**3GPP TSG RAN WG1 #110bis-e R1-2210523**

**e-Meeting, October 10th – 19th, 2022**

**Agenda item:** 9.1.2

**Source:** Moderator (Samsung)

**Title:** Summary of TDCP Alternatives for Comparison

**Document for:** Discussion and Decision

[110bis-e] **Agreement**

For the Rel-18 TRS-based TDCP reporting, down select one of the following alternatives by RAN1#110bis-e:

* AltA. Based on Doppler profile
	+ E.g., Doppler spread derived from the 2nd moment of Doppler power spectrum, average Doppler shifts, Doppler shift per resource, maximum Doppler shift, relative Doppler shift, etc
* AltB. Based on *quantized amplitude of* time-domain correlation profile
	+ E.g. Correlation within one TRS resource, correlation across multiple TRS resources
	+ Note: The correlation over one or more lags of TRS resource may be considered.  The lags may be within one TRS burst or different TRS bursts

Note: Different alternatives may or may not apply to different use cases

FFS: The need for a measure of confidence level in the TDCP report, and/or UE behaviour when the quality of TDCP measurement is not sufficiently high

FFS: TDCP parameter(s) signalled with respect to each alternative

For the purpose of performance comparison and down-selection in RAN1#111, the alternatives for TDCP are summarized below:

**Table 1**

|  |  |  |  |
| --- | --- | --- | --- |
| **TDCP report** | **What to report (possible spec impact, not an agreement yet)** | **How to calculate: examples, possible UE implementation for evaluation (companies are to state their calculation method)** | **Support (per RAN1#110bis-e)** |
| A1. Doppler spread | One Doppler spread value, i.e. . (see column 3 of A1)  | The normalized channel correlation for each delay can be calculated as follows where indicates the time domain estimated channel at delay in symbol i within a TRS burst. Further averaging for multiple TRS busts is necessary. The UE can optionally perform interference/noise reduction to get .The Doppler for each delay can be calculated as Where is the time duration for an OFDM symbol.To calculate , the UE can search candidate to minimize the error of UE does not need to calculate for the each tap, but it only needs to calculate it for top N tops. From multiple , the UE can calculate the following: | vivo, Google, LG, OPPO, Huawei/HiSi, Xiaomi, Mavenir, Apple (1st pref), IDC, Spreadtrum, NEC (2nd pref),  |
| A2. Relative Doppler shift per resource | With N>=1 TRS resources: Doppler shift per resource (e.g. differential or absolute) | * Doppler shift fd is derived based on the following equation: fd = angle(r)/(2\*pi\*t)
	+ where r is the channel correlation measured from different TRS symbols and t is the time domain interval for the channel correlation.
* For differential manner, the differential value (e.g., relative Doppler shift) is: fd - fd\_reference
 | ZTE, .. |
| A3 Single Doppler shift | One Doppler shift value | * The average Doppler shift across multiple delay-paths/peaks in measured CIR
	+ UE calculates and selects the first M peaks/delay-paths according to CIR (Chanel Impulse Response)/ PDP (Power Delay profile)
	+ UE calculates Doppler shifts fd,0…. fd,M-1according to M peaks/delay-paths respectively
	+ UE calculates and reports average Doppler shift by power weighted, i.e.
* Maximum Doppler shift across multiple delay-paths/peaks in measured CIR
	+ UE calculates and selects the first M peaks/delay-paths according to CIR (Chanel Impulse Response)/ PDP (Power Delay profile)
	+ UE calculates Doppler shifts fd,0…. fd,M-1according to M peaks/delay-paths respectively
	+ UE reports Maximum Doppler shifts fd,max among the M peaks/delay-paths
 | CATT |
| A4. Relative Doppler shift per CIR peak | With M identified peaks in measured CIR: (1) N Doppler shifts;(2) M values of delay shift in CIR | * UE-side:
	+ UE calculate and select the first M peaks/delay-paths according to CIR (Chanel Impulse Response)/ PDP (Power Delay profile)
	+ UE calculate Doppler shifts ~~f~~~~d,0….~~ ~~f~~~~d,M-1~~ according to ~~M~~ the m-th peak/delay-path respectively
	+ UE reports Doppler shift FFS: *M/N* is pre-defined by network or configured by gNB
* gNB-side:
	+ gNB matches fd,0 to the strongest path measured by SRS
	+ gNB matches N Doppler shifts ~~f~~~~d,1…~~~~f~~~~d,M-1~~ to the M paths measured by SRS
		- gNB matches M-1 paths measured by SRS according to (M-1) differential Delay shifts to the strongest path or (M-1) Delay shifts reported by UE
 | CATT, Huawei/HiSi |
| A5. Doppler spread estimated from peak Doppler frequency | DFT index corresponding to the peak Doppler frequency: whereand is the TRS time-correlation function, where is the TRS measurement on subcarrier at time  |  | Nokia/NSB |
| B. Time-domain correlation profile  | Non-zero quantized version of amplitude for a number of delay values  (quantized amplitude vs delay)Example equation whereand is the channel for subcarrier n. | * Normalized auto-correlation of a time series measured from a TRS resource.
* Multiple auto-correlation values can be calculated from different lags of the same resource or different resources
* The autocorrelation can be estimated by replacing the channel for subcarrier *n* in the defining formula in column 2, with the matched filter subcarrier components  of the received signal where is the complex conjugate of the known transmitted TRS signal. For one can use the arithmetic average over the two TRS symbols separated by the time , i.e.

Or, alternatively, one may use the geometric average for , i.e. Further methods to remove noise bias and to suppress noise can be used. | Samsung, Ericsson, MediaTek, vivo, Qualcomm, DOCOMO, OPPO, Sharp, Lenovo (highlighted bullet), Apple (2nd pref), IDC, NEC (1st pref), CEWiT, Fraunhofer IIS/HHI, |

**Table 2 Additional inputs**

|  |  |
| --- | --- |
| **Company** | **Input** |
| Mod V0 | **Share your inputs, if any, on each cell of Table 1** |
| Ericsson | **Alternative B column 2 in Table 1:**We propose the following changes/additions:Non-zero quantized amplitude for ~~each~~ a number of delay values (quantized amplitude vs delay):whereand is the channel for subcarrier n.**Alternative B column 3 in Table 1:**Comment 1. We propose to correct the following typo:* Multiple ~~profiles~~ Auto-correlation values can be calculated from different lags of the same resource or different resources

2. We have seen no one propose to report the un-normalized Auto-correlation. The overall rx power c(0) carries no useful information and the normalization saves a lot of overhead by making the Autocorrelation strictly smaller than one and removing the need to report the Auto-correlation for zero lag. We therefore propose to remove the bullet on Normalized versus un-normalized equation and instead include Normalization in the first bullet. Thus we propose the following changes:* Normalized Auto-correlation of a time series measured from a TRS resource.
* Multiple ~~profiles~~ Auto-correlation values can be calculated from different lags of the same resource or different resources
* ~~[Normalized vs un-normalized] [equation]~~

Comment 3. We also propose to include the following text giving two examples for how to perform estimation of the auto-correlation:How to perform the estimation should be up to UE implementation but for the purpose of evaluations we give two examples. The autocorrelation can be estimated by replacing the channel for subcarrier *n* in the defining formula in column 2, with the matched filter subcarrier components  of the received signal where is the complex conjugate of the known transmitted TRS signal. For one can use the arithmetic average over the two TRS symbols separated by the time , i.e.or one may use the geometric average for , i.e. Which example is used in evaluation can be stated by company along with their evaluation results. Further methods to remove noise bias and to suppress noise would typically be used.[Mod: Added with some edits. RE “...up to UE implementation ...” I don’t include this since it is obvious.] |
| Lenovo | **Re Alt-A:**We still would like to have better understanding from Alt-A proponents on how the Doppler shift can be differentiated from CFO, since they both cause a frequency shift with the same order of values. Even if this will be handled in a spec-transparent manner based on UE implementation, it is important that the proponents explain how this can be done so we can assess the feasibility and efficiency of Alt-A before supporting it**Re Alt-B:**We have added one bullet point (highlighted) that can help as a workaround regarding specifying the autocorrelation function. Instead of reporting the quantized correlation amplitude for a fixed lag, alternatively the lag is reported (in terms of a symbol index or TRS occasion index) with respect to a fixed correlation amplitude. The fixed correlation amplitudes can be configured from a small set of values, e.g., two values corresponding to strong, weak correlation, so that the process is less dependent on the underlying autocorrelation function as much as possible[Mod: This is a next-level detailed design if AltB is agreed. Not necessary at this point. But when you simulate it, you can implement it as such (you may state the design you assume)] |
| Ericsson2 | @Lenovo: Regarding what you have added in Alt B, it is one possibility. Just to make it clear, in either case, for what you have in mind also, the UE will be measuring normalized autocorrelation. And, the examples we showed for A(t,tau) above are also up to UE implementation and does not need those specific formulas to be specified in specs.Regarding your two level reporting idea, this is more related to how the measured correlation should be quantized (i.e., the small set of values). What type of quantization is needed can be determined later based on evaluations. |
| ZTE | Re A2, regarding component of report format (considering report overhead or not), in our views, the proposal from the FL is a good example, but may not be needed in this so-detailed level. Similarly, in B, we do not discuss the list of ‘non-zero quantized amplitude for each delay value’ (differential or absolute). [Mod: This table is to facilitate simulation, not for spec impact, since several companies (including ZTE ☺) brought up unclarity issue. If the proponents of A2 do not want to provide details (specifics) for evaluation, it is up to them. In that case, the proponents of B can assume and simulate A as they see fit. It is your choice.]To make it general, we have the following suggestion for second column. Then the sub-bullet(s) can be removed or captured in the third column, if needed.With N ≥ 1 TRS resources, Doppler shift per resource (e.g., differential or absolute value) [Mod: OK, this high level description doesn’t really help much but it is up to you ☺. This belongs in 2nd column not 3rd. This is what the UE reports. Not how to calculate. I will keep this in the 2nd]For calculating the Doppler shift, I guess that we may not need to further clarify it. All are senior delegates/experts. ^\_^ [Mod: This has nothing to do with expertise. This is to avoid, e.g. proponents of A complain that proponents of B assume a bad scheme for A that’s why the results are such and such. Or proponents of B complain that proponents of A assume a bad calculation scheme for B etc.The goal is to have a constructive evaluation.] If needed, we have the following example * Doppler shift fd is derived based on the following equation: fd = angle(r)/(2\*pi\*t)
	+ where r is the channel correlation measured from different TRS symbols and t is the time domain interval for the channel correlation.
* For differential manner, the differential value (e.g., relative Doppler shift) is: fd - fd\_reference
 |
| Qualcomm | Re Alt-BFor the formula of auto-correlation, our understanding is what Ericsson mentioned as “geometric average.”Actually, if the signal and are already the normalized version themselves, i.e. , the two formulas (arithmetic and geometric average) are equivalent.[Mod: Good point]Regarding profiles with longer lag than 2 slots, we can understand its motivation for lower-speed scenario, and we can also support (but should not require receiving phase continuity of course, which is satisfied by the formulation with operation in the numerator). Yet, however, maybe a 2nd-level thing to discuss is overhead. For example, for a 5msec lag, 2 TRS bursts with total 8 symbols seem redundant – actually 2 single-port CSI-RS symbols with 5msec time spacing would work. Therefore, we think longer lag does not need to be tied with existing TRS definition, and a single-port CSI-RS resource set with newly defined time spacing is enough – this can also leverage some work anyway need to be done for Type-II-Doppler CSI topic. |
| Mod V6 | **Revised per inputs****@Ericsson: Please check Qualcomm’s comment and see if the description for B needs to be refined** |
| Google | For Alt-A, we would like to provide an example on how to calculate the Doppler spread and what to report.***Possible evaluation assumption for UE operation***The normalized channel correlation for each delay can be calculated as follows where indicates the time domain estimated channel at delay in symbol i within a TRS burst. Further averaging for multiple TRS busts is necessary. The UE can optionally perform interference/noise reduction to get .The Doppler for each delay can be calculated as Where is the time duration for an OFDM symbol.To calculate , the UE can search candidate to minimize the error of UE does not need to calculate for the each tap, but it only needs to calculate it for top N tops. From multiple , the UE can calculate the following:***UE report content***UE reports the .For Alt-B, thank you for further clarification. We have one quick question, is it correct understanding that the UE should report all ?[Mod: Correct, for each where A() is “non-zero” (above a certain threshold, I presume) |
| Google2 | One more question to Alt-B, since we are going to evaluate both Alt-A and Alt-B, from Alt-B, we assume gNB needs to do some post-processing based on the reported channel correlation. Could proponent of Alt-A clarify it a bit on how gNB would do the post-processing? Otherwise, it would be challenging to compare both alternatives. |
| Mod V9 | **Added Google input for AltA1.** **@AltB proponents, please check “Google2” and respond** |
| CATT | Added the A3 and A4 in the Table 1 preferred by CATT |
| Ericsson | **Question to proponents of Alt A1:**We note that the proposed A1 estimation method is curve fitting to the Autocorrelation based on ‘a known form of the Autocorrelation profile’. This doesn’t work since there is no known form of Autocorrelation function. In our contribution we showed the form of the Autocorrelation function for CDL functions as well as for the TDL channels that follow the Jakes form. The form is very different for the different channels (see figure below). Note that one single channel ray, however weak it is, can completely change the Doppler spread, defined as the maximum minus minimum Dopplershift. An extremely weak channel ray would have negligible impact on the Autocorrelation while it could completely change the Doppler spread defined in this way.Chart, line chart  Description automatically generatedThe only commonality in the form of the Autocorrelation functions for different channels is the low lag formThis form applies to Jakes just as for all other channels. For Jakes we haveWe note that for the Jakes channel we haveWe note that if one estimates by fitting the estimated autocorrelation to for small autocorrelation lags , then is a measure of , i.e. the second moment of the Doppler power spectrum times the square root of two and not of . For the Jakes channel this happens to coincide with , but that is not true for other channels. Thus, the proposed estimator is an estimator of the second moment of the Doppler power spectrum and not of .Thus, we ask the proponents of A1 on how the proposed estimator can be expected to estimate the maximum minus minimum Dopplershift for other channels than the TDL channels?In an evaluation we would like to see the accuracy and bias of the proposed estimator compared to the ideal maximum minus minimum Dopplershift measure for realistic CDL channels and not only for the very ideal TDL channels.[Mod: While I appreciate this type of technical “question”, this goes beyond the intention of this table. If you think that A1 proponent has a faulty scheme, you are welcome to demonstrate it in Toulouse by showing that the curve fitting based on Jakes’ profile doesn’t work for a more realistic channel (assuming CDL is more realistic than TDL) – which would be your argument to show, e.g. B is superior than A1 ☺ As this goes beyond the scope of this document, we can stop and save the energy for Toulouse. If Ericsson still seeks more clarification, please continue offline. The same holds for other companies ☺ We have <1 day to conclude on Table 1]**Reply To Qualcomm**Yes, it’s true of course that if you have already normalized and then further normalization will not have any effect. The end result is then the same as using geometric normalization. Thus, arithmetic normalization can’t be achieved in this way. This doesn’t, however, say anything about the basic question whether we want geometric or arithmetic normalization.We note that for very low delay spread the channel is constant over the whole bandwidth. With geometric normalization the Autocorrelation then becomes identically one for all autocorrelation lags. Clearly, this isn’t the true Autocorrelation. Even a narrowband channel fades with time. This fading can be captured if the arithmetic normalization is used but not if the geometric normalization is used. This may not be a big issue (e.g. if the delay spread can be assumed to be sufficiently large) but we would still like to keep this open until the next meeting. **Reply to Google** would be reported for a small number of lag values , say maximum four. The current TRS burst allows intra burst measurement of lags corresponding to four symbols as well as of a lag corresponding to one slot. In addition to these lags we think two more inter-burst lags of ~5 and ~10 slots would be needed to give good accuracy also when the channel coherence time is long.**Reply to Google2**We think the first thing to evaluate should be to show the accuracy and bias of the measure relative to the ideal measurement.How the gNB should do the post-processing is up to implementation and also depends on the use-case. To decide on a CSI-RS/feedback periodicity one could e.g. find the autocorrelation lag such that the Autocorrelation is equal to a certain value *k* and select the periodicity as rounded to the closest larger number of slots. This lag can be found by interpolation between the reported values for the Autocorrelation for different lags. This would ensure that the Autocorrelation is larger than *k* for and thus also over the full period selected. Thus, one ensures that the channel doesn’t change too much during the selected period.Another possibility is to calculate the second moment of the Doppler power spectrum at the gNB based on the reported Autocorrelation values and take decisions based on thresholds on the second moment.[Mod: Thanks for the response. Your answers here should provide sufficient info for other companies to implement AltB] |
| Huawei, HiSilicon | **Re Alt A4:**From our observation as shown in the following figure, one delay can correspond to multiple Doppler shifts. The different Doppler shifts are useful for gNB to predict the channel.Therefore, we propose the following update to A4, which seems also covers CATT’s original A4 if , i.e., N=M.

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| --- | --- | --- |
| A4. Relative Doppler shift per CIR peak | With M identified peaks in measured CIR: (1) N Doppler shift ~~for a reference CIR peak + (M-1) differential Doppler shifts~~;(2) M values of delay shift in CIR | * UE-side:
	+ UE calculate and select the first M peaks/delay-paths according to CIR(Chanel Impulse Response)/ PDP(Power Delay profile)
	+ UE calculate Doppler shifts ~~f~~~~d,0….~~ ~~f~~~~d,M-1~~ according to ~~M~~ the m-th peak/delay-path respectively
	+ UE reports Doppler shift ~~for the strongest power CIR peak/delay path + (M-1) differential Doppler shifts~~
	+ ~~UE reports (M-1) differential Delay shifts~~
	+ ~~FFS: The definition of the reference CIR peak, i.e. the strongest power of delay paths~~
	+ ~~FFS: M is pre-defined by network or configured by gNB~~
* gNB-side:
	+ gNB matches fd,0 to the strongest path measured by SRS
	+ gNB matches N Doppler shifts ~~f~~~~d,1…~~~~f~~~~d,M-1~~ to the M paths measured by SRS ~~M-1 paths measured by SRS according to (M-1) differential Delay shifts reported by UE~~
 |

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| CATT2 | We can understand HUAWEI’s suggestion that one Delay might correspond to multiple Doppler shifts. We are fine with more unified scheme for A4. But for the point to match delay-path between SRS and TRS, the M Delay shifts are important for gNB to predict the channel. Hence, we are fine with the UE-side changes for our version, but still suggest to add the description on gNB-side calculation.

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| --- | --- | --- |
| A4. Relative Doppler shift per CIR peak | With M identified peaks in measured CIR: (1) N Doppler shifts ~~for a reference CIR peak + (M-1) differential Doppler shifts~~;(2) M values of delay shift in CIR | * UE-side:
	+ UE calculate and select the first M peaks/delay-paths according to CIR(Chanel Impulse Response)/ PDP(Power Delay profile)
	+ UE calculate Doppler shifts ~~f~~~~d,0….~~ ~~f~~~~d,M-1~~ according to ~~M~~ the m-th peak/delay-path respectively
	+ UE reports Doppler shift ~~for the strongest power CIR peak/delay path + (M-1) differential Doppler shifts~~
	+ ~~UE reports (M-1) differential Delay shifts~~
	+ ~~FFS: The definition of the reference CIR peak, i.e. the strongest power of delay paths~~
	+ FFS: *M/N* is pre-defined by network or configured by gNB
* gNB-side:
	+ gNB matches *f*d,0 to the strongest path measured by SRS
	+ gNB matches N Doppler shifts ~~f~~~~d,1…~~~~f~~~~d,M-1~~ to the M paths measured by SRS
		- gNB matches M-1 paths measured by SRS according to (M-1) differential Delay shifts to the strongest path or (M-1) Delay shifts reported by UE
 |

[Mod: OK, added] |
| Nokia/NSB | In our understanding, an indication of the Doppler spread can be calculated from the time-domain correlation of TRS. The time-domain correlation at lag is as indicated in Alt B: , where is the TRS measurement on subcarrier at time Then, instead of reporting the quantised profile of the time-correlation function, it is sufficient for a UE to report the Doppler frequency corresponding to the peak of the Doppler spectrum:, where [Mod: OK] |
| Mod V15 | **Incorporated all inputs** |