the requirement in TS 38.133, the accuracy of TA adjustment are ±256 Tc/ ±256 Tc/ ±128 Tc / ±32 Tc respectively for SCS 15/30/60/120 kHz.

Since TA is two times of propagation delay, therefore, the error for propagation delay estimation is half of the sum of the above ***Te*** , ***Tge*** , ***Tpd*** and ***Tpd*** . And when UE compensate the propagation delay, the total time synchronization need to add gNB transmit error **(*Tgte*).** Table 1 provide a summary of the above errors. In order to reduce the total error, one easy way is to introduce finer granularity to reduce the error caused by quantization, especial for smaller subcarrier space case, e.g., 15kHz and 30kHz. Other errors are either limited by hardware, or depend on UE or gNB detection performance.Table 1

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | 15kHz | 30kHz | 60kHz | 120kHz |
| **gNB transmit error** **(*Tgte*)** | 65ns | 65ns | 65ns | 65ns |
| **UE transmit timing error** **(*Te*)** | 391ns | 260ns | 228ns | 114ns |
| **gNB estimation error (*Tge*)** | 100ns | 100ns | 100ns | 100ns |
| **Propagation delay granularity (*Tpd*)** | 260ns | 130ns | 65ns | 32.5ns |
| **Timing Advance adjustment accuracy (*Tadj*)** | 130ns  | 130ns  | 65ns  | 16.25ns |
| **Total (*Tgte*+1/2\*( *Te*** + ***Tge*** +***Tpd*** +***Tpd*)** | 505.5 ns | 375ns | 294ns | 196.4ns |

**Observation #1: For large service area, propagation compensation is needed.** **Observation #2: Some other UL channel/signals, e.g., SRS, DMRS, PUSCH occupied larger bandwidth can be used for gNB to estimate propagation delay to increase the accuracy.** **Observation #3: Finer granularity for propagation delay compensation can help to improve the performance and it is the easiest way to reduce estimation error.** Based on the observations, the following proposals are made:**Proposal #1: Introduce a finer granularity for propagation delay compensation.**  |
| Nokia, R1-2006341 | Table 1. Summary of 5GS E2E breakdown based on achievable RAN, NW and UE accuracy performance.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Case | E2E requirement | RAN error (see Appendix 4.2) | NW error (see Appendix 4.1) | Remaining budget (e.g. for the UE) |
| Indoor factory, NW-TT to DS-TT, any vertical TD | <900 ns | <465 ns \* | <80 ns | 415 ns |
| Indoor factory, DS-TT to DS-TT, any vertical TD | <900 ns | <520 ns \* | <80ns | 380 ns |
| Smart grid, 5G TD, | <1000 ns | <580 ns \*\* | <100 ns | 420 ns |

\* No propagation delay compensation is used. \*\* Using Release-16 Timing Advance procedure as basis for Propagation delay compensation. From this evaluation of the RAN part time synchronization accuracy in a typical deployment, we first note that the two cases studied in the indoor factory, leaves at least 900ns-520ns=480ns for the NW and UE part. Assuming the NW parts needs **±**100ns, the UEs will have up to 380ns of the E2E time synchronization accuracy budget. We conclude that the configuration used in the RAN part, is sufficiently good to allow the full 5GS E2E to meet the performance requirements set in SA1. In the smart grid case, it is clear that PD compensation is needed and we find that using TA for PD estimation leaves 1000ns-580ns=420ns of the 5GS E2E time synchronization accuracy budget to the NW and UE parts. Subtracting the NW part of **±**100ns, this leaves 320ns to the UE, which should be plenty. We observe based on our analysis that propagation delay compensation is a strictly necessary feature for the smart grid scenario, and that propagation delay compensation based on Rel-16 timing advance, with a reasonable gNB implementation of the timing advance operation, is sufficient from a 5GS E2E perspective. A reasonable gNB implementation would for example include that the gNB filters out instantaneous errors (e.g. CIR detection changes due to fading) which are not reflecting a change of the propagation delay. It would also include that the gNB objective of timing advance is to minimize the measured UL and DL timing offset (accounting for specified offsets such as TDD offsets obviously) and at the same time keeps the UE up-to-date with the latest PD estimation, when a change of the PD has been determined. We note that this also assumes that the UE is conducting the PD compensation, which is desirable in order to support propagation delay compensation along with broadcasted SIB9. Achievable 5GS RAN time synchronization accuracyTable A1 summarizes the time synchronization errors contributing to the one-shot time synchronization accuracy of the RAN for the two considered scenarios and with and without propagation delay compensation.Table A1. Achieve one-shot synchronization accuracy performance.

|  |  |  |  |
| --- | --- | --- | --- |
|  |  | Indoor factory (30kHz SCS) | Smart-grid (15kHz SCS) |
| 1 | TEUE-DL-RX  | ±130ns | ±260ns |
| 2 | TEgNB-UL-RX  | ±92ns | ±100ns |
| 3 | dPD-DL  | <200ns | <4000ns |
| 4 | TETA-err  | ±130ns | ±130ns |
| 5 | TETA-C  | ±130ns | ±260ns |

**Observation 1: Propagation delay compensation is needed for Rel-17 to support the smart grid scenario.****Observation 2: Propagation delay compensation by the Rel-16 timing advance procedure is sufficient to fulfil the Rel-17 requirements, assuming a reasonable gNB implementation of the timing advance procedure.**By reusing the Rel-16 timing advance procedure, specification of a propagation delay compensation feature in Rel-17 will not require be any RAN1 involvement.**Observation 3: No RAN1 involvement for enabling sufficient propagation delay compensation in Release-17 has been identified.** |
| R1-2006803, Qualcomm | Requirement of timing error of UE transmitting is specified in TS 38.133 [4] as explained in the above section. Requirement of timing error of gNB detection is purely implementation and is not specified. Generally, accuracy of gNB detection should be higher than UE detection. For simplicity, it is assumed that inaccuracy caused by gNB detection is the same as or smaller than that of UE detection which is given in the above section. The granularity of TA value is . The inaccuracy caused by TA indication for different SCS is summarized in Table 3-1.**Table 1 Timing error caused by TA indication**

|  |  |
| --- | --- |
|  | **Different SCS (kHz)****(unit: ns)** |
| 15kHZ | 30kHz | 60kHz | 120kHz |
| Granularity of TA indication | 520 | 260 | 130 | 65 |
| Timing error caused by TA indication | 260 | 130 | 65 | 32 |

**Proposal 1: Propagation delay compensation in Rel-17 should be based on the Rel-16 timing advance procedure, which requires no RAN1 involvement.*****Observation 2: Considering in accuracy of UE transmitting, gNB detection and TA indication, TA is not a good way for propagation delay compensation.******Proposal 1: TA-based compensation is not considered for enhancements* for propagation delay compensation.****Proposal 2: The scheme based on propagation delay measure in Rel-16 is good candidate for propagation delay compensation.** |
| [R1-2006930](file:///C%3A%5CUsers%5Cwanshic%5COneDrive%20-%20Qualcomm%5CDocuments%5CStandards%5C3GPP%20Standards%5CMeeting%20Documents%5CTSGR1_102%5CDocs%5CR1-2006930.zip), Huawei/HiSi | Huawei R1-2006930According to the evaluation in TR 38.825, the error is mainly composed by the TAE (Time Alignment Error) defined in TS 38.104 section 6.5.3, the Te (Timing Error Limit) defined in TS 38.133 section 7.1.2, the TA adjustment accuracy defined in TS 38.133 section 7.3.2.2, the TA adjustment granularity of defined in TS 38.213 section 4.2, the asymmetry between downlink and uplink propagation delay and the gNB UL receive timing error. The corresponding spec for some components is shown below.The TAE is the timing difference of NR signals present at the BS transmitter in e.g. MIMO transmission. It is preferred to keep the TAE the same as the legacy value to avoid the potential impact to the BS transmitter implementation. And for the Te and the TA adjustment accuracy, it is related to the UE uplink timing adjustment, so also here it is preferred to keep it the same as legacy uplink timing adjustment procedures.**Proposal 1: For any potential propagation delay compensation enhancements considered in Rel-17, keep the TAE, Te and TA adjustment accuracy the same as legacy numbers.** |