**3GPP TSG RAN WG1 Meeting #104-e R1-xxxxxxx**

**E-meeting, January 25 – February 5, 2021**

**Agenda Item: 8.3.4**

**Source: Moderator (Huawei)**

**Title: Feature lead summary 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 RAN1#102-e and RAN1#103-e, 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#103-e meeting, the UE downlink frame timing error has been discussed but no conclusion could be reached. The controversial point is how to interpret the RAN4 specification.

Based on views from contributions submitted in this meeting, company position is summarized as below:

* **Option 1**: 100ns i.e. same as gNB UL detection error
	+ ***Support:*** *Nokia, OPPO, Ericsson, vivo, Huawei/HiSilicon*
* **Option 2**: Downlink frame timing error is not needed to be considered separately
	+ ***Support:*** *ETRI, CATT, Qualcomm*

**Feature lead**: According to the RAN4 specification as copied below, it should be clear that Te and DL frame detection error should both be considered in the evaluation of time synchronization accuracy of PD estimation options based on TA.

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| 7.1.2 RequirementsThe UE initial transmission timing error shall be less than or equal to Te where the timing error limit value Te is specified in Table 7.1.2-1. This requirement applies:- when it is the first transmission in a DRX cycle for PUCCH, PUSCH and SRS or it is the PRACH transmission.The UE shall meet the Te requirement for an initial transmission provided that at least one SSB is available at the UE during the last 160 ms. The reference point for the UE initial transmit timing control requirement shall be the downlink timing of the reference cell minus . The downlink timing is defined as the time when the first detected path (in time) of the corresponding downlink frame is received from the reference cell. *N*TA for PRACH is defined as 0. (in *Tc* units) for other channels is the difference between UE transmission timing and the downlink timing immediately after when the last timing advance in clause 7.3 was applied. *N*TA for other channels is not changed until next timing advance is received. The value ofdepends on the duplex mode of the cell in which the uplink transmission takes place and the frequency range (FR). is defined in Table 7.1.2-2. |

**Proposal 2.1-1:Take 100 ns as the assumption for downlink frame timing detection error at the UE for evaluation of the overall time synchronization error at least for TA based propagation delay compensation.**

**Please comment if you have strong concern on the above proposal 2.1-1.**

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| *Company* | *View* |
| CATT | We prefer Option 2 because we think Te already considers Downlink frame timing error and 100 ns as the assumption for downlink frame timing detection error isn’t necessary. |
| OPPO | We agree with including DL frame timing detection in the error modeling and also agree with using 100ns. But we think this error is equally applicable to both TA-based estimation and RTT-based estimation. This error is counted in both one-way propagation delay estimation (via Tx-to-Rx interval on UE side) and clock-compensation (via the difference between the actual clock-arrival time and UE conceived clock-arrival time).  |
| Samsung | For the case considering Te, we think there is no need to count $error\_{UE, DL, RX}$ again. But if for the evaluation of some method where Te is not used. We are fine to take 100ns as the assumption.  |
| Nokia, NSB | We are fine with FL proposal to take 100ns. Based on our evaluations R1-1900935, the DL reference signal can be for example PSS/SSS or DM-RS on PBCH, or a dedicated DM-RS transmission on PDSCH, or even DL-PRS. In this study we consider the case of DM-RS on PBCH, where the accuracy is estimated to ~130ns (one shot). Higher accuracies can, however, be achieved with time tracking algorithms at the UE or relying on more wideband DL reference signals (e.g. CSI-RS or DM-RS on PDSCH) which can further enhance the accuracy to the considered 100ns. |
| vivo | We agree with FL’s proposal. We think this error should be considered for both TA-based method and RTT-based method for PDC. |
| MediaTek | In our view, downlink frame timing detection error is already considered as part of Te, hence, there is no need to double-counting the error. However, for the cases where Te is not considered, downlink frame timing detection error can be considered. |

## 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.

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.**  |

**Feature lead**: It is true that the TAE represents the relative maximum timing error between any two antenna ports, however my original interpretation is that the maximum BS transmit timing error at a single antenna port can be 65 ns also depending on different implementations. But can hear more views from other companies.

**Question 2.2-1: Do you think that the agreed 65 ns value used to represent the BS transmit timing error should be interpreted as ±32.5 ns to represent a single gNB antenna port transmit timing error for the control-to-control scenario?**

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| --- | --- |
| *Company* | *View* |
| CATT | From our point of view, if 65ns used to represent the maximum BS frame transmission error ±32.5 ns can be interpreted as a single gNB antenna port transmit timing error for the control-to-control scenario. |
| OPPO | Not necessarily. 65ns is a safer assumption because there is no guarantee for the correct DL Tx timing to stay at the middle of 65ns interval. In addition, we do not think the change of this value from 65ns to the half could make any outstanding difference, and if it does, the RAN1 conclusion could become risky in practice.  |
| Samsung | We think 65ns is BS transmission timing error. But when we calculate the propagation delay error, half of it is used.  |
| Nokia, NSB | Agree with Samsung here – if 65ns is used, then only half of the error should be applied. If ±32.5 ns, then the full value should be used. So the decision here and the decision on the formula are therefore connected. We prefer ±32.5 ns as explained in R1-2100730 |
| vivo | We are fine with it.BS transmit timing error can be interpreted as ±32.5 ns to represent a single gNB antenna port transmit timing error for the control-to-control scenario. |

## BS transmit timing error for smart grid scenario

In RAN1#103e, the following agreement was achieved:

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

Nokia proposes to use ±100ns (i.e. corresponding to option 1) to represent the BS frame transmission timing error for the smart grid scenario.

**Feature lead**: Based on the discussion in RAN1#103-e, it seems difficult to achieve consensus on one of the options at this stage, therefore the intention for the agreement is to leave companies to pick one of them to evaluate the overall synchronization error, since in any case it seems the budget for smart grid would be sufficient. Therefore, I would suggest no more discussion on this in RAN1#104-e, and depending on the outcome for question 2.2-1 the values used here can be translated accordingly, e.g. if the answer to question 2.2-1 is yes, then ±100 ns can be used if option 1 is picked.

|  |  |
| --- | --- |
| *Company* | *View* |
| CATT | We prefer to Option 2 and BS frame transmission timing error for the smart grid scenario should use the same value on BS frame transmission timing error for control to control. |
| OPPO | Agree with FL. Our conclusion on smart grid remains the same across {65,100,200}ns.  |
| Samsung | Suggest to use 65ns as well.  |
| Nokia | We agree with the option 1 and therefore BS transmit timing error of ±100 ns would be consider for the smart grid use case. |
| vivo | We agree with FL’s suggestion.  |
| MediaTek | In our view, only Option 2 should be considered, so smart-grid and control-to-control scenarios use the same value.Although, this may not affect the outcome of going above or below the budget, but it will be more accurate estimation of the error with the TA-based method. |

# 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.

Based on the agreements achieved in RAN1#102-e and RAN1#103-e and the views in the contributions, 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, it was agreed to use 65ns for the evaluation.
	+ For smart grid, it was agreed to use 65ns or 200ns for the evaluation.
* **Downlink frame timing error (**$error\_{UE, DL, RX}$**):** Details as shown in section 2.1
	+ Value to be decided
* **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

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 based on Rel-16 mechanism to see whether enhancement is needed or not, if needed then how to improve the accuracy of time synchronization. Note that the overall time synchronization error for the enhanced schemes (i.e. propagation delay compensation and RTT-based propagation delay compensation) can be further evaluated in section 4.

Based on the contributions, the following 6 options are proposed:

**Option 1:**

$$error\_{total, TA\\_based}\leq error\_{BS, DL, TX}+\frac{error\_{BS, UL,RX}+error\_{TA\\_indication}}{2}+\frac{Te}{2}$$

* + ***Support:*** *CATT, Qualcomm, MediaTek*

**Option 2:**

$$error\_{total, TA\\_based}\leq error\_{BS, DL, TX}+\frac{error\_{BS, UL,RX}+error\_{UE, DL,RX}+error\_{TA\\_indication}}{2}+\frac{Te}{2}$$

* + ***Support:*** *Intel, Huawei/HiSi, LG, Ericsson, vivo*

**Option 3:**

$$error\_{total, TA\\_based } \leq error\_{BS,DL,Tx}+\frac{error\_{BS,UL,Rx}+error\_{TA\\_adjustment}}{2}+\frac{Te}{2}$$

* + ***Support:*** *~~MediaTek~~*

**Option 4:**

$$error\_{total, TA\\_based } \leq \frac{error\_{BS,DL,Tx}+error\_{BS,UL,Rx}+error\_{UE, DL,RX}+error\_{TA\\_indication}}{2}+\frac{Te}{2}$$

* + ***Support:*** *OPPO, Nokia*

**Option 5:**

$$error\_{total, TA\\_based}\leq \frac{error\_{BS, DL, TX}+error\_{BS, UL,RX}+error\_{TA\\_indication}}{2}+\frac{Te}{2}$$

* + ***Support:*** *Samsung*

***Option 6:***

$$error\_{total, TA\\_based}\leq \frac{error\_{BS, DL, TX}+error\_{BS, UL,RX}+error\_{TA\_{indication}}}{2}+\frac{Te}{2}-error\_{UE, DL,RX}$$

* + ***Support:*** *ZTE*

**Feature lead:** In RAN1#103-e meeting, the following agreements were achieved, therefore it seems option 3, option 4 and option 5are not aligned with the agreements.

|  |
| --- |
| 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.  |

As to option 6, it is expected that the time clock of the UE is equal to the received time clock of the gNB plus the downlink propagation delay as shown in the formula below, therefore it should be “*errorBS,DL,TX*” instead of “-*errorBS,DL,TX*” to be included in the equation. Therefore, it seems option 6 is not appropriate.

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

Then between option 1 and option 2, the difference is whether to consider downlink frame timing error as discussed in section 2.1, since in section 2.1 we propose to include downlink frame timing error, here the starting point is to propose option 2 for further discussion.

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

$$error\_{total, TA\\_based}\leq error\_{BS, DL, TX}+\frac{error\_{BS, UL,RX}+error\_{UE, DL,RX}+error\_{TA\\_indication}}{2}+\frac{Te}{2}$$

|  |  |
| --- | --- |
| *Company* | *View* |
| CATT | We prefer to Option1 and $error\_{UE, DL,RX}$ shouldn’t be included in formula because Te already considers Downlink frame timing error. |
| OPPO | It seems companies are quite diverging regarding to the total error formula. Then it could be helpful for each proponent to explain their tools in more details, rather than simply shouting out the equations. Here is our explanation (and Option-4 above in FL summary is NOT our equation for total error – it is the one for propagation delay estimation error). First, we think the total error should be: $$error\_{total, TA\\_based}\leq error\_{BS, DL, TX}+error\_{PD}+error\_{UE, DL, RX}$$Here we assume the DL Tx/Rx timing errors (1st and 3rd terms on right side of above inequality) at gNB/UE are NOT measurable, i.e., they cannot be taken as a part of Tx-to-Rx intervals on both sides of gNB and UE, where “not measurable” means either * the error cannot be measured once the error is less than a threshold (this would be hardware-dependent, e.g. the Tx is implemented by processor interruption); or
* the error can be somehow measured but the measurement at time t1 becomes invalid or not guaranteed at the time other than t1.

Meanwhile, given RAN1 assumes symmetric DL/UL propagation delays, these independent Tx/Rx timing errors cannot be merged into one-way propagation delay either. Next, the one-way propagation delay estimation error, $error\_{PD}$ , is the formula shown in Option 4 above, containing five terms, four of which are the errors generated at gNB-Tx($error\_{BS, DL, TX}$), gNB-Rx($error\_{BS, UL, RX}$), UE-Tx(=Te) and UE-Rx($error\_{UE, DL, RX}$), and the fifth error is the half of TA granularity ($error\_{TA\\_indication}$). Note that the $error\_{BS, DL, TX}$ in one-way propagation delay estimation is not necessary the same as the $error\_{BS, DL, TX}$ in the total error equation above (they just share the same math notation). The same applies to $error\_{UE, DL, RX}$.  |
| Samsung | Agree with CATT, we think $error\_{UE, DL,RX}$ already covered by Te. Agree with OPPO that $error\_{BS, DL, TX}$ should be added as half. Besides, for some cases, e.g., option 1C, that assuming UE is in connected mode and Te already been overcomed by TA adjustment or finer sync up with gNB, TA adjustment can be used as leftover, as well as $error\_{UE, DL,RX}$ can be added in this case.  |
| Nokia. NSB | The decision here and the discussion on 65ns vs. ±32.5 ns in Question 2.2-1, are related here (see our comments there) Assuming 65ns for Question 2.2-1 is used, then we do not agree with this and agree with Samsung that half of $error\_{BS, DL, TX}$ is applied.  |
| vivo | We support Proposal 3.1-1. |
| MediaTek | We would like to highlight that we meant $error\_{TA\\_indication}$ instead of $error\_{TA\\_adjustment}$ in Option-3 above (it was a typo in the contribution).Thus, we support option-1 as $error\_{UE, DL,RX}$ already covered by Te. |

## Overall time synchronization error over Uu interface

Once we achieve consensus on the equation to be used for calculating the overall time synchronization, we can get the overall time synchronization error achievable based on Rel-16 scheme based on the following assumption we agreed in RAN1#102-e.

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

In addition, 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 in section 3.1, 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

|  |  |  |
| --- | --- | --- |
| Source  | Control-to-control | Smart grid |
| 15kHz | 30kHz | 15kHz | 30kHz |
| Nokia | 458ns | 328ns | 525ns | 395ns |
| ZTE | 340.5ns | 210ns | 475.5ns | 345ns |
| Vivo | 490 | 360 | 490 | 360 |
| Intel | 491 | 360 | 491 | 360 |
| Ericsson  | 490 |  | 490 |  |
| 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.**

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| --- | --- |
| *Company* | *View* |
| CATT | We support observation 1 from our evaluation results. |
| OPPO | Ok. |
| Samsung | OK |
| Nokia, NSB | Agree |
| vivo | We support observation 1. |
| MediaTek | Agree with the observation. |

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

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| --- | --- |
| *Company* | *View* |
| CATT | We support observation 2 from our evaluation results. |
| OPPO | In our timing error analysis, the error budget for control-to-control scenario cannot be met even if TA command granularity (for TA-based estimation) and Tx-Rx interval indication granularity (for RTT-based estimation) go down to zero; even further, the error budget for 15kHz SCS cannot be met even if Te becomes zero as well. Therefore, our observation is that NO enhancement from RAN1/RAN4 perspective can help to meet the RAN2 error budget for control-to-control scenario.  |
| Samsung | Ok with the observation |
| Nokia | AgreeRAN1 should further evaluate the pros and cons of Option 1b and Option 2 as supplementary procedures to legacy timing advance. Option 1b may be used to satisfy the accuracy of the control-to-control scenario with 15kHz SCS with enhanced Te by at least 122ns. This includes RAN1 to ask RAN4 on the feasible enhancement of Te. |
| vivo | We support observation 2. |
| MediaTek | In our evaluation [R1-2100578], we don’t see a need for PDC in the control-to-control scenario. 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.Hence, we don’t see a need for observations for TA-based method in the control-to-control scenario given that there is no need for PDC. |

# 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).

## TA-based propagation delay compensation

This section will discuss details of TA-based propagation delay.

* **Option 1a**: Propagation delay estimation based on legacy Timing advance (potentially with enhanced TA indication granularity).

For option 1a, TA indication error $error\_{TA\\_indication}$ needs to be improved. Nokia (R1-2100730) proposes to take the Timing Delta MAC CE introduced in Release 16 for IAB as the baseline for TA-based propagation delay compensation enhancements.

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| *Nokia R1-2100730*It has been discussed how to enhance the time synchronization accuracy error caused by the NTA granularity (e.g. carried in the timing advance command). This is also partly the motivation behind PD estimation Option 1a, where a new MAC CE, could optionally be introduced to be used to supplement the current timing advance command. Alternatively, to introducing a new MAC CE, existing work in Release-16 may be used instead. In the context of IAB, a Timing Delta MAC CE has been introduced [TS 38.213 Section 14, TS 38.321 which serves the purpose of enhancing DL PD estimation accuracy and hence also the NTA signaling granularity. The description of the Timing Delta MAC CE is copied in below from TS 38.213 Section 14:

|  |
| --- |
| If an IAB-node is provided an index $T\_{delta}$ in a Timing Delta MAC CE [11, TS 38.321] from a serving cell, the IAB-node may assume that $\left(N\_{TA}/2+N\_{delta}+T\_{delta}⋅G\_{step}\right)⋅T\_{c}$ is a time difference between a DU transmission of a signal from the serving cell and a reception of the signal by the IAB-MT when $N\_{TA}/2+N\_{delta}+T\_{delta}⋅G\_{step}>0$, where $N\_{TA}$ is obtained as for a "UE" in Clause 4.2 for the TAG containing the serving cell and $N\_{delta}$ and $G\_{step}$ are determined as- $N\_{delta}=-70528$ and $G\_{step}=64$, if the serving cell providing the Timing Delta MAC CE operates in FR1, - $N\_{delta}=-17664$ and $G\_{step}=32$, if the serving cell providing the Timing Delta MAC CE operates in FR2The IAB-node may use the time difference to determine a DU transmission time. |

Utilizing this Timing Delta MAC CE will supplement NTA e.g. provided in the Timing Advance MAC CE, hence the UE. Based on our understanding this should be understood as the downlink air interface propagation delay even with the split between a DU and RU in IAB terminology. The signaling granularity of $T\_{delta}$ is given by $G\_{step}⋅T\_{c}$, where $G\_{step}=64$ for FR1 operation. This corresponds to 32ns and is 16 times smaller than NTA for 15kHz SCS, and 8 times smaller than NTA for 30kHz SCS. The drawback is that when NTA needs to be updated, Timing Delta MAC CE update might also be needed.**Observation 2: For Option 1 schemes, using the Timing Delta MAC CE introduced in Release 16 for IAB may reduce the error from NTA granularity by 16 and 8 times.****Proposal 7: RAN1 should use Release-16 as baseline for PD estimation accuracy enhancement evaluations, which includes the Timing Delta MAC CE introduced in Release 16 for IAB.** |

**Feature lead**: It seems make sense to take the R16 mechanism as the starting point. However, since not much details in the contributions on how to enhance the TA granularity, more views are needed from companies before making any way forward.

**Question 4.1-1: How to enhance the TA indication granularity in option 1a? Please also indicate the enhanced TA indication granularity that your solution can achieve.**

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| --- | --- |
| *Company* | *View* |
| CATT | If the TA indication granularity is only enhanced, TA-based PDC can’t meet Uu interface budget from RAN2. |
| OPPO | In our understanding, the Rel-16 IAB mechanism of using indication of T\_delta belongs to the RTT-based one-way delay estimation, not TA-based. For Opt 1a, it seems the only way to enhance is to reduce TA command granularity, which means quite some changes in RAN4 UE Tx timing requirements. As mentioned in section 3.2, it is better for RAN1 to firstly prove the feasibility and effectiveness of such enhancements before digging the solution – we do not see the feasibility of reducing TA command granularity down to zero, which still cannot meet the overall error budget.  |
| Samsung | First of all, we need to ensure gNB estimation can provide finer TA estimation. Then we can discuss how to indicate.  |
| Nokia | Only a very minor (≤±16ns) enhancement is feasible with PD estimation Option 1a compared to legacy timing advance supplemented by the Release-16 Timing Delta MAC CE. Following option 1a, even having TA indication granularity of 0ns, we cannot meet the requirements for the control-to-control scenario. |
| vivo | Improvement of TA indication granularity error is beneficial for satisfying the synchronization requirements. However, for Single Uu interface Budget for control-to-control scenario, option 1a cannot meet the requirement.  |
| MediaTek | We don’t see a need for enhanced TA indication granularity. We first need to justify the necessity for such enhancement before discussing the solutions. |

However, it can be expected that the gain that can be achieved by option 1a would be limited. If we only reply on option 1a, it is impossible to meet the synchronization budget. However, it might be possible to combine with other method, e.g. option 1b.

* **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)

For option 1b, TA indication error $error\_{TA\\_indication}$, TA adjustment accuracy $error\_{TA\\_adjustment}$ and Te should be improved compared to legacy UEs. In RAN1#103-e, it was agreed that TA adjustment accuracy is not considered for the evaluation of time synchronization error, thus we would mainly focus on enhance Te. However, since Te is specified by RAN4, we need RAN4 to evaluate the feasibility to define a new enhanced Te.

**Proposal 4.1-1:Send a LS to RAN4 to ask for feedback on the following two questions:**

* **Question 1:** Is it feasible to define a new enhanced initial transmit timing error Te?
* **Question 2:** If the answer to question 1 is yes, what the enhanced value(s) for Te?

**Please provide your views on the above proposal 4.1-1.**

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| *Company* | *View* |
| *CATT* | We support Option 1b because TA-based PDC can meet Uu interface budget from RAN2 if both TA indication error and Te can be enhanced simultaneously.For example, if TA indication error can be reduced by 8 times and Te can be reduced by 4 times.one Uu interface time synchronization error based on TA-based estimation for 15Hz SCS is [-147.5ns, 147.5ns] with BS transmit timing error(±32.5 ns) and the formula with option1. |
| OPPO | By following our error analysis given earlier, no non-negative value for Te can make the total error meet RAN2 error budget for 15kHz SCS in control-to-control scenario. It seems useless to consult RAN4 with Q1 and Q2. We would rather suggest to send LS to RAN2 to simply report the difficulty in meeting RAN2 error budget for control-to-control scenario.  |
| Samsung | Although we don’t think TA adjustment error needs to be considered for the calculation, it doesn’t mean we don’t need to introduce a finer TA. With 1b, propagation delay estimation requires to trigger a new PRACH for gNB to estimate propagation delay. Otherwise, UE need to calculate TA from the last RACH procedure.Therefore, we think it is not enough to only support 1b.  |
| Nokia, NSB | Yes, RAN1 should further evaluate the pros and cons of Option 1b as supplementary procedures to legacy timing advance. This includes RAN1 to ask RAN4 on the feasible enhancement of Te.Based on the analysis in our TDoc, Te should be enhanced by at least 122ns to satisfy the accuracy of the control-to-control scenario with 15kHz SCS |
| vivo | According to our evaluation, for single Uu interface budget with ±145ns for Control-to-Control use case, only 12.5ns is left for the sum of Te and TA granularity error assuming BS transmit timing error(±32.5 ns). It is difficult for meeting clock synchronization requirements.  |
| MediaTek | No need to send an LS to RAN4.Based on our evaluations, there is no need for PDC in the C2C scenario, and the exiting errors are within the smart-grid scenario budget. |

* **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)

This option relies on the gNB to estimate DL PD, and then use an additional signal to indicate the PD from gNB to UE. Since a separate signaling is used, it has no impact on TA procedure. However, based on the contributions, it seems there are different understanding whether gNB needs to estimate the DL PD based on TA or some other dedicated reference signal (e.g. Samsung proposes to use SRS, UL DMRS or PUSCH with predefined TA for propagation delay estimation). Nokia (R1-210037) mentioned that if the estimation is based on TA, then gNB may have to track all relative TA adjustments, and if the UE applies an autonomous adjustment to its timing advance value, the gNB cannot reliably determine the applied timing advance value at the UE.

**Question 4.1-2: Do you think that gNB will estimate the DL PD based on TA for option 1c? If your answer is NO, please provide your detailed solution.**

|  |  |
| --- | --- |
| *Company* | *View* |
| CATT | Option1c is one of the enhanced methods on TA-based PDC but signaling of current TA-based PDC is quite complete. So it isn’t necessary to introduce new signaling.  |
| OPPO | Same comments as for 4.1-1. Besides, it is a general assumption that the gNB cannot reliably track the NTA value which is the accumulation of series TA commands due to possible missing of HARQ-ACK for PDSCH containing the TA command MAC-CE.  |
| Samsung | Yes. We think gNB will estimate the DL PD based on a uplink transmission. Another motivation to separate the propagation delay estimation and indication from TA is that, there is no need to require to use finer TA for all the TA adjustment, and no need to change TA procedure when there is no need to compensate the propagation delay.   |
| Nokia, NSB | Yes.  |
| vivo | Yes. gNB need estimate the DL PD based on TA for option 1c. |

**Question 4.2-3: Do you have any other views on TA-based propagation delay compensation?**

|  |  |
| --- | --- |
| *Company* | *View* |
| CATT | From our point of view, TA-based propagation delay compensation can be considered for enhancement for propagation delay compensation with high priority because compared with RTT-based propagation delay compensation method, TA-based propagation delay compensation method already has the complete signalling/mechanism of air interface. |
| Samsung | In our view, the total error is from UE/gNB estimation, as well as UE/gNB transmission. For transmission error, it is limited by hardware. But for estimation, we can improve the accuracy. For example, we need to ensure that gNB can estimate TA with current PRACH, and UE can achieve a certain error for DL timing. In addition. If we jump out from PRACH, Te is not necessary to be used when we calculate the error, since Te is the minimal requirement for the UE when waking up from DRX idle. In some sense, we think option 1c might be closer to option 2. We only need to care about DL and UL signal for UE and gNB detection, and signaling/pre-defined rule for UE to use for DL timing. |
| Nokia, NSB | Legacy timing advance (Release-16) or Option 1a, the benefit of Option 1c seems to be limited as the options are potentially enhancing the same error source (i.e. signaling granularity). |

## 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.

Based on the views in the contributions, several companies expressed that RTT-based method is introduced only if TA-based propagation delay compensation enhancements are not sufficient. Before sufficient discussion is done on TA-based propagation delay compensation enhancements, it might be difficult to justify whether it is sufficient or not.

If TA-based propagation delay is necessary to be introduced, the following issues are raised by companies to further study:

* **Whether DL reference signals other than PRS could be used for DL time estimation at UE side, such as CSI-RS.**
* **Whether to leave the signaling design for RTT based delay compensation method to RAN2? e.g. how the UE reports the measurement to the gNB (e.g. via RRC) and what the report should contain (can be left for RAN2).**
* **What equation to use for evaluating the overall time synchronization error?**

In case we will need to introduce RTT based delay compensation enhancements, the following questions are set to collect the views from the proponents.

**Question 4.2-1: Whether DL reference signals other than PRS could be used for DL time estimation at UE side?**

|  |  |
| --- | --- |
| *Company* | *View* |
| CATT | PRS is enough for RTT-based PDC and it isn’t necessary to introduce other new DL signals. |
| OPPO | Yes. It seems a UE implementation issue to use what DL RS or RS combination for timing detection.  |
| Samsung | Other DL reference signals other than PRS can be considered. We think RAN 1 or RAN 4 can further study it. For example, we can estimate a range for DL sync and then make sure UE can achieve such requirement. However, this can be further discussion whether this is up to UE implementation  |
| Nokia, NSB | YesFor 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. Additionally, 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. Therefore, these options need to be further studies for discussion. |
| vivo | DL reference signals other than PRS used for DL time estimation can be further investigated. On the other hand, the required bandwidth of reference signals should be studied. For example, if the larger bandwidth of reference signal is required to meet the timing accuracy, the potential overhead should be considered, especially for URLLC service with small payload size. |

**Question 4.2-2: Whether to leave the signaling design for RTT based delay compensation method to RAN2, e.g. how the UE reports the measurement to the gNB (e.g. via RRC) and what the report should contain (can be left for RAN2)?**

|  |  |
| --- | --- |
| *Company* | *View* |
| CATT | We agree to leave the signaling design for RTT based delay compensation method to RAN2. |
| OPPO | It seems too early to decide for now.  |
| Samsung | We need to provide analysis on the error and assumption, e.g., what kind of assumption we used to achieve such result, including what parameters UE/gNB need to know. But we agree that, signaling/procedure design can up to RAN 2. |
| Nokia, NSB | Agree with Samsung. The signaling details can be left up to RAN2But on the signaling content (e.g. granularity etc.), at least RAN1 should be involved.  |
| vivo | The details for RTT-based delay compensation method should be clarified firstly.  |

As to what equation to use for evaluating the overall time synchronization error for RTT based propagation delay compensation enhancements, the following options are proposed from companies:

**Option 1:**

$$error\_{total, RTT based}\leq error\_{BS, DL, TX}+\frac{error\_{BS, UL,RX}+error\_{UE, DL, RX}+error\_{RxTxDiff, report}}{2}$$

* + $error\_{RxTxDiff, report}$ is to reflect the error due to report granularity of Rx-Tx time difference
	+ ***Support:*** *ETRI, Intel*

**Option 2:**

$$error\_{total, RTT based}\leq \frac{error\_{BS, DL, TX}+error\_{BS, UL, RX}+error\_{UE,DL,RX}+error\_{UE, UL, TX} }{2}$$

* + ***Support:*** *Qualcomm*

**Option 3:**

$$error\_{total, RTT based}\leq \frac{error\_{BS,DL, TX}+error\_{BS,UL,RX}+error\_{UE, UL, TX}+error\_{RxTxDiff, report}}{2}$$

* + ***Support:*** *CATT*

**Option 4:**

$$error\_{total, RTT based}\leq \frac{error\_{BS, DL, TX}+error\_{BS, UL, RX}+error\_{UE, DL, RX}+error\_{UE, UL, TX}+error\_{RxTxDiff, report}}{2}$$

* + ***Support:*** *LG, OPPO*

**Option 5:**

$$error\_{total, RTT based}\leq error\_{BS,DL,Tx}+\frac{error\_{UE,DL,Rx}+error\_{BS,UL,Rx}+error\_{gNB,RxTxDiff}+error\_{UE, RxTxDiff}+error\_{RxTxDiff, report}}{2}$$

* + $error\_{RxTxDiff, report}$ 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.
	+ ***Support:*** *Ericsson*

**Option 6:**

$$error\_{total, RTT based}\leq \frac{error\_{BS, DL, TX}+error\_{BS, UL, RX}+error\_{UE, DL, RX}+error\_{RxTxDiff, report}}{2}$$

* + ***Support:*** *Nokia, vivo*

**Option 7:**

$$error\_{total, RTT}\leq \frac{error\_{BS, DL, TX}+error\_{BS, UL,RX}+error\_{RxTxDiff, report}+Te+error\_{indication}}{2}$$

* + $error\_{RxTxDiff, report}$ is to reflect the error due to report granularity of Rx-Tx time difference
	+ $error\_{indication}$ is to reflect the error due to the granularity of propagation delay indication
	+ ***Propagation delay indication granularity error (***$error\_{indication}$***)****: gNB eventually need to signaling to UE about the propagation delay. Therefore, an additionally signaling to indicate propagation delay cannot be avoided. The granularity of propagation delay indication will also affect the total error.*
	+ ***Support:*** *Samsung*

The views are very divergent, maybe once we achieve consensus on the equation for TA-based method, some aspects can be straightforward, e.g. whether $error\_{BS, DL, TX}$ or $error\_{BS, DL, TX}/2$ should be included, whether $error\_{UE, DL, RX}$ should be considered, etc.

**Question 4.2-3: Do you have any suggestion on how to move forward on the equation to use for evaluating the overall time synchronization error for RTT based propagation delay compensation enhancements?**

|  |  |
| --- | --- |
| *Company* | *View* |
| CATT | From our perspective, common components in all of formula options can be made as baseline and then discuss about whether differential components is necessary or not one by one. |
| OPPO | Agree with FL that RAN1 should firstly try to converge on TA-based formula. In addition, option-4 above is just our formula to calculate the error in one-way propagation delay estimation, not the overall error. Our current observation is that, the error terms that are common to TA-based and RTT-based methods already make the RTT-based method fail to meet the error budget for control-to-control scenario. Our comments under 4.1-1 also apply here. |
| Samsung | Support CATT’s suggestion |
| Nokia, NSB | Agree with CATT & Samsung here. On the error of $error\_{BS, DL, TX}$ – if using half or not depends also here on the outcome of Sec. 1 discussions (65ns vs +-32.5ns) |
| vivo | We share the similar view with CATT. |

**Question 4.2-4: Do you have any other views on RTT-based propagation delay compensation?**

|  |  |
| --- | --- |
| *Company* | *View* |
| CATT | From our point of view, TA-based propagation delay compensation can be considered for enhancement for propagation delay compensation with high priority. If the TA-based propagation delay compensation can’t meet the requirements of synchronization budget per Uu Interface, RTT-based propagation delay compensation and the corresponding enhancement method can be considered as the candidate for propagation delay compensation in Rel-17. |
| Samsung | gNB eventually need to signaling to UE about the propagation delay. Therefore, an additionally signaling to indicate propagation delay cannot be avoided. The granularity of propagation delay indication will also affect the total error.  |
| Nokia, NSB | RAN1 should further evaluate the pros and cons of Option 2 (RTT). This include on how to consider **the effect of DRX for RTT based methods**? |
| vivo | For RTT-based solution, some aspects should be clarified. * Bandwidth of reference signal.

For RTT-based method, the large bandwidth of reference signal may be required to guarantee accuracy. The overhead of reference signal may be an issue, especially for UE specific reference signal.* The signaling overhead

Obtaining the required precision for external clock may need quite frequent time information updates over Uu interface. Thus, the signaling overhead caused by triggering RTT-based delay measurement may be huge in order to guarantee the synchronization error is always less than synchronicity budget requirement. |

## gNB-based pre-compensation of the reference time information

Intel (R1-200643) proposes to expand the list of propagation delay compensation options with gNB-based pre-compensation (both RTT-based and non-RTT based) in order to match with the latest status of RAN2 discussion.

**Feature lead**: It looks to me that RTT-based gNB-based pre-compensation is same as option 2. Therefore, option 3 here can focus more on non-RTT based gNB-based pre-compensation. However, since there is no more details in the contributions, it would be further clarify the details of this option here.

**Question 4.3-1: Any further details to be provided for gNB-based pre-compensation here?**

|  |  |
| --- | --- |
| *Company* | *View* |
| CATT | RTT-based gNB-based pre-compensation is one of RTT-based PDC methods. The difference between gNB-based pre-compensation and UE compensation is that for gNB-based pre-compensation, UE report s Rx-Tx time difference to gNB and gNB executes PDC while for UE compensation, UE receives from gNB report on the gNB Rx-Tx time difference and executes PDC. |
| Samsung | We think it can be decoupled from option 2. There were two methods discussed in RAN 2, one is UE to compensate PD, the other is gNB to pre-compensate PD. For UE compensated method, it doesn’t requires unicasted signaling for timing. But it requires UE specific singling for gNB pre-compensate methods. In our understanding, RTT based method can be UE compensate methods or pre-compensated method by gNB. |
| Nokia, NSB | gNB pre-compensation may have some severe RAN3 impact. Therefore, it would be good to involve RAN3 in further clarifications on the gNB-based pre-compensation.  |

# 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. R1-2100105 Discussion on propagation delay compensation enhancements ZTE
3. R1-2100185 Enhancements for Propagation Delay Compensation OPPO
4. R1-2100272 Propagation Delay Compensation Enhancements for Time Synchronization Ericsson
5. R1-2100380 Discussion on propagation delay compensation enhancements CATT
6. R1-2100440 Discussion on propagation delay compensation enhancements vivo
7. R1-2100578 Discussion on propagation delay compensation for time synchronization MediaTek Inc.
8. R1-2100653 Propagation delay compensation analysis and design considerations Intel Corporation
9. R1-2100730 Discussion on enhancements for propagation delay compensation Nokia, Nokia Shanghai Bell
10. R1-2100884 Discussion on propagation delay compensation enhancements LG Electronics
11. R1-2101078 Propagation delay compensation enhancements ETRI
12. R1-2101205 Discussion for propagation delay compensation enhancements Samsung
13. R1-2101265 Enhancements for support of time synchronization Huawei, BUPT, China Southern Power Grid, HiSilicon
14. R1-2101382 Orphan symbol treatment in unlicensed spectrum access Apple
15. R1-2101463 Enhancements for support of time synchronization for enhanced IIoT and URLLC Qualcomm Incorporated
16. R1-2100024 Reply LS on propagation delay compensation enhancements

# 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.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **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