**3GPP TSG RAN WG1 Meeting #104b-e R1-21xxxxx**

**E-meeting, April 12 – April 20, 2021, 2021**

**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:

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| 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][10][11][12][13][14][15], and aims to discuss a set of issues in RAN1#104-e.

# Remaining issues on error components

There are several aspects which have impact on the timing accuracy between UE and gNB. In the previous meetings, we discussed the potential error components that would have impact on the time accuracy one by one, and achieved agreements on most of the error components as shown in the Appendix. The following sections summarize the discussion for the remaining error components.

## Downlink frame timing error ($error\_{UE, DL, RX}$)

In the RAN1#104-e meeting, we have agreed to use ±100 ns for downlink frame timing detection error (errorUE,DL,RX$error\_{UE, DL, RX}$) at the UE for evaluation of the overall time synchronization error for TA based propagation delay compensation, if downlink frame timing detection error needs to be considered separately. It is FFS whether to apply the same value to RTT-based propagation delay compensation.

Agreements:Take ±100 ns as the assumption for downlink frame timing detection error (errorUE,DL,RX$error\_{UE, DL, RX}$) at the UE for evaluation of the overall time synchronization error for TA based propagation delay compensation, if downlink frame timing detection error needs to be considered separately.

* Send a LS to RAN4 to ask for clarification on whether downlink frame timing detection error is included in Te or not
	+ In the LS, to include more details about option 1 (included) & option 2 (not included); also including the necessary background
* FFS whether to apply the same value to RTT-based propagation delay compensation, and the corresponding condition (if any) if the same value will be applied

Final LS is approved in [R1-2102245](file:///C%3A%5CUsers%5CL00367611%5CAppData%5CRoaming%5CMicrosoft%5CDocs%5CR1-2102245.zip)

In this meeting, Nokia (R1-2102821) proposes to use the same value for RTT-based propagation delay compensation.

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| Nokia R1-2102821Related to the FFS point on value for RTT-based PDC techniques, we would like to note the following: The absolute SFN timestamp found in *referenceTimeInfo-r16* IE can be generated by the gNB-DU. The timestamp is therefore subject to an error between the gNB-DU and the air interface timing. Apart from this, the UE is tracking the DL frame timing to determine the SFN boundaries. Therefore, all evaluations of Uu interface accuracy must include both errors, a DL frame timing error and the gNB-DU SFN to air interface error.The DL frame detection error is therefore present in all PD estimation options when it comes to determining a reference point at the UE for either TA (UL Tx = DL Rx – TA) as well as an Rx-Tx measurement at the UE. During RAN1#104-e, there had been discussions that a smaller value may be applicable considering other RS usage such as CSI-RS and PRS. We would like to re-iterate our related comment here, that improvements using more wide-band reference signals can improve the detection accuracy of the first detected path. But this would equally apply to TA and RTT based PDC methods as the first detected path is equally used for the TA operation as well as RTT based measurements and feedback. Therefore, the same values should be applied for RTT and TA based methods unconditionally.**Observation 2: The downlink frame detection error at the UE is present at all PD estimation options due to the reference point detection related to SFN boundary referred from** *referenceTimeInfo-r16***. Improved accuracy of the DL frame detection error by using other DL RS such as PRS equally improves the performance of TA-based and RTT-based PDC methods.** Therefore, the same value should apply to TA and RTT-based methods by agreeing the following: **Proposal 3: Take ±100 ns as the assumption for downlink frame timing detection error (errorUE,DL,RX**$error\_{UE, DL, RX}$**) at the UE for evaluation of the overall time synchronization error for RTT based propagation delay compensation, if downlink frame timing detection error needs to be considered separately.** |

Ericsson (R1- 2102748) uses ±116ns in evaluation for RTT-based propagation delay compensation.

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| 1. $Err\_{UE,DL,rx}$: ±116 ns. This is obtained using the method shown in Table 1, but with minimum PRS bandwidth of 24 PRB. It is noted that the PRS bandwidth can be as large as 272 PRBs. In general, the larger the bandwidth of the DL reference signal used for timing detection, the smaller the DL timing detection error.
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**Feature lead**: It makes sense that same value for downlink frame timing error should be applied for both TA-based PDC method and RTT-based PDC method for fair comparison. Since we agreed to use 100 ns for TA-based PDC method, the same value should be used for RTT-based PDC method also. In addition, if we want to take another value, it seems evaluations are needed to check what over value to be used. Therefore, the following tentative proposal is made for further discussion and it would be good to hear the views from other companies also.

**Proposal 2.1-1**:**Take ±100 ns as the assumption for downlink frame timing detection error (errorUE,DL,RX**$error\_{UE, DL, RX}$**) at the UE for evaluation of the overall time synchronization error for RTT based propagation delay compensation, if downlink frame timing detection error needs to be considered separately.**

**Please provide your views on the above proposal 2.1-1. If you don’t agree with it, please provide the value with justification here also.**

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## How to interpret the agreed value for BS transmit timing error

In RAN1#103-e, we have agreed to use 65ns to represent the BS transmit timing error for the control-to-control scenario.

Agreements:

* Take 65 ns as the assumption of transmit timing error for evaluation of the overall time synchronization error for control-to-control.

In RAN1#104-e meeting, Nokia (R1-2100730) propose to clarify if this should be interpreted as a maximum (<) or a relative (±) value.

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| Nokia R1-2100730The agreed number of 65ns originates from the TAE requirement from TS 38.104, where the TAE represents the relative maximum timing error between any two antenna ports (i.e. <65ns). So, our interpretation of the agreed value is to use <65ns which translates to ±32.5ns per gNB antenna port.**Proposal 1: The agreed 65ns value used to represent the BS frame transmission error should be interpreted as ±32.5ns to represent a single gNB antenna port frame transmission error for the control-to-control scenario.**  |

In RAN1#104-e meeting, the following was proposed based on inputs from companies with the corresponding status as below:

* ***errorBS,DL,TX***$error\_{BS, DL, TX}$ ***(i.e. ±32.5 ns) is included in the equation for calculating the overall time synchronization for the control-to-control scenario.***
	+ **Support*:*** *CATT, Nokia/NSB, Vivo, ZTE, Intel, LG, Samsung, ETRI, Huawei/HiSilicon, MTK, ZTE*
	+ **Support ±65ns:** *OPPO (fine to follow the majority view for using 32.25ns if only one or two companies have concern)*
	+ **Strong concern:** *Ericsson*
		- *65ns defined for TAE is used to represent BS transmit timing error due to lack of better standardized values, since it is expected that transmit timing error is approximated as ±65ns.*
		- *±65ns is a safer assumption because there is no guarantee for the correct DL Tx timing to stay at the middle of 65ns interval*
		- *The assumption for the previous agreements is ±65ns.*

**Feature lead**: Based on the discussion in RAN1#104-e meeting, it seems further discussion is not helpful. This is an important issue and we need to make decision. Therefore, I would like to encourage people check if you can accept it.

**Proposal 2.1-2: e*rrorBS,DL,TX***$error\_{BS, DL, TX}$ **(i.e. ±32.5 ns) is included in the equation for calculating the overall time synchronization for the control-to-control scenario.**

**Please comment if you have strong concern on the above proposal.**

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# Evaluation on the achievable time synchronization accuracy over Uu interface in Rel-16

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

The potential error components that will have impact on the time synchronization accuracy over Uu interface are as below:

* **BS transmit timing error (**$error\_{BS, DL, TX})$:
	+ For control-to-control, FFS whether to use ±32.5 ns or 64 ns for the evalation.
	+ For smart grid, it was agreed to use 65ns or 200ns for the evaluation.
* **Downlink frame timing error (**$error\_{UE, DL, RX}$**):**
	+ Depending on the reply from RAN4
* **UE Initial transmit timing error (**Te**)** :
	+ The value defined in Table 7.1.2-1 for initial transmit timing error (Te) in TS 38.133



* **BS detecting error (**$error\_{BS, UL, RX}$**)** :
	+ 100 ns
* **Asymmetry between downlink and uplink channel (**$error\_{Asymmetry}$**)**:
	+ Not considered
* **TA indicating error (**$error\_{TA\\_indication}$**)**: Details as shown in section 3.2.3.3 in R1-2007068
	+ ±8\*64\*Tc/2μ
* **TA adjustment accuracy (**$error\_{TA\\_adjustment}$**)**:
	+ Not considered
* **Indication error**
	+ 5ns, it is already included in the network part budget [16]

## Equation to calculate the overall time synchronization error over Uu interface

Based on the contributions, the views are still very diverse. Instead of looking at the equations from different companies, I think we need to achieve common understanding on how to achieve the final equation step by step, otherwise it would be very difficult for us to achieve consensus. I made some draft steps as below as the starting point for further checking:

**Step 1**: gNB sends the reference time clock $T^{BS}$ (i.e. *referenceTimeInfo-r16*) to UE, and the actual time clock at the UE side should be

$$T^{UE}=\left(T^{BS}+error\_{BS, DL, TX}\right)+P\_{DL}+error\_{UE, DL, RX}$$

* $error\_{BS, DL, TX}: $BS transmit timing error **for transmitting the RRC signaling containing the reference time clock**
* $error\_{UE, DL, RX}: $Downlink frame timing detection error **for receiving the RRC signaling contacting the reference time clock**



**Question 3.1-1:** **Do you agree with the equation for actual time clock at the UE side in step 1 above,** i.e. $error\_{BS, DL, TX}$ *and* $error\_{UE, DL, RX}$ also need to be considered for the procedure of signaling the RRC containing the reference time clock from gNB to UE, regardless whether it is needed for propagation delay estimation error or not**? If your answer is NO, please explain which part is wrong and why it is wrong.**

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**Step 2**: When the UE receives *referenceTimeInfo-r16*, UE obtains $T^{BS}$ indicated by *referenceTimeInfo-r16*. After UE does the propagation delay compensation, the estimated time clock at the UE side is

$$\tilde{T}^{UE}=T^{BS}+P\_{DL}+error\_{P\_{DL}}$$

* $error\_{P\_{DL}}: $ DL propagation delay estimation error, e.g. $error\_{P\_{DL}}=\frac{TA}{2}-P\_{DL}$ for TA-based PDC. Note that details for $error\_{P\_{DL}}$ is defined in step 4 below.

**Question 3.1-2:** **Do you agree with the equation for estimated time clock at the UE side in step 2 above? If your answer is NO, please explain which part is wrong and why it is wrong.**

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**Step 3**: The overall time synchronization error (i.e. the difference between the actual time clock in step 1 and the estimated time clock in step 2) is

$error\_{total, TA\_{based}}\leq error\_{BS, DL, TX}$$+error\_{UE, DL, RX} +error\_{P\_{DL}}$

**Question 3.1-3:** **Do you agree with high level error components above for overall time synchronization error? If your answer is NO, please explain which part is wrong and why it is wrong.**

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| Feature lead | Companies may say that since we are calculating difference of actual time clock and estimated time clock, then the difference should be $error\_{P\_{DL}}-error\_{UE, DL, RX}-error\_{BS, DL, TX}$. However, in my understanding, since the value for each error component can be positive or negative, i.e. ± X, thus the maximum error should be the sum of all positive values.  |
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**Question 3.1-4:** **Do you agree that the above step 1 to step 3 are applied to both TA based PDC and RTT based PDC? If your answer is NO, please explain why.**

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| Feature lead | In my understanding, the above three steps are the same for both TA-based PDC and RTT-based PDC. The only difference between TA-based PDC and RTT-based PDC is the equation for $error\_{P\_{DL}}$. For TA-based PDC, the equation of is as defined in step 4 below. For RTT-based PDC, the equation will be discussed in section 4.2.  |
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**Step 4**: Discuss and determine error component(s) for DL propagation delay estimation (i.e. $error\_{P\_{DL}}$)

for TA-based compensation.



$$TA=P\_{DL}+P\_{UL}$$

Assuming $P\_{DL}=P\_{UL}$, the downlink propagation delay $P\_{DL}$ is calculated as:

$$P\_{DL}=\frac{TA}{2}$$



$$P\_{DL}+error\_{P\_{DL}}=\frac{(TA+error\_{TA})}{2}$$

Then the error of the downlink propagation delay $P\_{DL}$ is:

$$error\_{P\_{DL}}=\frac{error\_{TA}}{2}$$



$$error\_{P\_{DL}}=\frac{error\_{BS, DL,TX}+error\_{UE, DL,RX} +error\_{UE, UL, TX}+error\_{BS, UL,RX}+error\_{TA\_{indication}}}{2}$$

* $Further$ study the following two options (which option to choose depend on the reply from RAN4):
	+ **Option 1:** $error\_{UE, DL,RX}+error\_{UE, UL, TX}$ <= Te
	+ **Option 2:** $error\_{UE, UL, TX}$ = Te and $error\_{UE, DL,RX}$ considered separately
* $Further$ study whether $error\_{BS, DL,TX}$ in the above equation should be included or not for $error\_{P\_{DL}}$.
	+ Note 1: Not including $error\_{BS, DL,TX}$ implies that gNB needs to take it out for TA estimation, which may depend on the gNB implementation and may be different from the existing TA estimation procedure at the gNB side. Companies are encouraged to check.
	+ Note 2: Option 1c for TA-based PDC enhancement as in section 4.1 may be able to get rid of $error\_{BS, DL,TX}$ since it will introduce a separate procedure for synchronization compensation here instead of reusing the normal TA procedure.

**Question 3.1-5:** **Do you agree with the above step 4 for** $error\_{P\_{DL}}$ **for TA-based PDC? If your answer is NO, please explain why. Please also provide your views on the second FFS (i.e. whether to include** $error\_{BS, DL,TX}$**) if your answer is ready now, or you can just indicate need more time to check instead of simply saying NO.**

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Though the overall equation would depend on the understanding for the above two questions, the following proposal is made as the starting point.

**Proposal 3.1-1:Take the following equation for evaluation of the overall time synchronization error for TA based propagation delay compensation:**

$$error\_{total, TA\_{based}}\leq $$

$error\_{BS, DL, TX}+error\_{UE, DL,RX}+\frac{error\_{BS, DL,TX}+error\_{UE, DL,RX} +error\_{UE, UL, TX }+error\_{BS, UL,RX}+error\_{TA\_{indication}}}{2}$

* $Further$ study which option to use depending on RAN4 LS reply:
	+ **Option 1:** $error\_{UE, DL,RX}+error\_{UE, UL, TX}$ <= Te
	+ **Option 2:** $error\_{UE, UL, TX}$ = Te and $error\_{UE, DL,RX}$ is considered separately
* $Further$ study whether to include $error\_{BS, DL,TX}$ highlight in Red above

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## Overall time synchronization error over Uu interface

According to the LS [16] from RAN2, the single Uu interface budget for control-to-control scenario and smart grid scenario are as shown below:

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| **Scenario** | **Single Uu interface Budget** |
| Control-to-Control | ±145ns to ±275ns |
| Smart Grid | ±795ns to ±845ns |

Although the discussion on the equation to calculate the total error is still ongoing, some companies also provide some evaluation in the contribution based on their equation, which is summarized as shown in the following table.

**Table 1** Summary of overall synchronization error over Uu interface

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| Source  | Control-to-control | Smart grid |
| 15kHz | 30kHz | 15kHz | 30kHz |
| Nokia | 458ns | 328ns | 525ns | 395ns |
| ZTE | 340.5ns | 210ns | 475.5ns | 345ns |
| Vivo | 457.5 | 327.5 | 457.5 | 327.5 |
| Intel | 441 | 310 | 576 | 445 |
| Ericsson  | 579.5 |  | 579.5 |  |
| Huawei, HiSilicon | 490 | 360 | 625 | 360 |
| Qualcomm | 546 |  | 546 |  |
| Samsung  | 408 | 277.5 | 408 | 277.5 |
| MediaTek | 440.5 |  | 575.5 |  |
| CATT | 440 | 310 | 440 | 310 |
| OPPO | 458 | 360 | 458 | 360 |

Based on the above table, the following observations can be seen:

**Observation 1**: **Rel-16 TA-based propagation delay compensation is sufficiently to be used as propagation delay estimation for the smart grid scenario with no enhancements needed.**

**Observation 2: Enhancement for propagation delay compensation is needed for control-to-control scenario.**

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| Feature lead | The status of this observation from RAN1#104-e is as below:* ***Support observation 2:*** *CATT, Samsung, Vivo, ZTE, Intel, Huawei/HiSilcion, LG, Ericsson, ETRI*
* ***Not support:*** *MTK*
	+ *Given the small ISD for a typical control-to-control use-case deployment, the estimated timing error is within the Uu timing budget provided by RAN2.*

If I got the point from MTK correctly, they assume that for control-to-control propagation delay compensation is not needed for control-to-control, i.e. UE can just the received timing directly, therefore no any enhancement needed also. Not sure if all companies have a chance to look that analysis from MTK, therefore one question is set below for companies to check.  |
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| *MTK R1-2102698*To justify the necessity of using propagation delay compensation, first, we need to find/calculate the maximum distance between the gNB and UE that achieves the Uu timing synchronization budget. Second, we compare the calculated maximum distance, for each use case, to the provided inter-BS distance from SLS assumptions in TR 38.824 [4]. The Uu timing budget consists of: Uu timing budget = gNB tx timing error ($Error\_{BS,DL,tx}$) + Max propagation delay + UE rx timing error ($Error\_{UE,DL,rx}$)Where gNB transmission error is the timing error between the actual transmission and the assumed transmission at the transmitter side of gNB, propagation delay is the time needed for a signal to travel from a gNB to a UE, and the UE timing detection error is the uncertainty associated with the UE downlink frame timing detection. The maximum propagation delay and the maximum distance that achieves the Uu timing budget requirements can be found for each use case as:* **Control-to-control use case**: we substitute the timing synchronization budget and errors in the above formula:

Uu timing budget (±275ns) = 65ns + Max propagation delay + ~100nsResolving this results in the maximum propagation delay, which is equal to 110 ns. This can be translated into the maximum distance between UE and gNB, which equals to 33 m. This means that if the propagation distance between the gNB and UE for control-to-control use case is ≤ 33 m, then there is no need for propagation delay compensation. Now, given that the typical inter-BS distance for the factory automation at 4 GHz is equal to 20 m, thus, we can conclude that there is no need for using propagation delay compensation in control-to-control use case.1. ***For control-to-control use case, the maximum distance between the UE and gNB that achieves the Uu timing budget is larger than the typical inter-BS distance in factory automation scenario.***
2. ***Do not support introducing propagation time delay compensation for control-to-control use case.***
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**Question 3.2-1:** **Do you agree with the analysis in R1-2102698 for control-to-control scenario, i.e. no propagation delay compensation is needed for control-to-control and thus no any enhancement needed, at least for deployment with smaller ISD e.g. 33 m?**

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# Potential enhancements for propagation delay compensation

In RAN1#102-e meeting, the following option 1 and option 2 are agreed for further study in RAN1.

* **Option 1**: TA-based propagation delay
	+ **Option 1a**: Propagation delay estimation based on legacy Timing advance (potentially with enhanced TA indication granularity).
	+ **Option 1b**: Propagation delay estimation based on timing advanced enhanced for time synchronization (as 1a but with updated RAN4 requirements to TA adjustment error and Te)
	+ **Option 1c:** Propagation delay estimation based on a new dedicated signaling with finer delay compensation granularity (Separated signaling from TA so that TA procedure is not affected)
* **Option 2**: RTT based delay compensation:
	+ Propagation delay estimation based on an RAN managed Rx-Tx procedure intended for time synchronization (FFS to expand or separate procedure/signaling to positioning).

## Common issues for enhancements for propagation delay compensation

There are some issues that are common for both RTT-based PDC and TA-based PDC.

**Issue 4.1-1**: **When a PD estimation is to be acquired after DRX for both TA-based PDC and RTT-based PDC?**

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| *Nokia R1-210821***Considerations when comparing PD estimation Option 1 (incl variants) and Option 2.**When it comes to the evaluation assumptions applicable for Option 1 (and variants) and Option 2, we need to remember that in the process of evaluating time synchronization accuracies of PD estimation options a fair evaluation is essential to ensure the right options for the desired accuracies are chosen. For this matter, it is important that we do not make option specific assumptions that other options would also be impacted of, e.g. what reference signals are applied and what bandwidths and channel conditions are present/available. **Proposal 5: Assume equivalent downlink and uplink frame detection error assumptions at all considered PD options to ensure unbiased evaluation.** Caution is needed regarding the assumption on when DL PD estimation is assumed to be acquired after a DRX period. Figure 1 provides an example timeline related to PD estimation after a DRX period. Timeline  Description automatically generatedFigure 1. Timeline example for PD compensation times after DRX, either at time a or time b.If a PD estimation is to be acquired immediately after the UE wakes up from a DRX period (the UE has not yet transmitted anything), the best PD estimation will be the latest one acquired (from an earlier wake-up period, e.g. using either RTT­1/2 or NTA1/2 as per Figure 1). This applies to all PD estimation options considered and is illustrated with PD option a in Figure 1. If PD option a is to be further considered in RAN1, it would need to be discussed what the accuracy of using a PD estimation from a previous DRX cycle. If the PD estimation is to be acquired after the gNB issues an additional signal based on the uplink transmission detected arrival time, the gNB may issue an updated timing advance value, a PD estimation signal, or even a reference signal to complete an Rx-Tx measurement procedure. In this case, the UE may use an updated PD estimate (from either NTA2/2 or RTT2/2), which is illustrated as PD option b in Figure 1. Here, the PD accuracy evaluation assumptions should be quite different; * For timing advance the UE will have an up to date NTA value and hence Te does not apply anymore. Instead, the TA adjustment error would be applicable.
* For an Rx-Tx procedure, as both an UL and DL reference signal has been available, e.g. CSI-RS in DL and some UL transmission (e.g. SRS), the Rx-Tx measurement can be conducted, but if the initial UL transmission is used, Te would still apply.
* The UE potentially has acquired multiple DL reference signals to enhance its DL frame timing accuracy.

Two options could be considered to align the assumptions between Rx-Tx and timing advance moving forward:* Option a. The UE utilize a PD estimation from its previous DRX awake period, as the UE needs an PD estimation immediately after waking up from DRX. A similar error related to using an old PD for PDC applies to all PD estimation options.
* Option b. The UE may acquire an up-to-date PD estimation after waking up from DRX. This implies that the gNB may signal an updated timing advance value (if needed) or complete a Rx-Tx measurement procedure to acquire an updated RTT estimation.

Opt. a is aligned with the current discussion in RAN1 and if the assumption of using Te in the evaluations is maintained, then an implementation error similar to Te should be applied to both options 1 and 2 based on TA and Rx-Tx measurements. Alternatively, it should be agreed to not capture Te for both PD estimation procedures with the argument that the initial UL transmission is not involved. Opt. b is a somewhat leaner approach as it assumes that the UE acquire a PD update after waking up from DRX (even simpler if it is assumed that the initial UL transmission is not involved), and would be applied for both PD estimation options based on TA and by the use of Rx-Tx measurements.This issue had been discussed during RAN1#104-e, without any conclusion. It has been discussed that it may be better to request feedback from RAN2 on this issue. As noted in the discussions, clearly the same assumption when combing back from DRX would need to be applied to both methods – as otherwise, the comparison of the methods (and the evaluated related t-sync performance) may present different assumptions when re-turning from DRX. **Proposal 6: For a fair comparison between PD estimation Option 1 (TA) and Option 2 (RTT), alignment on when a PD estimation is acquired after DRX is required. RAN1 should ask RAN2 when a PD estimation can be assumed to be acquired after DRX, either:*** **Option a. The UE utilize a PD estimation from its previous DRX awake period, as the UE needs a PD estimation immediately after waking up from DRX. A similar error related to using an old PD for PDC applies to all PD estimation options.**
* **Option b. The UE may acquire an up-to-date PD estimation after waking up from DRX. This implies that the gNB may signal an update timing advance value or complete a Rx-Tx measurement procedure.**

**Proposal 7: After having RAN2 feedback on the PD estimation assumptions after DRX, align the assumption across PD estimation Options 1 (TA) and 2 (RTT).**  |

**Proposal 4.1-1: Send a LS to RAN2 to ask which option RAN1 should take as the assumptions on when a PD estimation is to be acquired after DRX for both RTT-based PDC and TA-based PDC:**

* **Option 1: The UE utilize a PD estimation from its previous DRX awake period**, as the UE needs an PD estimation immediately after waking up from DRX. A similar error related to using an old PD for PDC applies to all PD estimation options.
* **Option 2: The UE may acquire an up-to-date PD estimation after waking up from DRX.** This implies that the gNB may signal an update timing advance value or complete a Rx-Tx measurement procedure.

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## TA-based propagation delay compensation

This section will discuss some key issues for TA-based propagation delay compensation.

**Issue 4.2-1**: **Required reduced Te and/or TA indication granularity for TA-based PDC**

Based on the discussion in previous meeting, it seems common understanding that option 1a itself cannot meet the requirement anyway even enhanced TA indication granularity is introduced. However, there is different views on whether combination of option 1a + option 1b or option 1c can meet the requirement or not, which would depend on how much Te and/or TA command indication granularity can be reduced based on inputs from RAN4 though. In RAN1#104-e meeting, the following proposal was given but no consensus achieved:

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***Revised proposal xx: Send a LS to RAN4 to ask for feedback on the following three questions:***

* ***Question 1:*** *Is it feasible to assume a smaller value than the current Te for UEs supporting accurate PDC and the use of accurate PDC assuming the same definition of Te in the current RAN4 specification? If the answer is yes, please also provide feedback on how much it can be reduced, e.g. reduced to (1/4)\*Te.*
* ***Question 2:*** *Is it feasible to assume a smaller uplink transmission timing error than Te in RRC connected mode, e.g. assuming non-contention based PRACH or SRS with pre-defined TA? If the answer is yes, please also provide the potential smaller value we can assume for propagation delay compensation.*
* ***Question 3:*** *Is it feasible to introduce enhanced TA command indication granularity and enhanced TA estimation accuracy? If the answer is yes, please also provide feedback on how much it can be reduced, e.g. reduced to (1/4)\*for enhanced TA command indication granularity.*
* ***Note:*** *For the purpose of satisfying time synchronization target, sum of the two errors (UE transmit timing error (Te) and error from TA granularity) need to be small, e.g. ~110ns or lower at least for SCS 15 kHz.*

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Before sending LS to RAN4 to ask for the inputs, RAN1 would need to evaluate and provide some examples on the reduced Te or enhanced TA indication granularity to RAN4 first, then RAN4 can further check the feasibility.

Some companies (e.g. Huawei, Vivo, Ericsson, Intel, Nokia) provide some evaluations on the potential required Te and/or TA indication granularity or whether TA-based PDC enhancements can meet the budget or not, however the views are diverse since the value would highly depend on the equation to calculate the overall synchronization error as discussed in section 3.1. Therefore, let’s focus on the equation there first, and once we achieve some common understanding there, we can further discuss issues in this section.

**Feature lead**: Delay the discussion here till we achieve some common understanding on the equation to calculate the overall synchronization error as shown in section 3.1.

**Issue 4.2-2**: **Whether to introduce a separate procedure for gNB to estimate the propagation delay?**

It is assumed that the current Te given in RAN4 spec is defined assuming channel/signal used during initial access, e.g. SSB for downlink frame timing error and contention based PRACH for uplink transmit timing error.

In RAN1#104-e meeting, Samsung proposed to adopt a new way for gNB to estimate the propagation delay, i.e. estimate the propagation delay based on non-contention based PRACH or SRS with pre-defined TA, which may provide the room to reduce the uplink transmission timing error smaller than Te. Pre-defined TA is to avoid TA adjustment error. However, it seems further discussion needed to allow companies to fully understand it.

**Question 4.2-1:** **Do you agree that we can introduce a separate procedure to estimate the propagation delay assuming non-contention based PRACH or SRS with pre-defined TA in RRC connected mode for TA-based PDC method? If yes, how to define the pre-defined TA to be used?**

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## RTT based propagation delay compensation

For RTT based delay compensation, propagation delay estimation is based on an RAN managed Rx-Tx procedure intended for time synchronization.

**Issue 4.3-1**: **Equation to calculate the overall time synchronization error over Uu interface for RTT-based PDC?**

As discussed in section 3.1, step 1 to step 3 should be common for both RTT-based PDC and TA-based PDC, and the difference is the detailed equation for $error\_{P\_{DL}}$.

**Step 4a**: Discuss and determine error component(s) for DL propagation delay estimation (i.e. $error\_{P\_{DL, RTT}}$)

for RTT-based compensation.



For RTT based delay compensation, propagation delay estimation is based on the RAN managed Rx-Tx procedure. Note that the ones highlight in Red below needs to be further discussed.

$$P\_{DL}+error\_{P\_{DL, RTT}}=\frac{(t\_{2}- t\_{1}+ t\_{4}- t\_{3})}{2}$$



$$P\_{DL}+error\_{P\_{DL, RTT}}=\frac{(t\_{2}- t\_{3}+ t\_{4}- t\_{1})}{2}$$



$$error\_{P\_{DL, RTT}}=\frac{error\_{BS, DL,TX}+error\_{UE, DL,RX} +error\_{UE, UL, TX}+error\_{BS, UL,RX}+error\_{gNB,RxTxDiff}+error\_{UE, RxTxDiff}+error\_{RxTxDiff, report}+error\_{indication}}{2}$$

* + $error\_{RxTxDiff, report}$ is to reflect the error due to report granularity of Rx-Tx time difference
	+ $error\_{gNB,RxTxDiff}$ and $error\_{UE, RxTxDiff}$ reflects the measurement inaccuracy of gNB Rx-Tx time difference, and the measurement inaccuracy of UE Rx-Tx time difference, respectively.
	+ $error\_{indication}$ is to reflect the error due to the granularity of propagation delay indication

**Feature lead:** The views on the equation is very diverse, thus we have to discuss with the following questions to achieve common understanding one-by-one.

The first issue is whether to consider UE and BS transmit timing error. According to the definition for Rx – Tx time difference below, the reference point for transmit measurement is antenna connector as highlight in yellow below, it seems in this case $error\_{BS, DL,TX}$ and $error\_{UE, UL, TX}$ don’t need to be considered. However, companies view are needed before making any decision here.

Similarly, whether to include $error\_{UE, DL,RX} $ and $error\_{BS, UL,RX}$ also need to be discussed. Based on the definition highlight in blue, since it is defined by the first detected path, it seems $error\_{UE, DL,RX} $ and $error\_{BS, UL,RX}$ need to be considered.

5.1.30 UE Rx – Tx time difference

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| **Definition** | The UE Rx – Tx time difference is defined as TUE-RX –TUE-TXWhere:TUE-RX is the UE received timing of downlink subframe #*i* from a Transmission Point (TP) [18], defined by the first detected path in time.TUE-TX is the UE transmit timing of uplink subframe #*j* that is closest in time to the subframe #i received from the TP.Multiple DL PRS resources can be used to determine the start of one subframe of the first arrival path of the TP.For frequency range 1, the reference point for TUE-RX measurement shall be the Rx antenna connector of the UE and the reference point for TUE-TX measurement shall be the Tx antenna connector of the UE. For frequency range 2, the reference point for TUE‑RX measurement shall be the Rx antenna of the UE and the reference point for TUE‑TX measurement shall be the Tx antenna of the UE. |
| **Applicable for** | RRC\_CONNECTED |

5.2.3 gNB Rx – Tx time difference

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| **Definition** | The gNB Rx – Tx time difference is defined as TgNB-RX –TgNB-TXWhere:TgNB-RX is the Transmission and Reception Point (TRP) [18] received timing of uplink subframe #*i* containing SRS associated with UE, defined by the first detected path in time.TgNB-TX is the TRP transmit timing of downlink subframe #*j* that is closest in time to the subframe #*i* received from the UE.Multiple SRS resources for positioning can be used to determine the start of one subframe containing SRS.The reference point for TgNB-RX shall be:- for type 1-C base station TS 38.104 [9]: the Rx antenna connector,- for type 1-O or 2-O base station TS 38.104 [9]: the Rx antenna (i.e. the centre location of the radiating region of the Rx antenna),- for type 1-H base station TS 38.104 [9]: the Rx Transceiver Array Boundary connector.The reference point for TgNB-TX shall be:- for type 1-C base station TS 38.104 [9]: the Tx antenna connector,- for type 1-O or 2-O base station TS 38.104 [9]: the Tx antenna (i.e. the centre location of the radiating region of the Tx antenna),- for type 1-H base station TS 38.104 [9]: the Tx Transceiver Array Boundary connector. |

**Question 4.3-1: Do we need to consider** $error\_{BS, DL,TX}$ **and** $error\_{UE, UL, TX}$ **for DL propagation delay estimation error** $error\_{P\_{DL, RTT}}$**for RTT-based PDC? Please provide your reason also.**

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**Question 4.3-2: Do we need to consider** $error\_{BS, UL,RX}$ **and** $error\_{UE, DL, RX}$ **for DL propagation delay estimation error** $error\_{P\_{DL, RTT}}$**for RTT-based PDC? Please provide your reason also.**

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Another issue is whether and how to consider the measurement inaccuracy of gNB Rx-Tx time difference, and the measurement inaccuracy of UE Rx-Tx time difference, respectively. The problem is that there is no any definition in RAN4 for NR yet. If need to be considered, we need RAN4 to provide some values for us to use also. In theory, it should be included.

**Question 4.3-3: Do we need to consider** $error\_{gNB,RxTxDiff} and error\_{UE, RxTxDiff}$? **If your answer is yes, do we need to ask RAN4 to provide inputs on the potential value?**

* + $error\_{gNB,RxTxDiff}$ and $error\_{UE, RxTxDiff}$ reflects the measurement inaccuracy of gNB Rx-Tx time difference, and the measurement inaccuracy of UE Rx-Tx time difference, respectively.

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Some companies also mentioned that gNB eventually need to signal to UE about the propagation delay. Therefore, an additionally signaling to indicate propagation delay cannot be avoided. The granularity $error\_{indication}$ of propagation delay indication will also affect the total error. I think this is only for gNB-based RTT PDC assuming gNB pre-compensation is not used. Companies view are needed.

**Question 4.3-4: Do you agree that** $error\_{indication}$ **is only needed for gNB-based RTT PDC without gNB pre-compensation? If your answer is NO, please provide your reason also.**

* + $error\_{indication}$ is to reflect the error due to the granularity of propagation delay indication

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**Issue 4.3-2**: **What reference signal to use for estimating Rx-Tx time difference for time synchronization?**

For positioning, PRS is used for estimating Rx-Tx time difference. The question here is that for time synchronization, whether other DL reference signal other than PRS can be used or not? We did the discussion in RAN#104-e and the status is as below:

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**Question: Whether DL reference signals other than PRS could be used for DL time estimation at UE side?**

* **No:** *CATT, ETRI*
	+ PRS is sufficient for RTT-based PDC
* **UE implementation issue:** *OPPO*
* **Yes:** *Samsung, Nokia/NSB, Vivo, ZTE, Intel, LG, Ericsson,*
	+ *For the purpose of time synchronization, there might not be the same accuracy requirement as for positioning, and hence some of the enhancements introduced for positioning with higher power density and large bandwidths might not be needed for all time synchronization use cases*
	+ *There might not be any need for the gNB to initiative PRS transmissions only for the sake of time synchronization, if other reference signals are available and can provide sufficient accuracy, e.g. CSI-RS.*

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Accordingly a proposal was made in RAN1#104-e, which can be the starting point of the discussion in this meeting.

**Proposal 4.2-1: DL reference signals other than PRS could be used for DL time estimation at UE side for RTT-based propagation delay compensation, if RTT-based propagation delay compensation is supported.**

* **FFS whether PRS can be used for DL time estimation or not**
* **FFS whether which DL reference signal to be used is UE implementation or not, i.e. whether we need to explicit define the reference signal to be used in the specification or not.**

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| Feature lead | If possible, **please also provide your views on what signal to be used and your views on the two FFS**. I think in the end we may also need to discuss whether any restriction on the RS needed or not in order to meet the budget, e.g. the bandwidth. But at this stage difficult to discuss since we still don’t have agreement on the equation. In my understanding, we cannot leave it to UE implementation, since the value of the error components would depend on the RS to be used, e.g. measurement inaccuracy, downlink frame timing error, etc.  |
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**Issue 4.3-3**: **Whether to take gNB based pre-compensation or UE-based compensation?**

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| *Intel R1-2103031***Option 2 – RTT-based UE compensation or gNB pre-compensation**The RTT-based compensation could be realized using the existing gNB Rx-Tx time difference and UE Rx-Tx time difference measurements, or re-defined Rx-Tx time difference using other signals. In this matter, there are two possible flavors:* Alt. 1: UE side compensation. A UE measures UE Rx-Tx time difference and receives from gNB the gNB Rx-Tx time difference, so that total PD can be calculated and compensated. The signaling in this case should be UE-specific. This introduces additional signaling overhead in DL, same way as UE-specific pre-compensation at gNB, where reference timing information is assumed to be delivered in dedicated RRC message.
	+ In order to reduce the gNB Rx-Tx time difference signaling overhead towards UEs, group-common signaling options could be considered at physical or higher layer.
* Alt. 2: gNB side pre-compensation. A UE measures UE Rx-Tx time difference and reports it to gNB. gNB measures the gNB Rx-Tx time difference, receives the UE Rx-Tx time difference, and pre-compensates the reference timing information before sharing it with the UE. From perspective of the overall signaling exchange, this alternative may be a bit easier to implement if the UE Rx-Tx time difference measurement is defined as just another regular measurement as part of *MeasurementReport*.

**Observation 2*** *RTT-based propagation delay compensation requires additional UE-specific signal exchange between gNB and UE:*
	+ *In DL direction, group-common signalling could be utilized to reduce overhead.*
 |

In addition, there is an LS R1-2102293 from RAN3 mentioning that gNB-based pre-compensation may have impact on RAN3.

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*RAN3 has begun discussing propagation delay compensation (PDC) enhancements, including gNB-based PDC (i.e. propagation delay pre-compensation by the gNB).*

*RAN3 considers that gNB-based PDC may have RAN3 specification impacts. However, it is RAN3 understanding that support for gNB-based PDC is up to RAN1 and RAN2 decisions. Therefore, RAN3 will not further discuss gNB-based PDC unless support for the functionality is first confirmed by RAN1/RAN2.*

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**Feature lead:** Whether to take gNB-based pre-compensation or UE base compensation was discussed in RAN1#104-e but no consensus was achieved. Since it will have impact on the detailed design, it seems we will have to discuss again. In addition, if we decide to take gNB-based compensation, we would need to inform RAN3 earlier since it will have impact on RAN3.

**Question 4.3-5: Which option do you prefer for RTT-based PDC, gNB-based compensation or UE-based compensation?**

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| **Feature lead** | Status on this question from last meeting:* **RTT-based UE compensation:** *OPPO, CATT, Nokia/NSB, Samsung, Intel, ZTE, LG*
	+ *Easier for the UE to handle as the UE can simply change the timestamp provided in ReferenceTimeInfo*
	+ *No RAN3 impact*
* **RTT-based gNB compensation:** *CATT, Samsung, Ericsson, Intel, LG*
* **Feature lead:** Based on the current position, it seems hard to say which one is better. Maybe leave time for companies to check more and we can further discuss next meeting.

Note that once we achieve consensus here, the conclusion (i.e. UE-based or gNB-based) may be applied to non-RTT based method also.  |
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## Implicit propagation delay compensation

OPPO (R1-2102396) proposes an implicit PDC method as below:

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| *OPPO R1-2102396*

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| Message flow in Method-1 (Implicit PDC) | Message flow in Method-2 (Explicit PDC, assuming PDC is performed on UE side) |
| 1. UE sends to gNB at UE’s local time $n\_{UL,TX}^{'}$: a message containing $n\_{UL,TX}^{'}$. The gNB needs to measure and record reception time $m\_{UL,RX}^{'}$. An example candidate for this message is RRC referenceTimeInfo-r16.
2. gNB sends to UE a message containing $m\_{UL,RX}^{'}-n\_{UL,TX}^{'}$.
3. gNB sends to UE at gNB’s local time $m\_{DL,TX}^{'}$: a message containing $m\_{DL,TX}^{'}$. The UE needs to measure and record reception time $n\_{DL,RX}^{'}$. An example of this message is RRC referenceTimeInfo-r16.
4. UE derives $\tilde{e}\_{clk}$ based on $m\_{UL,RX}^{'}-n\_{UL,TX}^{'}$, $m\_{DL,TX}^{'}$ and $n\_{DL,RX}^{'}$, and may change its clock time accordingly.
 | 1. gNB sends to UE a message containing RTT measured in gNB. An example of this message is T\_delta MAC-CE from Rel-16 IAB protocol.
2. gNB sends to UE at gNB’s local time $m\_{DL,TX}^{'}$: a message containing $m\_{DL,TX}^{'}$. UE needs to measure and record reception time $n\_{DL,RX}^{'}$. An example of this message is RRC referenceTimeInfo-r16.
3. UE sets its clock time to $m\_{DL,TX}^{'}+\tilde{T}\_{PD}$ at moment of $n\_{DL,RX}^{'}$, where $\tilde{T}\_{PD}$ is the estimated one-way propagation delay based on gNB-side RTT and UE-side TA interval. (The one-way delay estimation becomes TA-based if gNB-side RTT is deemed to be known to UE without need of signaling)
 |

***Observation-1: The explicit-PDC (RTT-based PDC) method may need message exchange between gNB and UE in both MAC layer (for propagation delay estimation) and RRC layer (for propagation delay compensation). Then for explicit PDC, it can be a question how to get synchronization procedure in specification to involve two different protocol layers (MAC and RRC) in order to minimize the synchronization error. Such question, however, falls out of RAN1 scope.*** ***Observation-2: The explicit-PDC (RTT-based PDC) method can be sensitive to inconsistent RTT measurements (i.e., for the two RTT measurements in gNB and UE, one is done before TA adjustment and another is done after TA adjustment).*** ***Proposal-1: RAN1 to take implicit PDC method into account for enhancing time synchronization.**** ***The method targets to find the difference between two local clock times respectively in gNB and UE.***
* ***Both gNB and UE individually transmit at least one message to each other, where the message contains the local clock time corresponding to the time at which the message is sent.***
	+ ***Note: The current spec already supports such message sent from gNB to UE.***
* ***gNB sends to UE another message corresponding to the information of its local clock time corresponding to the time at which the above-mentioned message from the UE is received at the gNB.***

***Proposal-2: With implicit PDC, RAN1 relies on averaging technique (as gNB/UE implementation issue) to statistically reduce impacts from the errors generated in gNB/UE Tx/Rx, rather than asking RAN4 to tighten UE hardware requirements and/or parameters.***  |

**Feature lead**: Since the method is raised the first time, companies are encouraged to check and if there is any question or comments would be good to share.

**Question 4.4-1:** **Do you have any comment/question on implicit PDC proposed in R1-2102396?**

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# 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. R1-2100024 Reply LS on propagation delay compensation enhancements
3. R1-2102396 Enhancement for support of time synchronization OPPO
4. R1-2102497 Discussion on propagation delay compensation enhancements ZTE
5. R1-2102525 Discussion on propagation delay compensation enhancements vivo
6. R1-2102632 Discussion on propagation delay compensation enhancements CATT
7. R1-2102698 Discussion on propagation delay compensation for time synchronization MediaTek Inc.
8. R1-2102748 Propagation Delay Compensation Enhancements for Time Synchronization Ericsson
9. R1-2102821 Discussion on enhancements for propagation delay compensation Nokia, Nokia Shanghai Bell
10. R1-2103031 Further analysis and design considerations regarding propagation delay compensation Intel Corporation
11. R1-2103167 Enhancements for support of time synchronization for enhanced IIoT and URLLC Qualcomm Incorporated
12. R1-2103240 Discussion for propagation delay compensation enhancements Samsung
13. R1-2103328 Propagation delay compensation enhancements ETRI
14. R1-2103351 Discussion on propagation delay compensation enhancements LG Electronics
15. R1-2103398 Enhancements for support of time synchronization Huawei, HiSilicon, SIA

# Appendix Agreements in the past meetings

**RAN1#102-e**

Agreements:

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

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| **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
 |

Agreements:

* $\pm 8∙64∙T\_{c}/2^{μ}$±8\*64\*Tc/2μ as the TA indicating error is assumed in the evaluation.

Agreements:

For 5GS synchronicity budget requirement,

* One Uu interface is assumed for smart grid.
* Two Uu interfaces are assumed for control-to-control.

Agreements:

For BS transmit timing error, further study the following three options:

* **Option 1**:65 ns
* **Option 2**:±130ns for the indoor scenario and ±200ns for the smart grid scenario
* **Option 3**:82.5 ns

Agreements:

The value defined in Table 7.1.2-1 for initial transmit timing error (Te) in TS 38.133 should be considered for evaluation of the time synchronization.

Agreements:

Asymmetry between downlink and uplink channel for control-to-control scenario is not considered.

Agreements:

100 ns is assumed for BS detecting error.

Agreements:

Timing advance adjustment accuracy defined in Table 7.3.2.2-1 in TS 38.133 is assumed for evaluation of the time synchronization.

Agreements:

Both 15 kHz and 30 kHz are assumed for both control-to-control and smart grid for evaluation of the time synchronization.

Agreements:

Send an LS to RAN2 with the content including

* Inform RAN2 the two representative use cases concluded in RAN1 for further study;
* Ask RAN2 for input about Uu interface error budget for each of the two use cases;

Agreements:

The following options for propagation delay compensation are further studied in RAN1

* **Option 1**: TA-based propagation delay
	+ **Option 1a**: Propagation delay estimation based on legacy Timing advance (potentially with enhanced TA indication granularity).
	+ **Option 1b**: Propagation delay estimation based on timing advanced enhanced for time synchronization (as 1a but with updated RAN4 requirements to TA adjustment error and Te)
	+ **Option 1c:** Propagation delay estimation based on a new dedicated signaling with finer delay compensation granularity (Separated signaling from TA so that TA procedure is not affected)
* **Option 2**: RTT based delay compensation:
	+ Propagation delay estimation based on an RAN managed Rx-Tx procedure intended for time synchronization (FFS to expand or separate procedure/signaling to positioning).

Draft LS R1-2007445 is approved, with final LS in R1-2007446.

**RAN1#103-e**

Agreements:

* Take 65 ns as the assumption of transmit timing error for evaluation of the overall time synchronization error for control-to-control.
* Asymmetry between downlink and uplink channel for smart grid scenario is not considered.
* ~~TA adjustment accuracy is not considered for the evaluation of time synchronization error.~~
* *errorBS,DL,TX*$error\_{BS, DL, TX}$ is included in the equation for calculating the overall time synchronization error.

Agreements:

TA adjustment accuracy is not considered for the evaluation of time synchronization error.

Agreements:

For evaluation of the overall time synchronization error for smart grid, companies can take one of the following two options as the assumption for BS transmit timing error:

* Option 1: 200 ns
* Option 2: 65 ns

**RAN1#104-e**

Agreements:Take ±100 ns as the assumption for downlink frame timing detection error (errorUE,DL,RX$error\_{UE, DL, RX}$) at the UE for evaluation of the overall time synchronization error for TA based propagation delay compensation, if downlink frame timing detection error needs to be considered separately.

* Send a LS to RAN4 to ask for clarification on whether downlink frame timing detection error is included in Te or not
	+ In the LS, to include more details about option 1 (included) & option 2 (not included); also including the necessary background
* FFS whether to apply the same value to RTT-based propagation delay compensation, and the corresponding condition (if any) if the same value will be applied

**Decision:** As per email posted on feb 5th, the draft LS is endorsed. Final LS is approved in [R1-2102245](file:///C%3A%5CUsers%5Cc00387628%5CAppData%5CLocal%5CTemp%5CDocs%5CR1-2102245.zip).