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Dynamic Beam Selection for Beam-RSRP Based Direction Finding in mmW 5G Networks

Elizaveta Rastorgueva-Foi
Laboratory of Electronics and Communications Engineering
Tampere University of Technology
Tampere, Finland
elizaveta.rastorgueva-foi@tut.fi

Mário Costa
Radio Network Technologies
Huawei Technologies
Helsinki, Finland
mariocosta@huawei.com

Mike Koivisto
Laboratory of Electronics and Communications Engineering
Tampere University of Technology
Tampere, Finland
mike.koivisto@tut.fi

Kari Leppänen
Radio Network Technologies
Huawei Technologies
Helsinki, Finland
kari.leppanen@huawei.com

Mikko Valkama
Laboratory of Electronics and Communications Engineering
Tampere University of Technology
Tampere, Finland
mikko.e.valkama@tut.fi

***Abstract*—This paper considers direction-finding in millimeter wave (mmW) fifth generation (5G) networks by means of beam-based downlink (DL) reference signal received power (RSRP) measurements and subsequent reporting. In particular, we propose two methods that allow user equipments (UEs) to select, in an independent and dynamic manner, the most-relevant beam-RSRP (BRSRP) measurements as a trade-of between angle-related information and load of the feedback channel. A likelihood ratio (LR)-test is derived in which the hypothesis for ”noise-only” BRSRP measurement is compared to that of ”reference signal (RS)-plus-noise” observations, under a given significance level. A power threshold based method is also proposed in which the BRSRP measurements are compared to a threshold proportional to the noise power. Such a noise variance is estimated at each UE independently. The performance of the proposed beam selection schemes is assessed by means of an extended Kalman filter (EKF) tracking the direction of departure (DoD) of the line-of-sight (LoS) path between base stations (BSs) and a UE. Extensive numerical results are provided on a realistic mmW 5G outdoor deployment scenario operating at** $39\,\mathrm{GHz}$ **and with a ray-tracing propagation model based on the METIS Madrid grid.**

***Index Terms*—5G networks, beamforming, RSRP, positioning, localization, tracking, direction-of-departure, location-awareness, extended Kalman filter, line-of-sight**

I. INTRODUCTION

Extensive use of directional transmission and reception is one of the most distinguishing features of the fifth generation (5G) compared to other wireless communication standards. It is crucial for radio access technology (RAT) at the millimeter wave (mmW) frequency-band due to the high path-losses at such frequencies. Directional communication at the radio access network (RAN) is typically achieved by means of dynamic beamforming or by employing fixed beams. A line-of-sight (LoS) channel between base stations (BSs) and user equipments (UEs) is usually required due to the aforementioned severe path-loss. Designing the transmit and receive beams used by BSs and UEs can thus be achieved by exploiting the angles of arrival and departure of the corresponding LoS paths. This is a classic problem in the sensor array and multichannel signal processing literature for which many algorithms have been proposed [1], [2]. However, the use of mmW frequencies and the practical limitations of wireless communication standards motivates revisiting direction finding schemes [3]–[6].

In this paper, we propose two methods that allow UEs to determine the beam reference signal received power (RSRP) measurements that carry relevant information regarding the angle of the LoS path to BSs. In general, RSRP measurements from downlink (DL)-reference signals (RSs), and subsequent reporting, have been widely used in wireless communication standards, and are also part of the 5G specification [7]. Directional transmissions make it possible for UEs to report beam-RSRP (BRSRP) measurements from multiple BS beams to the network, which in turn exploits such quantized measurements for estimating and tracking the direction of departure (DoD) of the LoS path [8]. The methods proposed in this paper may be understood as providing a trade-off between angular accuracy and load of the feedback channel in a manner that is solely determined by the UEs themselves. Related work includes that in [3], [4] where direction-finding algorithms based on power-measurements are proposed. This work may be understood as an extension of that in [3], [4] to beam-based DL power-measurements including beam-selection and reporting.

In particular, the beam-selection methods proposed in this paper are based on a likelihood ratio (LR)-test and power threshold. Both methods aim at deciding whether the received BRSRP measurement for a given beam-pair is due to ”noise-

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only" or "RS-plus-noise" observations. More precisely, the first method consists in comparing the log-likelihood function of both "noise-only" and "RS-plus-noise" hypotheses, under a given significance level, for the BRSRP measurement corresponding to each beam-pair. The second method consists in letting the UE determine a noise-power estimate from its beam(s) that are known to receive "noise-only" measurements, and comparing such a value with the BRSRP measurement for a given beam-pair.

The rest of the paper is organized as follows. Section II provides the necessary background including the system model employed in this paper. The proposed schemes for selecting the BRSRP measurements for reporting are given in Section III. Section IV includes extensive numerical results using a ray-tracing channel model. Finally, Section V concludes the paper.

II. BACKGROUND

Let $\boldsymbol{y}_{i,j} \in \mathbb{C}^{\mathcal{M}_f}$ denote the multicarrier observation in an orthogonal frequency-division multiplexing (OFDM) system at the UE. The number of subcarriers is denoted by $\mathcal{M}_f$, while the subscripts (i,j) denote the ith UE receiver (Rx) beam and the jth BS transmitter (Tx) beam. The multicarrier observation at the UE may be modeled as follows

$$\boldsymbol{y}_{i,j} = \boldsymbol{S}\boldsymbol{h}_{i,j} + \boldsymbol{n}_{i,j}, \tag{1}$$

where $\boldsymbol{S} \in \mathbb{C}^{\mathcal{M}_f \times \mathcal{M}_f}$, $\boldsymbol{h}_{i,j} \in \mathbb{C}^{\mathcal{M}_f}$, and $\boldsymbol{n}_{i,j} \in \mathbb{C}^{\mathcal{M}_f}$ denote a diagonal matrix composed of transmitted symbols in frequency domain, radio-channel vector, and measurement noise vector, respectively. In particular, the (frequency-domain) radio channel vector $\boldsymbol{h}_{i,j}$ includes effects due to multipath propagation, Tx beam j and Rx beam i, as well as Tx-Rx radio frequency (RF)-chains. The measurement noise vector $\boldsymbol{n}_{i,j}$ in (1) is assumed to be complex-circular Gaussian distributed with zero-mean and covariance $\boldsymbol{C}_n = \sigma^2_{i,j}\boldsymbol{I}$. The measurement noise for different beam-pairs are also assumed to be uncorrelated, i.e., $\mathbb{E}\{\boldsymbol{n}_{i,j}\boldsymbol{n}^H_{k,l}\} = \boldsymbol{0}$, for $i \neq k$ or $j \neq l$. Finally, and for the sake of simplicity, the measurement noise variance is assumed to be independent of the beam-pair, i.e. $\sigma^2_{1,1} = \sigma^2_{1,2} = \ldots = \sigma^2$.

Let $\beta_{i,j} \in \mathbb{R}$ denote the RSRP measurement corresponding to the (i,j) beam-pair. $\beta_{i,j}$ is sometimes called BRSRP measurement, and it is defined as follows

$$\beta_{i,j} = \frac{1}{\mathcal{M}_f}\sum_{k=1}^{\mathcal{M}_f} |[\boldsymbol{y}_{i,j}]_k|^2. \tag{2}$$

Typically, RSRP measurements are carried out at the UE, quantized, and reported to the BS. In [8], we have shown that the distribution of BRSRP measurements approaches a Gaussian for increasing number of subcarriers $\mathcal{M}_f$ or signal-to-noise ratio (SNR). In particular, we have the following result

$$\beta_{i,j} \sim \mathcal{N}\left(b_{i,j} + \sigma^2, \tilde{\sigma}^2\right), \tag{3}$$

where $\tilde{\sigma}^2$ in an unknown variance and $b_{i,j} \in \mathbb{R}$ is a product between the jth Tx beam-gain in the DoDs of the propagation paths between BS and UE, and the ith Rx beam-gains in the channel's directions of arrival (DoAs) as well as the channel's path-weights, and power allocated to the RSs. Direction-finding is then carried out from (reported and quantized) BRSRP measurements for a collection of beam-pairs. For example, the DoD of the LoS path between BS and UE may be determined by fitting a collection of BRSRP measurements, acquired between a given (fixed) UE beam and multiple BS beams, to a model of the BS's beams; see [8] for details.

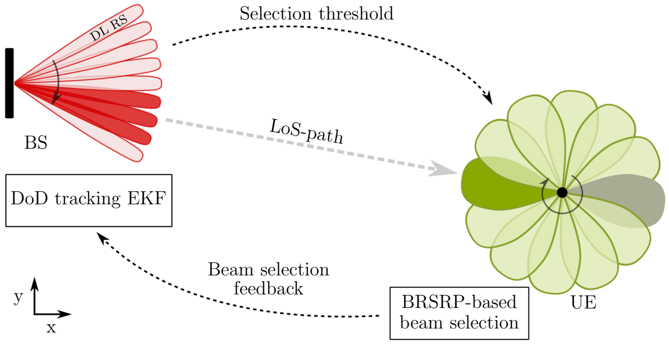

Fig. 1: Illustration of the direction-finding approach considered in this paper. In particular, UEs feedback (quantized) RSRP measurements obtained from DL RSs and transmitted across multiple BS beams. The reported beam-RSRP measurements are used for angle estimation and tracking at the BSs [8]. The contribution of this paper consists in two novel schemes that allow UEs to select the most relevant beams to be reported as a trade-off between direction-finding accuracy and load of the control channel.

It follows from (3) that the mean of BRSRP measurements carries information regarding angles of the LoS path between BS and UE. However, in low-SNR (when $b_{i,j} \ll \sigma^2$) such an information is negligible and one may safely discard such a BRSRP measurement since the corresponding BS beam is directed away from the LoS path. Identifying such uninformative BRSRP measurements also allows one to improve the efficiency of the feedback control channel since there is no need for the UE to report them. This is the problem addressed in this paper. In particular, we propose two adaptive schemes for identifying BRSRP measurements that have relevant information regarding angles of the LoS path between BS and UE.

III. PROPOSED BEAM SELECTION METHODS

In this section two methods for identifying BRSRP measurements that carry relevant information on the angle of the LoS path between BS and UE are proposed. Both schemes aim at deciding whether the received BRSRP measurement for a given BS-UE beam-pair is essentially due to "noise-only" or "RS-plus-noise" observations. The first method is a LR-test that consists in comparing the log-likelihood function of both "noise-only" and "RS-plus-noise" hypotheses, under a given significance level, for each BRSRP measurement. The second approach consists in letting the UE determining a noise-power estimate from Rx beams that are known to receive "noise-only" measurements, and comparing such a value with received BRSRP measurements. Typically, UEs operating in the mmW frequency-band comprise Rx beams spanning 360° in azimuth. This is done for coverage and due to the high path-loss in such frequency-band. Hence, the BRSRP measurement of the UE beam with smallest receive power is very likely to be due to "noise-only" observations since it is directed towards the opposite direction of the UE beam pointing to the BS.

A. Likelihood Ratio Test

Let $\mathcal{M}_{\text{BS}}$ denote the number of BS beams. The BRSRP measurements between such $\mathcal{M}_{\text{BS}}$ BS beams and the ith UE beam is denoted by $\boldsymbol{\beta}_i \in \mathbb{R}^{\mathcal{M}_{\text{BS}}}$, and its multivariate distribution follows from (3):

$$\boldsymbol{\beta}_i \sim \mathcal{N}\left(\boldsymbol{b}_i + \mathbf{1}\sigma^2, \tilde{\sigma}^2\boldsymbol{I}\right). \tag{4}$$

Note that the mean of $\boldsymbol{\beta}_i$ is nonzero even in the absence of RSs, i.e. in the "noise-only" case. Now, let $\boldsymbol{P}_1^{\perp} \in \mathbb{R}^{\mathcal{M}_{\text{BS}}\times\mathcal{M}_{\text{BS}}}$ denote a projection matrix onto the nullspace of $\mathbf{1}$. It is given by $\boldsymbol{P}_1^{\perp} = \boldsymbol{I} - \boldsymbol{P}_1$, where $\boldsymbol{P}_1 = \frac{1}{\mathcal{M}_{\text{BS}}}\mathbf{1}\mathbf{1}^T$ is the projection onto $\mathbf{1}$. Note that $\boldsymbol{P}_1^{\perp}\mathbf{1} = \mathbf{0}$. Let us also define $\boldsymbol{\xi}_i \in \mathbb{R}^{\mathcal{M}_{\text{BS}}}$ as

$$\boldsymbol{\xi}_i \triangleq \boldsymbol{P}_1^{\perp}\boldsymbol{\beta}_i. \tag{5}$$

From (3) and (4) it follows that the distribution of the mth element of $\boldsymbol{\xi}_i$ for the "noise-only" and "RS-plus-noise" hypotheses are, respectively,

$$\mathcal{H}_0^m : [\boldsymbol{\xi}_i]_m \sim \mathcal{N}\left(0, \sigma_\xi^2\right), \quad m = 1, \ldots, \mathcal{M}_{\text{BS}} \tag{6}$$

$$\mathcal{H}_1^m : [\boldsymbol{\xi}_i]_m \sim \mathcal{N}\left(\mu_m, \sigma_\xi^2\right), \quad m = 1, \ldots, \mathcal{M}_{\text{BS}}. \tag{7}$$

Here, $\mu_m \in \mathbb{R}$ and $\sigma_\xi^2 \in \mathbb{R}$ denote unknown mean and variance, respectively.

We now need to estimate the parameters μ_m and σ_ξ^2 corresponding to each hypothesis $(\mathcal{H}_0^m, \mathcal{H}_1^m)$ for all $\mathcal{M}_{\text{BS}}$ beams. Note that $\mu_m = 0$ for the null-hypothesis. Let $\boldsymbol{\xi}_i^m = [[\boldsymbol{\xi}_i(1)]_m, \ldots, [\boldsymbol{\xi}_i(N)]_m]^T$ denote N independent and identically distributed (iid) measurements of BRSRP between the mth BS beam and the ith UE beam. For example, this may be obtained from the multicarrier observation $\boldsymbol{y}_{i,j}$ as follows:

$$[\boldsymbol{\xi}_i(n)]_m = \frac{N}{\mathcal{M}_f}\sum_{k=\frac{(n-1)\mathcal{M}_f}{N}+1}^{\frac{n\mathcal{M}_f}{N}} |[\boldsymbol{y}_{i,j}]_k|^2. \tag{8}$$

The log-likelihood function for the null-hypothesis is then

$$\ell_0(0, \sigma_\xi^2|\boldsymbol{\xi}_i^m) = -\frac{N}{2}\ln 2\pi - \frac{N}{2}\ln\sigma_\xi^2 - \frac{1}{2\sigma_\xi^2}\|\boldsymbol{\xi}_m\|^2. \tag{9}$$

Maximizing (9) with respect to σ_ξ^2 yields

$$\hat{\sigma}_{\xi_0}^2 = \frac{1}{N}\|\boldsymbol{\xi}_m\|^2. \tag{10}$$

Similarly, the log-likelihood function for the alternative hypothesis is

$$\ell_1(\mu_m, \sigma_\xi^2|\boldsymbol{\xi}_m) = -\frac{N}{2}\ln 2\pi - \frac{N}{2}\ln\sigma_\xi^2 - \frac{1}{2\sigma_\xi^2}\|\boldsymbol{\xi}_m - \mathbf{1}\mu_m\|^2, \tag{11}$$

where the corresponding maximum likelihood estimators (MLEs) are given by

$$\hat{\mu}_m = \frac{1}{N}\mathbf{1}^T\boldsymbol{\xi}_m, \tag{12}$$

$$\hat{\sigma}_{\xi_1}^2 = \frac{1}{N}\|\boldsymbol{\xi}_m - \mathbf{1}\hat{\mu}_m\|^2. \tag{13}$$

The LR test-statistic for the mth BS beam is now given by

$$\text{LR}_m = -2\left(\ell_0(0, \hat{\sigma}_{\xi_0}^2) - \ell_1(\hat{\mu}_m, \hat{\sigma}_{\xi_1}^2)\right). \tag{14}$$

Let $\chi_{1-\alpha}^2(1)$ denote the so-called $(1-\alpha)$ critical value of the chi-squared distribution with 1 degree-of-freedom, where α denotes the significance level, i.e. the probability of rejecting the null-hypothesis under $\mathcal{H}_0^m$ (type-I error) [9]. The significance level is typically a design parameter. In particular, the null hypothesis is rejected for a significance level of α if $\text{LR}_m > \chi_{1-\alpha}^2(1)$, and failed to be rejected otherwise. In other words, if (14) is larger than $\chi_{1-\alpha}^2(1)$, for a given α, the BRSRP measurement of the corresponding BS beam is reported to the network. Otherwise, no reporting is done for such a beam.

B. Power Threshold

Let us denote the BRSRP measurements between the "strongest" UE beam and all BS beams as $\boldsymbol{\beta}_{\text{LoS}} \in \mathbb{R}^{\mathcal{M}_{\text{BS}}}$. The "strongest" UE beam, or the beam that best matches the BS transmission, is chosen based on the measured BS's BRSRP. It can be, for example, the UE beam that corresponds to the largest BRSRP measurements among all BS-UE pairs or, alternatively, the one that yields the largest sum of BS beams' measurements among all UE beams, i.e., $\max_i \sum_{j=1}^{\mathcal{M}_{\text{BS}}} \beta_{i,j}$. The latter is used throughout this paper. In general, $\boldsymbol{\beta}_{\text{LoS}}$ contains BRSRP measurements that are due to "RS-plus-noise" and "noise-only" since the BS beams point towards different directions.

Let $\boldsymbol{\beta}_{\text{FB}} \in \mathbb{R}^{\mathcal{M}_{\text{FB}}}$ denote the subset of $\boldsymbol{\beta}_{\text{LoS}}$ that is reported to the BS. More precisely, $\boldsymbol{\beta}_{\text{FB}} \subseteq \boldsymbol{\beta}_{\text{LoS}}$ and $\mathcal{M}_{\text{FB}} \leq \mathcal{M}_{\text{LoS}}$. Vector $\boldsymbol{\beta}_{\text{FB}}$ contains the BRSRP measurements that are used as an input to an extended Kalman filter (EKF) in order to sequentially estimate the DoD. The process of determining $\boldsymbol{\beta}_{\text{FB}}$ from $\boldsymbol{\beta}_{\text{LoS}}$ is carried out by the UE itself. Such a decision making process is given as follows:

1) Estimate σ^2 in (3) from BRSRP measurements corresponding to a UE beam that is known to point in a direction opposite from the BS:

$$\hat{\sigma}^2 = \frac{1}{\mathcal{M}_{\text{BS}}}\sum_{j=1}^{\mathcal{M}_{\text{BS}}}[\boldsymbol{\beta}_N]_j, \tag{15}$$

where $\boldsymbol{\beta}_N \in \mathbb{R}^{\mathcal{M}_{\text{BS}}}$ denote "noise-only" BRSRP measurements.

2) Set a power threshold $\rho_{\text{tr}} \in \mathbb{R}$ based on $\hat{\sigma}^2$ and a given $\mathcal{B}(\mathcal{B} \geq 1) \in \mathbb{R}$

$$\rho_{\text{tr}} = \mathcal{B}\hat{\sigma}^2. \tag{16}$$

3) Determine $\boldsymbol{\beta}_{\text{FB}}$ as follows:

$$\boldsymbol{\beta}_{\text{FB}} = [\boldsymbol{\beta}_{\text{LoS}}]_{\mathcal{I}}, \tag{17}$$

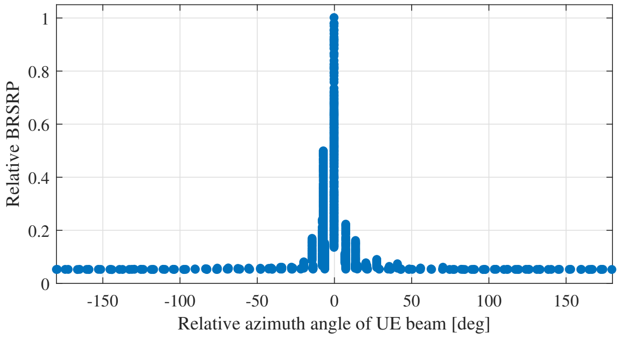

Fig. 2: Average (normalized) received power per UE beam for both BSs along the UE route (see Section IV). The azimuth angle is relative to the LoS direction to a BS (the "strongest" UE beam points to 0°). Power is normalized to the maximum value. The measurements for most of the UE beams outside the region $[-20°, 20°]$ are essentially due to measurement noise, only.

where the set of selected vector indices is defined as

$$\mathcal{I} = \{i \mid [\boldsymbol{\beta}_{\text{LoS}}]_i > \rho_{\text{tr}},\, i = 1, \ldots, \mathcal{M}_{\text{LoS}}\}. \qquad (18)$$

Determining the UE beam that points in the opposite direction from the BS may be done in two ways: finding the UE beam that points opposite from the "strongest" UE beam, or choosing the UE beam that yields the smallest sum of BS beams' measurements, i.e., $\min_i \sum_{j=1}^{\mathcal{M}_{\text{BS}}} \beta_{i,j}$. As illustrated in Fig. 2, the average received power per UE beam for most of the beams, including the opposite to the "strongest", is at the noise level. Thus, these two approaches are equivalent. Throughout this paper we adopt the former.

One should also note that $\mathcal{B}$ is a design-parameter, and the UE needs to find a suitable value for it. As shown in Section IV, the relationship between $\mathcal{B}$ and the number of reported beams depends on SNR, which can in turn be determined by the UE itself. Alternatively, the BS may indicate the UE to use a particular value for $\mathcal{B}$.

IV. NUMERICAL RESULTS

A. Deployment Scenario and System Parameters

The deployment scenario used in our numerical study is the so-called Madrid grid [10], modified in order to have a large open area of about 550 m long and 150 m wide. Fig. 3 illustrates the employed modified Madrid grid along with the locations of the BSs (black dots) and UE (red cross). The height of the BSs and UE are 50 m and 1.5 m, respectively. Using the Madrid grid is motivated by the reproducibility of our results since such a layout is well documented, and has been widely used in the so-called Mobile and wireless communications enablers for the twenty-twenty information society (METIS) project; see [10] and references therein. In particular, the radio channels between a given UE and BSs are modelled according to the METIS ray-tracing channel model [10]. Hence, all multipath components between the UE and BSs are taken into account in the BRSRPs measurements, and re-calculated for every UE position.

The mmW cellular system, considered in this numerical study operates at 39 GHz with a bandwidth of 100 MHz and a subcarrier spacing of 120 kHz. Thus, there are 800 subcarriers available for DL-RSs transmission (the DC-component is not used). Each BS has 64 (fixed) beams spanning 40° both in co-elevation and azimuth, and with a 3 dB beamwidth of ≈ 3°. DL-RSs are transmitted via such 64 beams with a Tx power of 10 dB per beam. The UE receives DL-RSs from its 52 beams spanning 360° in azimuth and a fixed co-elevation of (≈ 75°). The 3 dB beamwidth of UE beams is ≈ 6° in azimuth and ≈ 40° in co-elevation. The maximum gain of the BS beams is ≈30 dBi while that of UE beams is ≈17 dBi.

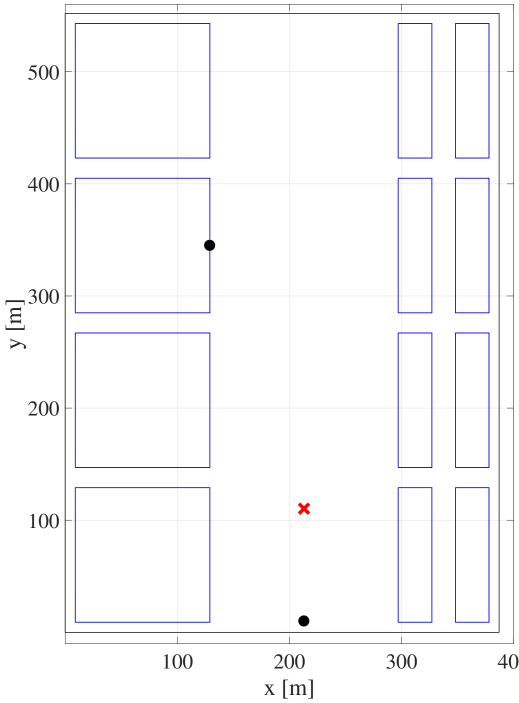

Fig. 3: Illustration of the modified Madrid grid considered in this paper. A large open area of about 550 m long and 150 m wide is considered for assessing the performance of the proposed beam-selection scheme. BSs are depicted by black dots while the initial position of the (moving) UE is illustrated by a red cross. The (multipath) radio channel between UE and BSs is determined by means of the METIS ray-tracing channel model [10].

In this numerical study, DL-RSs are assumed to be scheduled in orthogonal radio resources for different beams and different BSs. The UE measures the BRSRP for all 64 × 52 beam-pairs, for both BSs, in 160 ms, after which it employs the beam selection schemes proposed in Section III, and feedbacks the indices of the detected beams as well as the corresponding BRSRPs. In particular, each reported BRSRP measurement is quantized using 7 bits in the range $[-140, -44]$ dBm. This is identical to the RSRP reporting in 5G Rel. 15 [7].

B. Performance of the Proposed Beam Selection Schemes

We assess the performance of the beam selection schemes proposed in Section III in terms of the amount of reported BRSRP measurements (load of the control channel) and corresponding accuracy of the angle estimates acquired by our DoD-EKF tracking algorithm [8]. We consider a UE moving with a velocity of $2\,\mathrm{m\,s^{-1}}$ along a 100 m (straight) trajectory

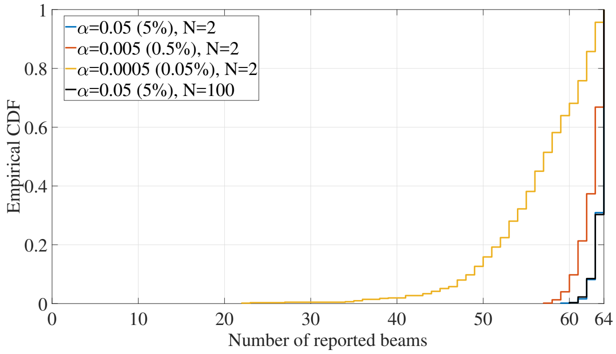

Fig. 4: Empirical cumulative distribution function (CDF) of the number of reported beams using the proposed scheme based on LR-test for different significance levels. These are the reported beams along the UE trajectory. Results show that decreasing the significance level (type-I error-probability) reduces the amount of reported beams. In particular, for a significance level of 0.05% a reduction of $\approx 10\%$ from all available beams is achieved.

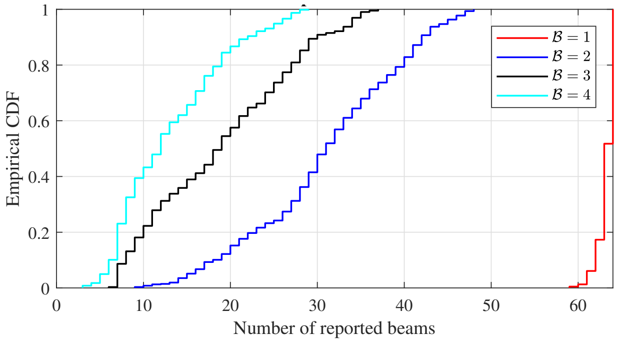

Fig. 5: Empirical CDF of the number of reported beams using the proposed power threshold scheme for different values of $\mathcal{B}$. These are the reported beams along the UE trajectory. Results show that increasing the power threshold reduces the amount of reported beams significantly without loss of angular accuracy (see Figs. 7 and 9). In particular, for the value of $\mathcal{B} = 3$, the median number of reported beams is 18 (out of 64). Further reduction of reported beams due to an increase of $\mathcal{B}$ to the value of 4 leads to a performance degradation of the corresponding azimuth angle estimates (see Fig. 9).

with a south-to-north direction. The starting position of the UE is illustrated in Fig. 3 by a red cross. The southernmost BS is north-facing while the northernmost BS has a 60° orientation clockwise from East-side. The reporting period of BRSRP measurements from the UE is $160\,\mathrm{ms}$.

Figs. 4 and 5 illustrates the performance of the proposed methods in terms of CDF of the number of reported beams. Fig. 4 illustrates the performance of the LR-test based scheme for different significance levels i.e., type-I error-probabilities $(\alpha = 0.05, 0.005, 0.0005)$. Fig. 5 shows the CDF of the number of reported beams for the power threshold method for different values of $\mathcal{B}$. The corresponding performance of the DoD-EKF algorithm is illustrated in Figs. 6-9 in terms of CDF of the error in co-elevation and azimuth angles for both beam selection methods. As a benchmark, the performance of the DoD-EKF algorithm using reported BRSRP measurements from all of the 64 beams is illustrated as well. Results for the LR-test based scheme (Figs. 6 and 8) show that decreasing the significance level leads to a smaller number of reported beams, as expected.

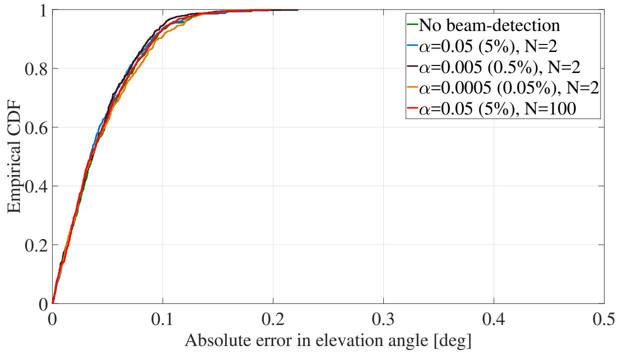

Fig. 6: Empirical CDF of the error in co-elevation angle for different significance levels. These results are obtained from the DoD-EKF algorithm [8] using the quantized BRSRP measurements corresponding to the beams selected by the LR-test. Results show that reducing the number of feedback BRSRP measurements by $\approx 10\%$ does not significantly change the angle estimation performance. The discarded measurements do not carry substantial information on the DoD.

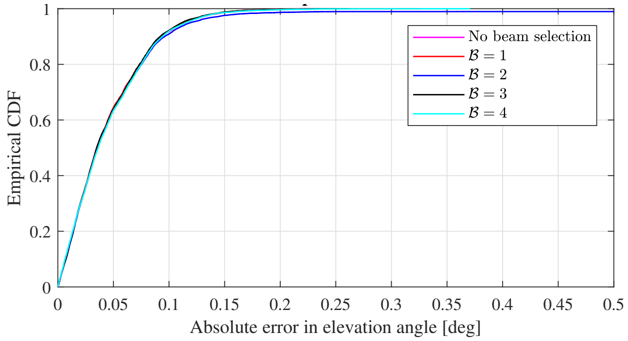

Fig. 7: Empirical CDF of the error in co-elevation angle for different values of $\mathcal{B}$. The case with no beam selection (always 64 UE beams are reported) is included for comparison. These results are obtained from the DoD-EKF algorithm [8] using the quantized BRSRP measurements corresponding to the beams selected by the power threshold method.

Results show that reducing the number of feedback BRSRP measurements by $\approx 10\%$ does not significantly change the angle estimation accuracy. The discarded BRSRP measurements do not carry substantial information on the DoD. Similarly, for the power threshold method (Figs. 7 and 9), the performance does not change significantly for the values of $\mathcal{B} \in [1, 3]$, however, for $\mathcal{B} = 4$ the accuracy of the azimuth angle degrades slightly. Such a result can be interpreted in the scope of our previous results [8], where we show that the accuracy of the azimuth and elevation angle estimates deteriorates as the amount of reported beams decreases substantially. In particular, the absolute error of azimuth angle noticeably increases when the number of reported beams for each BS is capped at 8 beams, while for the elevation angle error this limit is 6 beams. According to Fig. 5, the amount of reported beams for the value of $\mathcal{B} = 4$ is ≤ 8 in 40% of locations, which explains the observed decrease in accuracy of azimuth angle estimates.

V. CONCLUSION

In this paper we have considered direction-finding in mmW 5G networks by means of reported beam-based DL RSRP

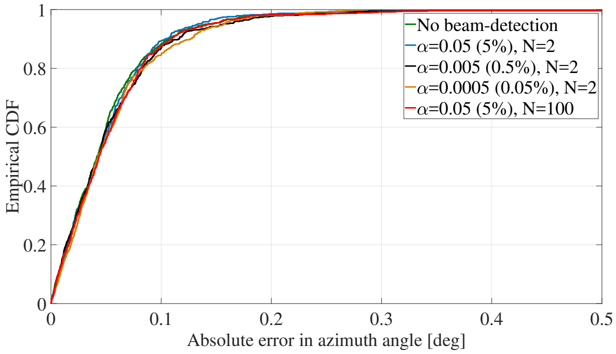

Fig. 8: Empirical CDF of the error in azimuth angle for different significance levels. These results are obtained from the DoD-EKF algorithm [8] using the quantized BRSRP measurements corresponding to the beams selected by the LR-test. Results show that reducing the number of feedback BRSRP measurements by $\approx 10\%$ does not significantly change the angle estimation performance. The discarded measurements do not carry substantial information on the DoD.

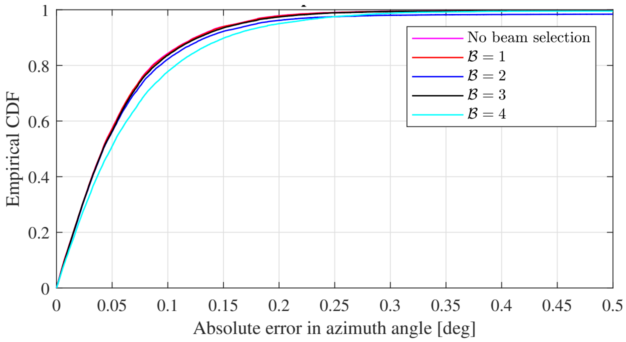

Fig. 9: Empirical CDF of the error in azimuth angle for different values of $\mathcal{B}$. The case with no beam selection (always 64 UE beams are reported) is included for comparison. These results are obtained from the DoD-EKF algorithm [8] using the quantized BRSRP measurements corresponding to the beams selected by the power threshold method.

measurements. A typical deployment is that of a moving UE in LoS condition to one or multiple BSs. Such a UE measures the RSRP of DL-RSs transmitted from multiple BS beams. We have proposed two methods that allow UEs to determine and report only the most relevant BRSRP measurements for estimation and tracking of the DoD of the LoS path. We have assumed an EKF running at each BS. The proposed beam selection schemes provide a trade-off between angle estimation accuracy and load of the feedback channel. In particular, the first method is based on the LR-test while second method employs a threshold to the BRSRP measurements that is proportional to the noise power at the UE. Extensive numerical results carried out on a realistic ray-tracing based environment operating at 39 GHz show that the power threshold method outperforms the LR-test scheme. For example, the median number of reported beams for the power threshold method is 30% of all available BRSRP measurements, but the corresponding angle estimates have essentially the same accuracy as those obtained by reporting all of the available measurements.

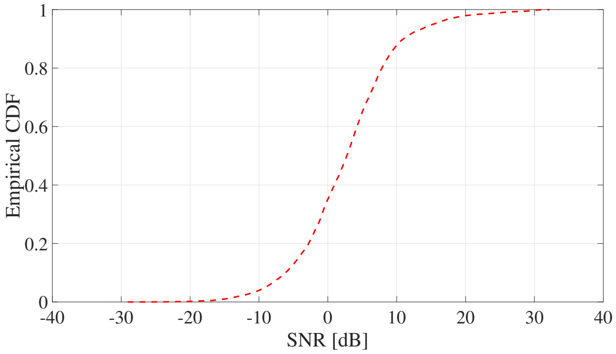

Fig. 10: Empirical CDF of received SNR (per beam) at the UE, after gain from transmit/receive beams, for all of the 64 beams considered for reporting.

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