**3GPP TSG RAN WG1 #109-e R1-220xxxx**

**e-Meeting, May 09 – May 20, 2022**

**Agenda item:** **9.2.3.1**

**Source:** Moderator (Samsung)

**Title:** Feature lead summary #1 evaluation of AI/ML for beam management

**Document for:** Discussion and Decision

# Introduction

In RAN#94-e, Rel-18 new study item on “Study on Artificial Intelligence (AI)/Machine Learning (ML) for NR Air Interface” was approved. The following use cases were identified as the initial set:

* Initial set of use cases includes:
  + CSI feedback enhancement, e.g., overhead reduction, improved accuracy, prediction [RAN1]
  + Beam management, e.g., beam prediction in time, and/or spatial domain for overhead and latency reduction, beam selection accuracy improvement [RAN1]
  + Positioning accuracy enhancements for different scenarios including, e.g., those with heavy NLOS conditions [RAN1]

The performance of AI/ML based algorithms for the use cases includes the following aspects:

1. Evaluate performance benefits of AI/ML based algorithms for the agreed use cases in the final representative set:
   * Methodology based on statistical models (from TR 38.901 and TR 38.857 [positioning]), for link and system level simulations.
     + Extensions of 3GPP evaluation methodology for better suitability to AI/ML based techniques should be considered as needed.
     + Whether field data are optionally needed to further assess the performance and robustness in real-world environments should be discussed as part of the study.
     + Need for common assumptions in dataset construction for training, validation and test for the selected use cases.
     + Consider adequate model training strategy, collaboration levels and associated implications
     + Consider agreed-upon base AI model(s) for calibration
     + AI model description and training methodology used for evaluation should be reported for information and cross-checking purposes
   * KPIs: Determine the common KPIs and corresponding requirements for the AI/ML operations. Determine the use-case specific KPIs and benchmarks of the selected use-cases.
     + Performance, inference latency and computational complexity of AI/ML based algorithms should be compared to that of a state-of-the-art baseline
     + Overhead, power consumption (including computational), memory storage, and hardware requirements (including for given processing delays) associated with enabling respective AI/ML scheme, as well as generalization capability should be considered.

In this contribution summarized the discussions and proposal on evaluation methodology (EVM) and KPIs from contributions submitted to AI 9.2.3.1 for beam management (BM).

The issues in this document are tagged and color coded with High Priority or Medium Priority. The issues that are in the focus of this round of the discussion are furthermore tagged FL1.

Follow the naming convention in this example:

* Document-v000-Mod.docx
* Document-v001-Mod-CompanyA.docx
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If needed, you may “lock” a spreadsheet file for 30 minutes by creating a checkout file, as in this example:

* CompanyC uploads an empty file named Document-v003-CompanyB-CompanyC.checkout
* CompanyC checks that no one else has created a checkout file simultaneously, and if there is a collision, CompanyC tries to coordinate with the company who made the other checkout
* CompanyC then has 30 minutes to upload Document*-v003-CompanyB-CompanyC.docx*
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#### FL1 Question 0-1a

* **Please consider entering contact info below for the points of contact for this email discussion.**

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# Evaluation methodology on AI/ML in beam management

## 1.1 Dataset construction

Most of the companies proposed to use the dataset generated based on statistical channel models for evaluation:

* Huawei/HiSi [1]: For AI/ML-based beam management evaluation, training inputs generated from simulation platform should be a baseline.
* ZTE [2]: Since the data sets and AI models used by different companies are different, it is necessary to provide common data sets and baseline models for simulation calibration and performance cross-validation.
* Ericsson [4]: Beam management should be evaluated based on the scenarios defined in (simulation assumption of Rel-17 BM in R1-2007151)
* CATT [6]: A few typical scenarios in TR 38.901 can be considered for the evaluations for AI/ML-based beam management.
* vivo [7]: Data set constructed based on 3GPP channel model from TR 38.901 is mainly considered for beam management case. SLS deployment is used to obtain dataset for performance evaluation.
* Apple [15]: System level simulator can be used to generate the dataset, where the number of cells can be 1 to speed up the dataset generation procedure and full spatial consistency modeling is recommended.
  + Other parameters can be selected based on traditional system level evaluation
* DCM [17]: 3GPP statistical channel models are considered in the evaluation for representative sub use-case selection.
* DCM [17]: Discuss and decide whether and which deterministic channel models should be used to capture the final evaluation results of selected sub use-cases.
  + Option 1: Field data as indicated in SID.
  + Option 2: Ray-tracing channel model.
  + Option 3: Map-based hybrid channel model as defined in TR38.901.
* Lenovo [18]: Generate the dataset for the model training and evaluation for beam management sub use cases based on the statistical models in TR 38.901 taking in to account spatially consistency.
* Nokia/NSB [19]: The preliminary phase uses synthetic data generated from a system-level simulator that implements the 3GPP statistical channel models from 3GPP TR 38.901. The list of assumptions detailed in Table 2.1 2 can be considered for system-level simulations of different beam management sub-use cases.
* NVIDIA [21]: Use the simulation assumptions in TR 38.901 as a starting point for the evaluation of AI/ML based algorithms for beam management.
* Qualcomm [23]: RAN1 to use channel model in TR 38.901 for the evaluations on AI/ML for temporal beam prediction. A set of simulation assumptions should be agreed upon for evaluation purposes.
* Qualcomm [23]: RAN1 to use channel model in TR 38.901 for the evaluations on AI/ML for codebook-based spatial domain beam prediction. A set of simulation assumptions should be agreed upon for evaluation purposes.

Some companies suggested to encourage companies to provide common/public dataset for training and validation for cross check purposes. In [14], a website for mobile communication open dataset was mentioned as <http://www.mobileai-dataset.com/>.

* Vivo [7]: It is encouraged for companies to provide publicly accessible dataset for training and validation for cross-check purposes.
* Intel [20]: A common dataset across companies should be considered for each use-case to ensure robustness and fair comparison of AI/ML model performance taking into account, a reasonable dataset size.

Moreover, one company proposed that no need to use field data for the study item beam management use case, while two companies proposed that real data should be part of the evaluation work, and suggested to encourage companies to contribute realistic data to develop and evaluation.

* Ericsson [4]: No need for field data for the study item BM use case
* DCM [17]: Discuss and decide whether and which deterministic channel models should be used to capture the final evaluation results of selected sub use-cases.
  + Option 1: Field data as indicated in SID.
  + Option 2: Ray-tracing channel model.
  + Option 3: Map-based hybrid channel model as defined in TR38.901
* NVIDIA [21]: Identifying existing sets of real data should be part of the evaluation work for AI/ML based beam management.
* NVIDIA [21]: Companies are encouraged to contribute real data to develop and evaluate AI/ML based algorithms for beam management.

Based on the above views, the following proposal related to dataset construction can be considered.

#### FL1 High Priority Question 1-1

**Proposal 1-1:**

* **Dataset constructed based on 3GPP channel model(s) in TR 38.901 is used for beam management use case.**

**Question 1-1:**

1. Whether the above proposal 1-1 can be adopted?
2. Whether real data/field data is optionally needed as part of the study?

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## 1.2 Dataset generation and evaluation assumptions with SLS

Most of companies proposed to use SLS to evaluate the performance of beam management. Two companies explicitly proposed to use evaluation methodology (EVM) for Rel-17 beam management (R1-2007151), while other companies provided detailed proposals and analysis for the evaluation assumption for SLS. Table 1-1 in appendix summarized the main parameters proposed/used in some contributions.

* Ericsson [4]: Beam management should be evaluated based on the scenarios defined in (simulation assumption of Rel-17 BM), which are summarized in the appendix
* Samsung [9]: Consider Table A.2.5-2 (for SLS) and Table A.1.6.4 (for LLS) of TR 38.802 as the starting point for Rel-18 AI/ML for beam management evaluation, based on which necessary modifications/simplifications can be further discussed for the specific evaluation purpose and/or sub use case.
* LGE [13]: Reuse agreed simulation assumptions in Rel-17 BM (R1-2007151) except AI/ML related function for Rel-18 evaluation on AI/ML for beam management.
* CAICT [14]: Umi scenario with carrier frequency 30GHz could be considered as baseline for dataset construction and performance comparison.
* Nokia/NSB [19]: The preliminary phase uses synthetic data generated from a system-level simulator that implements the 3GPP statistical channel models from 3GPP TR 38.901. The list of assumptions detailed in Table 2.1 2 can be considered for system-level simulations of different beam management sub-use cases.
* Intel [20]: For temporal domain beam prediction, system level simulation based urban deployment e.g., dense urban and urban macro and related 3GPP channel models should be used for dataset generation
* NVIDIA [21]: The evaluation scenarios for beam management include UMi-street canyon and UMa scenarios.
* NVIDIA [21]: Focus on millimeter wave frequencies for the evaluation of AI/ML based algorithms for beam management.
* AT&T [22]: Consider both a single-cell and multi-cell SLS evaluation scenarios
* AT&T [22]: Consider modified Urban Macro and Indoor Hotspot layouts with non-uniform inter-site distances and antenna height/orientations
* AT&T [22]: Consider a venue/stadium layout with a dense deployment of base stations/TRPs oriented towards one or more cluster of users

Based on the above views, the following proposal related to evaluation methodology can be considered. Moreover, Table 1 in Appendix summarized and simplified the baseline assumptions Table 1 and Table 2 in R1-2007151 for Rel-17 BM EVM. The parameters for high-speed train scenario were removed comparing with the tables in R1-2007151, which will be separated discussed in Question 1-9. Companies are encouraged to indicate necessary changes of those parameters and the reasons.

#### FL1 High Priority Question 1-2

**Proposal 1-2:**

* **For dataset construction and performance evaluation for AI/ML based BM, SLS is the baseline tool.**

**Question 1-2:**

1. Whether the above proposal 1-2 can be adopted?
2. Which parameters in Table 1 on baseline assumptions for SLS need to be modified, and why?
3. Whether Dense Urban scenario (FR2) can be used as the baseline assumption for AI/ML for BM? If the answer is yes, which parameters in Table 2 need to be updated, and why?
4. Any other scenario(s) can be optionally considered for dataset generation and performance evaluation of AI/ML for BM?

Note: Mixed scenario(s) for generalization can be discussed in section 2.2.1. This question only focuses on single scenario case for dataset and performance evaluation.

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### 1.2.1 Spatial consistency

Several companies discussed spatial consistency for UE time domain beam prediction.

* Vivo [7]: Spatial consistency should be modeled for UE mobility scenario for time domain beam prediction.
* Samsung [9]: For evaluation of beam prediction in the time domain, in addition to the spatially-consistent mobility modelling and UE trajectory modelling, the selection of UE speed, blockage [Section 7.6.4 in TR 38.901], and/or UT rotating [Section 7.6.7 in TR 38.901] should be considered.
* Samsung [9]: Spatially-consistent UE mobility modelling: Procedure A in clause 7.6.3.2 in TR38.901
  + Note: Spatial consistency model is needed to evaluate beam prediction performance, by generating the correlated cluster power, delay, AOD/AOA/ZOD/ZOA.
* Futurewei [12]: To properly model and assess the performance of prediction in time domain, spatial consistency along the mobility trajectory needs to be ensured.
* Apple [15]: System level simulator can be used to generate the dataset, where the number of cells can be 1 to speed up the dataset generation procedure and full spatial consistency modeling is recommended.
  + Other parameters can be selected based on traditional system level evaluation
* Lenovo [18]: Generate the dataset for the model training and evaluation for beam management sub use cases based on the statistical models in TR 38.901 taking in to account spatially consistency.
* Nokia/NSB [19]: A suitable UE mobility model is needed for the spatial-temporal domain beam prediction study.
  + As shown in table 2.4-1, the current UE mobility model for spatial-temporal beam prediction assumes a straight trajectory traveled by the UE with a random direction and channel spatial consistency type-A defined in TR 38.901.
* Intel [20]: Spatially consistent large-scale parameter generation should be used for mobility evaluations. Additionally, only spatial consistency model B in [TR 38.901] can be used for mobility evaluation.

Based on the above views, the following proposal related to spatial consistency for mobility evaluation can discussed.

#### FL1 High Priority Question 1-3

**Question 1-3:**

1. Whether spatial consistency should be modeled for time domain beam prediction?
2. Which procedure can be used, procedure A or procedure B in TR38.901, and why?

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### 1.2.2 Trajectory model for UE mobility

Some companies pointed out that impact of discontinuous UE trajectory model needs to be considered.

* Samsung [9]: The impact of discontinuous UE trajectory model on the beam prediction performance shall be considered for UE mobility model selection.
* Nokia/NSB [19]: A suitable UE mobility model is needed for the spatial-temporal domain beam prediction study.
  + As shown in table 2.4-1, the current UE mobility model for spatial-temporal beam prediction assumes a straight trajectory traveled by the UE with a random direction and channel spatial consistency type-A defined in TR 38.901.
* Intel [20]: The UE trajectory should be sampled at least at the minimum decorrelation distance of the large-scale parameters corresponding to the scenario of evaluation.

Moreover, in [9], there options are proposed for the trajectory model for UE mobility:

* Observation 1-1: For the trajectory model for UE mobility, at least the following options exist:
  + Option #1: Linear and fixed trajectory model, e.g., the intra-cell mobility model in Table 2 of R1-2007151.
  + Option #2: Linear trajectory model with random direction change.
  + Option #3: Linear trajectory model with random and smooth direction change.

Based on the above views, the following questions can be discussed for UE trajectory model.

#### FL1 Medium Priority Question 1-4

**Question 1-4:**

1. Whether the UE trajectory model in Table 2 of R1-2007151 is sufficient for the training and/or evaluation of time and/or spatial domain beam prediction?
2. If the answer of a) is no, how to define the trajectory model including the following two options?
   * Option #2: Linear trajectory model with random direction change.
   * Option #3: Linear trajectory model with random and smooth direction change.

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### 1.2.3 Others aspects for data generation or evaluation

The following aspects were discussed and proposed:

* Samsung [9]: For evaluation of beam prediction in the time domain, in addition to the spatially-consistent mobility modelling and UE trajectory modelling, the selection of UE speed, blockage [Section 7.6.4 in TR 38.901], and/or UT rotating [Section 7.6.7 in TR 38.901] should be considered.
* Lenovo [18]: The beam management AI/ML model evaluation methodology should support evalutations with realistic modeling of UE mobility and rotation, spatially consistent channel models, different UE speeds, and single-beam/panel and multi-beam/panel scenarios for evaluating a model's robustness and adaptability.
* NVIDIA [21]: Additional simulation methodology for generating synthetic data, such as digital twins, should be explored for the study of AI/ML based algorithms for beam management.

Based on the above views, the following questions can be discussed for other assumptions:

#### FL1 Low Priority Question 1-5

**Question 1-5:**

1. What other assumptions or parameters need to be defined for SLS based dataset generation and evaluation for beam management?

Note: Mixed scenario(s) for generalization can be discussed in section 2.2.1. This question only focuses on single scenario case for dataset and performance evaluation.

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## 1.3 Dataset generation and evaluation assumptions with LLS

Two companies proposed to use LLS for the evaluation of the beam prediction in time domain or for spatial domain beam prediction.

* Samsung [9]: Link-level simulation can be used for the evaluation of beam prediction in the time domain.
  + For the evaluation of beam prediction in the time domain, the CDL extension used in the Rel-17 HST-SFN evaluation should be a good starting point in link-level evaluation.
* Samsung [9]: Consider Table A.2.5-2 (for SLS) and Table A.1.6.4 (for LLS) of TR 38.802 as the starting point for Rel-18 AI/ML for beam management evaluation, based on which necessary modifications/simplifications can be further discussed for the specific evaluation purpose and/or sub use case.
* Intel [20]: For spatial domain beam prediction, CDL channel models should be used for dataset generation and RSRP can be used as the beam specific parameter for the dataset.
* Intel [20]: Assumptions on gNB and UE antenna arrays and beamforming should be aligned across companies for common dataset generation
* Intel [20]: Dataset normalization based on specific sub-use case should be reported by companies

Based on the above views, the following questions can be discussed for LLS for AI/ML-based beam management.

#### FL1 Medium Priority Question 1-6

**Question 1-6:**

1. Whether LLS can be used as a complementary evaluation methodology for AI/ML in beam management?
2. If the answer is yes, whether Table A.1.6.4 (for LLS) of TR 38.802 can be used as the starting point for Rel-18 AI/ML for beam management evaluation?

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## 1.4 AI/ML model related aspects

Some companies suggested to define reference AI/ML model for calibration, while some companies believed no need to introduce a reference AI/ML model:

* Huawei/HiSi [1]: The calibration of the AI/ML model and dataset for beam management evaluations can be achieved by aligning simulation assumptions and calibrating intermediate results such as beam prediction accuracy.
* Ericsson [4]: No need to introduce a reference AI/ML model for calibration
* Vivo [7]: Fully-connected neural network with a limited number of model parameters for beam management case is considered as the basic model. Other models can also be considered if found beneficial.
* Apple [15]: During the use case study phase, it is not necessary to define a common AI architecture.
* NVIDIA [21]: Baseline AI model(s) should be identified for the purpose of calibration in the study of AI/ML based algorithms for beam management.
* Fujitsu [24]: Calibrate the performance of the AI/ML method, a common reference model is recommended, and its generation procedure needs to be studied.

Based on the above discussion, it is better to discuss whether a reference AI/ML model needs to be defined.

#### FL1 Medium Priority Question 1-7

**Question 1-7:**

1. Whether a reference AI/ML model needs to be defined, and why?
2. If the answer is yes, please explain the purpose to define the reference AI/ML model.

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On the other hand, the following aspects related to AI/ML models and input/output of AI/ML models were proposed:

* Huawei/HiSi [1]: For AI/ML-based spatial domain beam prediction evaluation, adopt the RSRP for sparse beams and the optimal beam ID as the training inputs.
* Ericsson [4]: Evaluation should provide a description of ML/AI model, model input/output, along with the training methodology
* Samsung [9]: For AI/ML training and inferring, the detailed AI/ML model, and loss/reward function design should be decided by companies, while the relevant information should be explained by companies:
  + AI/ML model selection: e.g., DNN, CNN, LSTM with the number of layers, and the number of nodes in each layer, and some necessary description for the node connection, etc.
  + Input of AI/ML model.
  + Output of AI/ML model.
* LGE [13]: Consider following information as input data for AI/ML based DL Tx beam prediction in time domain.
  + For gNB side AI/ML, gNB measurement (e.g., UE position/trajectory, UL measurement) and UE beam related reporting.
  + For UE side AI/ML, UE own measurement (e.g., UE position/velocity, UE orientation/rotation, DL beam/CSI measurement).
* Lenovo [18]: Any additional side information (e.g., measurements from non-3GPP technologies) needed for a proposed beam management AI/ML model should be stated.
* Ericsson [4]: Model validity area should be described, if the AI/ML model is trained for a cell (cell-specific), multiple-cells, or for the entire scenario (valid for all cells).
* Ericsson [4]: Models are trained offline (no sequential update of the model)

Besides, the following training methodology were proposed:

* Ericsson [4]: Training methodology could for example include the training optimization function, loss function and/or number of training/test samples
* Vivo [7]: Training dataset and validation dataset should be collected from different drops to keep data independence.

#### FL1 Medium Priority Question 1-8

**Proposal 1-8:**

* **Each company should provide a description of ML/AI model, [model input/output], along with the training methodology.** 
  + **FFS on the details**

**Question 1-8:**

1. Whether proposal 1-8 can be adopted? Why?
2. What parameter(s)/aspect(s) of AI/ML model(s) need to be reported by each company?
3. Whether to define model input(s)/output(s) subjected to each sub-use case or the model input(s)/output(s) of each sub-use case can be reported by each company for AI/ML in BM?
4. What aspects need to be reported or defined for training methodology?

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## Others

### 1.5.1 HST in FR2

Two companies mentioned beam management enhancement for high-speed train in FR 2.

* ZTE [2]: Consider predictable mobility for beam management as an enhancement aspect for improving UE experience in FR2 high mobility scenario (e.g., high-speed train and high-way).
  + Study and evaluate the feasibility and potential system level gain on predictable mobility for beam management based on the identified scenario(s).
* PML [3]: Consider predictable mobility for beam management as an enhancement aspect for improving UE experience in FR2 high mobility scenario (e.g., high-speed railway and high-way) in a Rel-18 WI.
  + Study the implementation and design of predictable mobility for beam management in various scenarios.
  + Evaluate the performance gain and cost of predictable mobility for beam management in a more concrete and comprehensive manner.

Based on the above views, the following questions can be discussed for high-speed train scenario in FR 2 for AI/ML for beam management.

#### FL1 Medium Priority Question 1-9

**Question 1-9:**

1. Whether HST can be considered as one of the scenarios for AI/ML for beam management? If the answer is yes, which shall be the baseline tool for dataset generation and performance evaluation, e.g., LLS or SLS?

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### 1.5.2 Other consideration for evaluations

Several companies propose to define two phases for evaluations:

* CATT [6]: For AI/ML based beam management, the following evaluation can be considered:
  + Intermediate evaluation: Evaluate the result of beam selection from the AI model, or the overhead reduction due to AI/ML-based approach;
  + Final evaluation: Evaluate the system-level transmission performance based on the output of AI model.
* Vivo [7] Intermediate results for performance comparison across companies can be considered.
* Samsung [9]: The following two-stage approach is adopted for gNB/UE beambook design:
  + Stage-1: Alignment on the number of beams (as input/output for AI/ML beam prediction)
  + Based on the initial evaluation results, and to be concluded by RAN1 #110.
  + Stage-2: Based on the agreed number of beams (as input/output for AI/ML beam prediction), companies provide the simulation results:
    - Companies shall disclose the detailed beambook design: beam directions/beamwidth.
    - Companies shall disclose the detailed beam measurement and report configuration.

This can be discussed together with performance KPIs.

# KPIs on AI/ML in beam management

Two types of KPIs were proposed by companies for evaluation. One is performance related KPIs, the other is AI/ML model capability related KPIs including size of the models, computation complexity, generalization, etc.

## Performance KPIs

### 2.1.1 Beam measurement related KPIs

Beam measurement or selection accuracy were proposed by most of the companies, including:

* ZTE [2]: Top-K candidate beams with higher predicted RSRP can be filtered out for refined small-range beam sweeping, resulting in a relatively good trade-off between training overhead and performance.
* ZTE [2]: Beam prediction accuracy can be used as the performance indicators at the early stage, which may include top-1/top-K beam prediction accuracy, average RSRP difference, and CDFs of RSRP difference between the AI-predicted beam and ideal beam.
* Ericsson [4]: Use case performance metrics could include metrics defined in Rel-17 EVM for BM including a potential energy saving metric, for example using the models defined in [4].
* InterDigital [5]: The following parameters should be considered to accurately evaluate benefits of AI/ML aided beam management.
  + Difference between estimated qualities and actual qualities
  + Optimal beam selection accuracy (%)
  + System performance based on the selected optimal beams
* CATT [6]: Intermediate KPI: Probability of identifying the best beam (pair), average power loss between the selected beam (pair) and the optimal beam (pair), and the ratio of overhead reduction;
* Vivo [7]: The 4 proposed RSRP-related KPIs should be considered for performance evaluation and comparison among different selected algorithms.
  + RSRP difference 1 for all predicted beam
  + RSRP difference 2 for predicted beam set
  + beam pair prediction deterioration
  + beam pair prediction accuracy
* xiaomi [8]: KPI:
  + KPI#1: The probability of right best Tx beam predicted by AI.
  + KPI#2: The L1-RSRP gap between the predicted best Tx beam and the real best Tx beam.
* Samsung [9]: For the performance-related KPI for AI/ML based beam prediction (in both time and spatial domains), the following two KPIs can be utilized, especially for Phase-I:
  + Accuracy of predicted best beam within the Top-N from genie-aided beam measurement.
  + Performance gap from the genie-aided beam measurement.
* Samsung [9]: In this SI, study and evaluate the performance of AI/ML beam prediction in the time domain in terms of the top N beam prediction accuracy and the overhead and latency reduction.
* OPPO [10]: Adopt L1-RSRP as performance metric for AI/ML beam prediction as a starting point.
* OPPO [10]: Study and evaluate the correct beam prediction rate for AI/ML beam prediction in spatial and time domain as one of the key performance metrics.
* Beijing Jiaotong University [11]: Beam selection accuracy, mean square error (MSE), throughput and system capacity, need to be considered as the KPI for the evaluation of beam selection.
* Beijing Jiaotong University [11]: Overhead, latency and beam selection accuracy of existing L1-RSRP measurement scheme, need to be considered as the benchmark of AI-based beam selection.
* Futurewei [12]: Include Top-1 prediction accuracy (Top1\_acc) as one of the evaluation metrics for AI/ML-based beam management use case.
* Futurewei [12]: Include Top-K (e.g., Top-3) prediction accuracy as one of the evaluation metrics for AI/ML-based beam management use case.
* Futurewei[12]: Include measured RSRP as one of the evaluation metrics for AI/ML-based beam management use case.
* CAICT [14]: The success rate of selecting best link quality beam pair(s) under a given number of measurements is used for performance comparison between AI/ML based algorithm and non-AI/ML based algorithm.
* CAICT [14]: The performance of the optimal beam pair(s) prediction by AI/ML model(s) could also be considered.
* CAICT [14]: Inference accuracy should be the main KPI for AI/ML based beam management algorithm.
* Apple [15]: The KPI for AI based beam prediction could be the beam prediction accuracy and the L1-RSRP distribution for the AI predicted beam.
* Lenovo [18]: KPIs for the AI/ML beam management performance evaluation should include beam alignment success rate, effectiveness (in terms of improvement in L1-RSRP or L1-SINR relative to legacy schemes), and beam failure rate.
* Nokia/NSB [19]: RAN1 shall consider the following KPIs for the ML-based beam management use case,
  + Beam prediction accuracy (Top-1 Prediction, Top-K Prediction, Top-1 and Top-K Prediction with 1 dB margin)
  + RSRP error/difference
* Intel [20]: For beam management use cases, hard metric KPIs like accuracy of best beam index or top K beam index prediction can be considered. Additionally, RSRP of predicted beams should also be considered as a key KPI for performance evaluation.
* NVDIA [21]: Define a KPI which measures beam management accuracy with and without AI/ML based algorithms.
* Qualcomm [23]: The KPIs for temporal beam prediction can be trade-off between reference signal overhead reduction (and/or UE power consumption) and a measure for beam prediction accuracy (such as RSRP prediction accuracy and/or top-M beam selection accuracy) and/or overall system performance (e.g., throughput).
* Qualcomm [23]: The KPIs for spatial (+time) domain beam prediction can be trade-off between reference signal overhead reduction (and/or UE power consumption) and a measure for beam prediction accuracy (such as L1-RSRP prediction accuracy and/or top-M beam selection accuracy) and/or overall system performance (e.g., throughput).
* Fujitsu [24]: The following KPIs are recommended for performance evaluation of beam prediction.
  + Probability of correct prediction
  + Average L1-RSRP difference

Based on the proposals, the following proposal can be considered.

#### FL1 High Priority Question 2-1

**Proposal 2-1:**

* The following beam prediction accuracy related KPIs for AI/ML in BM can be considered as a starting point:
  + L1-RSRP related KPIs:
    - Top-1/Top-K predicted beams:
      * Average L1-RSRP difference
      * CDF of L1-RSRP difference
      * CDF of L1-RSRP
  + Beam selection accuracy (%) without margin or with 1dB margin.
    - Top-1
    - Top-N
  + Note: Top-K beams are the Top-N from genie-aided beam measurement

**Question 2-1:**

1. Whether proposal 2-1 can be adopted? If no, what else is necessary to be considered and why?
2. Which KPI(s) are preferred as basic KPI(s)?
3. Which KPI(s) can be optional reported by each company?

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### 2.1.2 System performance related KPIs

Other than beam measurement related KPIs, several companies mentioned that the system performance shall be also evaluated:

* Huawei/HiSi [1] Consider a super-narrow codebook (e.g., with 256 Tx beams) for the evaluation of the AI/ML-based spatial domain beam prediction to improve the system performance (e.g., coverage, throughput) from the network perspective without increasing the maximum number of CSI-RS resources.
* Ericsson [4]: Use case performance metrics could include metrics defined in Rel-17 EVM for BM including a potential energy saving metric, for example using the models defined in [4].
* Vivo [7]: Throughput performance for space/time domain beam prediction are also considered.
* Samsung [9]: For Phase-II, user-perceived throughput (UPT) can be utilized as the KPI to evaluate the performance benefits obtained by AI/ML-based beam measurement.
* Samsung [9]: Shannon capability based simplified model for UPT can be employed in the EVM of AI/ML-based beam management.
* Beijing Jiaotong University [11]: Beam selection accuracy, mean square error (MSE), throughput and system capacity, need to be considered as the KPI for the evaluation of beam selection.
* Nokia/NSB [19]: RAN1 shall consider the following KPIs for the ML-based beam management use case,
  + Beam management measurement overhead
  + Cell throughput (average, 5%ile, 50%ile)
* Qualcomm [23]: The KPIs for temporal beam prediction can be trade-off between reference signal overhead reduction (and/or UE power consumption) and a measure for beam prediction accuracy (such as RSRP prediction accuracy and/or top-M beam selection accuracy) and/or overall system performance (e.g., throughput).
* Qualcomm [23]: The KPIs for spatial (+time) domain beam prediction can be trade-off between reference signal overhead reduction (and/or UE power consumption) and a measure for beam prediction accuracy (such as L1-RSRP prediction accuracy and/or top-M beam selection accuracy) and/or overall system performance (e.g., throughput).

Based on the proposals, the following proposal can be considered.

#### FL1 High Priority Question 2-2

**Proposal 2-2:**

* **System performance is considered as one of the general KPIs for AI/ML in beam management. FFS on the following details:**
  + **UE throughput: CDF of UE throughput, avg. and 5%ile UE throughput**

**Question 2-2:**

1. Whether proposal 2-2 can be adopted? If not, why?
2. Which KPI(s) are preferred as basic KPI(s)? Are they common for all the sub-use cases or subject to some of sub-use case(s)?
3. Which KPI(s) can be optional reported by each company?

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| Company | Y/N | Comments |
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### 2.1.3 Other performance KPIs

Overhead reduction and latency were proposed as one of the KPIs for AI/ML in beam management:

* Huawei/HiSi [1]: Consider the evaluation of the AI/ML based spatial domain beam prediction with the target to obtain accurate narrow beams for CSI-RS beam sweeping to reduce the UE’s overhead and power consumption.
* ZTE [2]: AI/ML based solutions are expected to be studied and evaluated to do beam prediction so as to reduce beam tracking latency and RS overhead in high mobility scenarios.
* Ericsson [4]: The study item should investigate how beam predictions can improve robustness and reduce overhead associated to beam management
* CATT [6]: Intermediate KPI: Probability of identifying the best beam (pair), average power loss between the selected beam (pair) and the optimal beam (pair), and the ratio of overhead reduction;
* Samsung [9]: Reference signal overhead (SSB or CSI-RS) and reduced latency for the specific beam management procedure should be considered as performance-KPI for beam prediction in both time and spatial domains.
* Samsung [9]: In this SI, study and evaluate the performance of AI/ML beam prediction in the time domain in terms of the top N beam prediction accuracy and the overhead and latency reduction.
* Beijing Jiaotong University [11]: Overhead, latency and beam selection accuracy of existing L1-RSRP measurement scheme, need to be considered as the benchmark of AI-based beam selection.
* Lenovo [18]: Beam acquisition/selection latency including Tx/Rx beam training should be evaluated for a proposed AI/ML
* Nokia/NSB [19]: RAN1 shall consider the following KPIs for the ML-based beam management use case,
  + Beam management measurement overhead
* NVIDIA [21]: Define a KPI which measures the reference signal overhead for beam management with and without AI/ML based algorithms.
* NVIDIA [21]: Define a KPI which measures the latency for beam management with and without AI/ML based algorithms.
* Qualcomm [23]: The KPIs for temporal beam prediction can be trade-off between reference signal overhead reduction (and/or UE power consumption) and a measure for beam prediction accuracy (such as RSRP prediction accuracy and/or top-M beam selection accuracy) and/or overall system performance (e.g., throughput).
* Qualcomm [23]: The KPIs for spatial (+time) domain beam prediction can be trade-off between reference signal overhead reduction (and/or UE power consumption) and a measure for beam prediction accuracy (such as L1-RSRP prediction accuracy and/or top-M beam selection accuracy) and/or overall system performance (e.g., throughput).

Based on the above proposals, the following question can be discussed.

#### FL1 Medium Priority Question 2-3

**Question 2-3:**

1. Whether the reference signaling overhead reduction ratio can be considered as one of the KPIs for AI/ML in BM (when applicable)? If yes, how to define the metric?
2. Whether latency can be considered as one of the KPI for AI/ML in BM (when applicable)? If yes, how to define the metric?

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| Company | Y/N | Comments |
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Power consumption were proposed by three companies as the metric for evaluation.

* Huawei/HiSi [1]: Consider the evaluation of the AI/ML based spatial domain beam prediction with the target to obtain accurate narrow beams for CSI-RS beam sweeping to reduce the UE’s overhead and power consumption.
* Ericsson [4]: Use case performance metrics could include metrics defined in Rel-17 EVM for BM including a potential energy saving metric, for example using the models defined in [4].
* CATT [6]: Intermediate KPI: Probability of identifying the best beam (pair), average power loss between the selected beam (pair) and the optimal beam (pair), and the ratio of overhead reduction;
* Qualcomm [23]: The KPIs for temporal beam prediction can be trade-off between reference signal overhead reduction (and/or UE power consumption) and a measure for beam prediction accuracy (such as RSRP prediction accuracy and/or top-M beam selection accuracy) and/or overall system performance (e.g., throughput).
* Qualcomm [23]: The KPIs for spatial (+time) domain beam prediction can be trade-off between reference signal overhead reduction (and/or UE power consumption) and a measure for beam prediction accuracy (such as L1-RSRP prediction accuracy and/or top-M beam selection accuracy) and/or overall system performance (e.g., throughput).
* Ericsson [4]: Evaluation results could include ML-performance metrics related to beam predictions, both comprising classification and regression performance metrics

Based on the above proposals, the following question can be discussed.

#### FL1 Medium Priority Question 2-4

**Question 2-4:**

1. Whether power consumption can be considered as one of the KPIs for AI/ML in BM? If the answer is yes, how to define the power consumption metric?

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| Company | Y/N | Comments |
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## Capability-related KPIs

### 2.2.1 Generalization

Generalization is one of the important aspects to verify the performance of AI/ML model. The following proposals were proposed:

* Huawei/HiSi: [1] For AI/ML-based beam management evaluation, study how to evaluate the generalization of the AI/ML model in simulation.
* Vivo [7]: Generalization performance should be considered as performance-related KPIs.
* Vivo [7]: Different number of Tx beam and Rx beam should be considered for construction of the data set for generalization performance evaluation.
* Samsung [9]: For the use case of AI/ML based beam management, at least the following capability-related KPI shall be considered:
  + Generalization of AI/ML model by considering the performance degradation for test case with mixed scenarios.
* Lenovo [18]: Inference accuracy of a proposed beam management AI/ML model (without model updates) should be reported for different channel models including UMa, UMi (with various parameters), UE speed, UE orientations, and beam codebook design.
* Nokia/NSB [19]: For training/testing the supervised learning ML model, the number of scenarios/deployments and configurations of other simulation parameters can be extended and generalized beyond those detailed in Table 2.1 2.

#### FL1 Medium Priority Question 2-5

**Question 2-5:**

1. Whether generalization should be one of the KPIs for AI/ML in BM?
2. If the answer is yes, how to define or test the generalization performance? For example, how to mix or extend the simulation parameters?

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| Company | Y/N | Comments |
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### 2.2.2 Model size and computational complexity

Several companies proposed to consider model size and computation complexity for AI/ML model.

* Vivo [7]: Beam sweeping overhead, AI processing latency, computational complexity, model size and power consumption can be considered are all relevant for assessment.
* Samsung [9]: For the use case of AI/ML based beam management, at least the following capability-realted KPI shall be considered:
  + Size of AI/ML model;
  + Complexity of training and inference of AI/ML operation.
* Futurewei [12]: Include model/space complexity as one of the KPIs to evaluate the complexity of AI/ML-based approach for beam management use case. Model/space complexity measurements include number of parameters in the model and memory usage.
* Futurewei [12]: Include computational complexity as one of the KPI list to evaluate the complexity of AI/ML-based approach for beam management use case. Computational complexity can be estimated using number of floating-point operations (FLOPs) or number of multiplies and accumulates (MACs).
* CAICT [14]: AI/ML model size should be controlled during the evaluation phase.
* Lenovo [18]: Computation complexity of the proposed AI/ML model should be evaluated at every phase in the model lifecycle-training, inference, update.
* NVDIA [21]: Provide information on the used computing platform (such as the GPU model) when reporting KPIs for AI/ML based beam management.
* Fujitsu [24] The following KPIs are recommended for complexity of AI/ML models.
  + Computational complexity of AI/ML model inference
  + Memory size for AI/ML model storage

#### FL1 Low Priority Question 2-6

**Question 2-6:**

1. Whether AI/ML model size can be considered as one of the KPIs for AI/ML in BM? If the answer is yes, how to quantify it, e.g., reported by each company with model size in Bytes?
2. Whether computation complexity at least for inference can be considered as one of the KPIs for AI/ML in BM? If the answer is yes, how to quantify it, e.g., reported by each company with number of floating-point operations (FLOPs) or number of multiplies and accumulates (MACs)?

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### 2.2.3 Other KPIs

Several other KPs were proposed, including reporting/model management overhead, AI processing latency, scalability:

* Vivo [7]: Beam sweeping overhead, AI processing latency, computational complexity, model size and power consumption can be considered are all relevant for assessment.
* LGE [13]: Study whether the procedure for training/update/management of AI/ML model can be considered as overhead and latency of beam management or not, and how to quantify the overhead/latency of AI/ML model.
* Lenovo [18]: Beam management signaling (e.g., RS, measurement reports) overhead required for a proposed AI/ML model (at every phase in the model lifecycle) should be evaluated. This can be reported relative to state-of-the-art Rel-17 based baseline schemes.
* Lenovo [18]: Inference accuracy sensitivity of a proposed beam management AI/ML model should be evaluated for a range of noisy input data and delay constraints.
* Lenovo [18]: Scalability of a proposed beam management AI/ML model for different parameter settings, e.g., number of beams at gNB/UE, should be evaluated.
* Lenovo [18]: KPIs for the AI/ML beam management evaluation should at least include accuracy and effectiveness, beam measurement overhead, latency, training convergence time, model robustness, scalability, adaptability and complexity/power consumption.
* NVIDIA [21]: Define a KPI which measures the measurement reporting overhead for beam management with and without AI/ML based algorithms.
* Lenovo [18]: A proposed AI/ML model that is based on online learning (e.g., online training, model update/re-training) should evaluate the convergence time for the model to reach a valid inference state.

#### FL1 Low Priority Question 2-7

**Question 2-7:**

1. Any other KPI/metric needs to be considered for AI/ML in BM?

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## Baseline performance

Some companies provided some analysis on baseline performance for benchmark.

* CATT [6]: On the simulations for AI/ML-based beam management, conventional beam management strategy (i.e. exhaustive beam sweeping) can be considered as baseline.
* InterDigital [5]: No collaboration framework: AI/ML algorithms purely implementation based and not requiring air-interface changes’ could be an appropriate baseline to accurately evaluate the benefits of AI/ML with specification enhancements.
* Samsung [9]: EVM on AI/ML based beam measurement feedback compression shall at least be able to evaluate the system performance while considering one or both of the following aspects
  + (1) the compressed beam measurement feedback has lower feedback overhead as compared to the legacy feedback for a given number of reported beams
  + (2) the number of reported beams in the compressed beam measurement feedback is larger than the legacy feedback for the same beam measurement feedback overhead.
* OPPO [10]: To make more meaningful comparison between traditional beam selection scheme and AI/ML beam prediction, study and decide the EVM and benchmark for comparison.
* CMCC [16]: Baseline of spatial domain beam prediction needs to be studied, the following three options of baseline can be considered:
  + Option 1: gNB performs exhaust beam sweeping, UE selects best beam pair among all beam pairs.
  + Option 2: gNB performs sparse beam sweeping with fixed sparse pattern, UE selects best beam pair among measured beam pairs.
  + Option 3: gNB performs sparse beam sweeping with variable sparse pattern, UE selects best beam among measured beam pairs.
* Nokia/NSB [19]: Baselines for supervised learning spatial-temporal domain beam prediction are needed. The following are possible candidates:
  + UE measures all the CSI-RS resources with an exhaustive search at all time instants and selects the best beam at each time instant.
  + UE selects the best beam based on the measurements of all the CSI-RS resources during the time instants within the observation window and maintains the selected beam during the time instants of the prediction window.
* Intel [20]: Baseline performance evaluation schemes for benchmarking the performance of AI/ML tools should be based on exhaustive beam search and more practical hierarchical beam search procedures.
* Qualcomm [23]: Based on the agreed KPIs, RAN1 should study and identify baseline prediction schemes for temporal beam prediction as a benchmark for AI/ML-based schemes to compare against
* Qualcomm [23]: Based on the agreed KPIs, RAN1 should study and identify baseline prediction schemes for spatial domain beam prediction as a benchmark for AI/ML-based schemes to compare against

The baseline performance is subject to each sub-use case. However, this is one of the important issues for evaluation, we can have some open discussion

#### FL1 Medium Priority Question 2-8

**Question 2-8:**

1. For spatial domain beam prediction, what can be the baseline performance?
2. For time domain beam prediction, what can be the baseline performance?

Note: The baseline performance of other sub-use cases can be discussed after the sub-use cases are well defined.

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# Others

Some companies suggest to consider multiple scenarios for evaluations.

* InterDigital [5]: Consider the following AI/ML aided beam prediction scenarios for evaluations.
  + Simple specification extension of UE reporting which enables AI/ML beam prediction
  + Partial beam measurement
  + Beam prediction in time domain
  + Association between beams with different beam widths
  + Handling of UE Rx beams
* Qualcomm [23]: Based on evaluations using the agreed KPIs, RAN1 should identify the deployments/scenarios/use cases for which AI/ML based temporal beam prediction may be beneficial.

# Appendix: Detailed evaluation assumptions

Table Baseline assumptions for SLS

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| Parameters | Values |
| Frequency Range | FR2 @ 30 GHz,   * SCS: 120 kHz * BW: 80 MHz |
| Scenarios | High speed @FR2:   * Dense Urban (macro-layer only, TR 38.913) @FR2, 200m ISD, 2-tier model with wrap-around (7 sites, 3 sectors/cells per site), 100% outdoor   One UE is dropped for each of the 21 sectors/cells (see mobility description below) |
| UE Speed | For Dense Urban: 60 km/hr and 120 km/hr |
| Transmission Power | Maximum Power and Maximum EIRP for base station and UE as given by corresponding scenario in 38.802 (Table A.2.1-1 and Table A.2.1-2) |
| BS Antenna Configuration | (M, N, P, Mg, Ng) = (4, 8, 2, 2, 2). (dV, dH) = (0.5, 0.5) λ. (dg,V, dg,H) = (2.0, 4.0) λ  Companies to explain TXRU weights mapping.  Companies to explain beam selection.  Companies to explain number of BS beams |
| BS Antenna radiation pattern | TR 38.802 Table A.2.1-6, Table A.2.1-7 |
| UE Antenna Configuration | Number/location of panels: 3 panels (left, right, and back)  Panel structure: 1x4x2 or (M, N, P) = (1, 4, 2), dH = 0.5 λ  Companies to explain TXRU weights mapping.  Companies to explain beam and panel selection.  Companies to explain number of UE beams |
| UE Antenna radiation pattern | TR 38.802 Table A.2.1-8, Table A.2.1-10 |
| Beam correspondence | Companies to explain beam correspondence assumptions (in accordance to the two types agreed in RAN4) |
| Link adaptation | Based on CSI-RS |
| Traffic Model | Full buffer |
| Inter-panel calibration for UE | Ideal, non-ideal following 38.802 (optional) – Explain any errors |
| Control and RS overhead | Companies report details of the assumptions |
| Control channel decoding | Ideal or Non-ideal (Companies explain how it is modelled) |
| UE receiver type | MMSE-IRC as the baseline, other advanced receiver is not precluded |
| BF scheme | Companies explain what scheme is used |
| Transmission scheme | Multi-antenna port transmission schemes  Note: Companies explain details of the using transmission scheme. |
| Other simulation assumptions | Companies to explain serving TRP selection  Companies to explain scheduling algorithm |
| Algorithm details (when applicable) | Companies to report:   * Beam reporting mechanism * Beam metric L1-RSRP * Number of active panels |
| Other potential impairments | Not modelled (assumed ideal).  If impairments are included, companies will report the details of the assumed impairments |

Table Baseline assumptions for SLS: Additional simulation assumptions for Dense Urban scenario (FR2) mainly from TR 38.802 Table A.2.1-1, and TR 38.901.

|  |  |
| --- | --- |
| Parameters | Values |
| Carrier Frequency | 30 GHz |
| Scenario | UMa LOS |
| System BW | 80 MHz |
| BS Tx Power | 40 dBm |
| Maximum UE Tx Power | 23 dBm |
| BS receiver Noise Figure | 7 dB |
| UE receiver Noise Figure | 10 dB |
| Inter site distance | 200m |
| BS Antenna height | 25m |
| UE Antenna height | 1.5 m |
| Car penetration Loss | 38.901, sec 7.4.3.2: μ = 9 dB, σp = 5 dB |

# Reference

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| --- | --- | --- | --- |
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| [2] | [R1-2203250](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_109-e/Docs/R1-2203250.zip) | Evaluation assumptions on AI/ML for beam management | ZTE |
| [3] | [R1-2203255](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_109-e/Docs/R1-2203255.zip) | Model and data-driven beam predictions in high-speed railway scenarios | PML |
| [4] | [R1-2203283](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_109-e/Docs/R1-2203283.zip) | Evaluations on AI-BM | Ericsson |
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| [10] | [R1-2204017](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_109-e/Docs/R1-2204017.zip) | Evaluation methodology and preliminary results on AI/ML for beam management | OPPO |
| [11] | [R1-2204059](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_109-e/Docs/R1-2204059.zip) | Evaluation methodology of beam management with AI/ML | Beijing Jiaotong University |
| [12] | [R1-2204102](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_109-e/Docs/R1-2204102.zip) | Discussion on evaluation of AI/ML for beam management use case | FUTUREWEI |
| [13] | [R1-2204151](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_109-e/Docs/R1-2204151.zip) | Evaluation on AI/ML for beam management | LG Electronics |
| [14] | [R1-2204182](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_109-e/Docs/R1-2204182.zip) | Some discussions on evaluation on AI-ML for Beam management | CAICT |
| [15] | [R1-2204240](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_109-e/Docs/R1-2204240.zip) | Evalulation on AI based Beam Management | Apple |
| [16] | [R1-2204297](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_109-e/Docs/R1-2204297.zip) | Discussion on evaluation on AI/ML for beam management | CMCC |
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| [20] | [R1-2204795](https://www.3gpp.org/ftp/TSG_RAN/WG1_RL1/TSGR1_109-e/Docs/R1-2204795.zip) | Evaluation for beam management | Intel Corporation |
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