Beam Tracking for Mobile Millimeter Wave Communication Systems

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I. Introduction

Millimeter wave (mmWave) has many applications

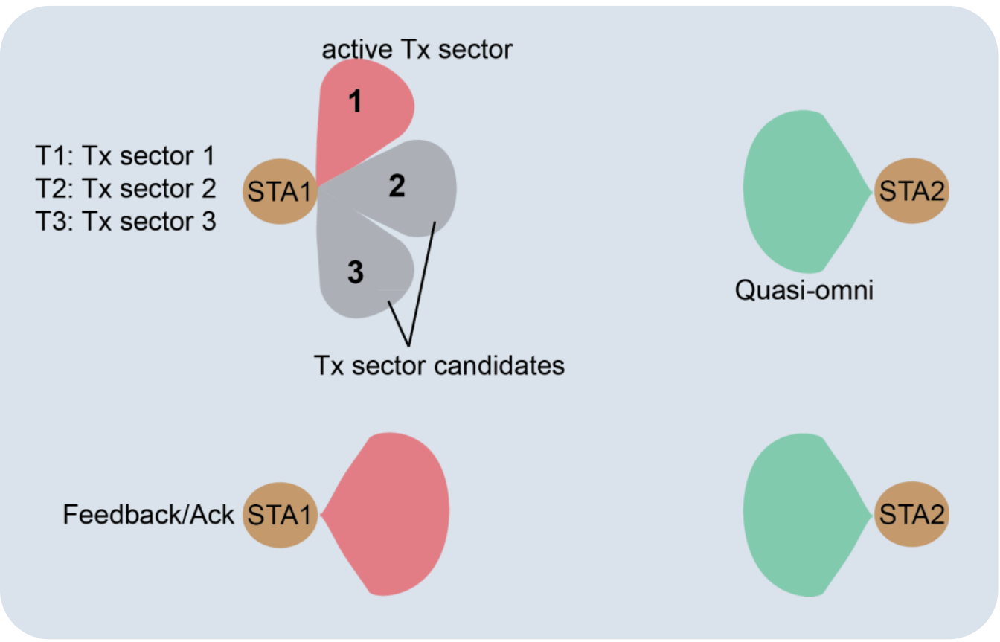
MmWave WiFi [1]

5G cellular [2]

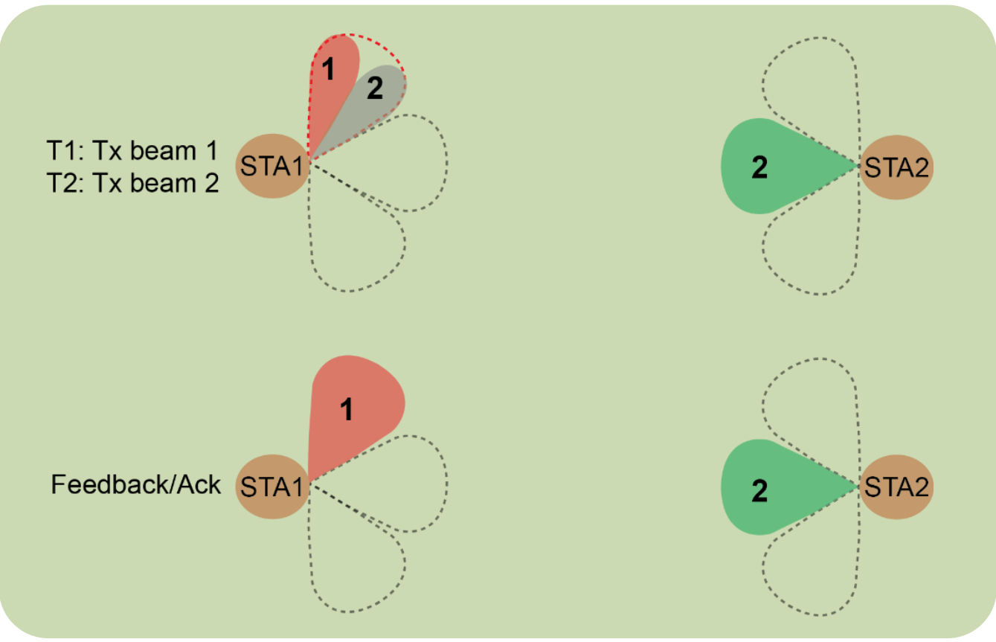
Vehicular comm. [3]

MmWave beam alignment is expensive

Sector level search



Beam level search



IEEE 802.11ad beam training can take up to ~50 ms for beamwidth of 10° [4]

Our contributions:

- Proposed a low overhead beam tracking method
- Investigate impacts of SINR and array size on tracking

II. System model

Channel model:

Number of paths

Complex channel gain

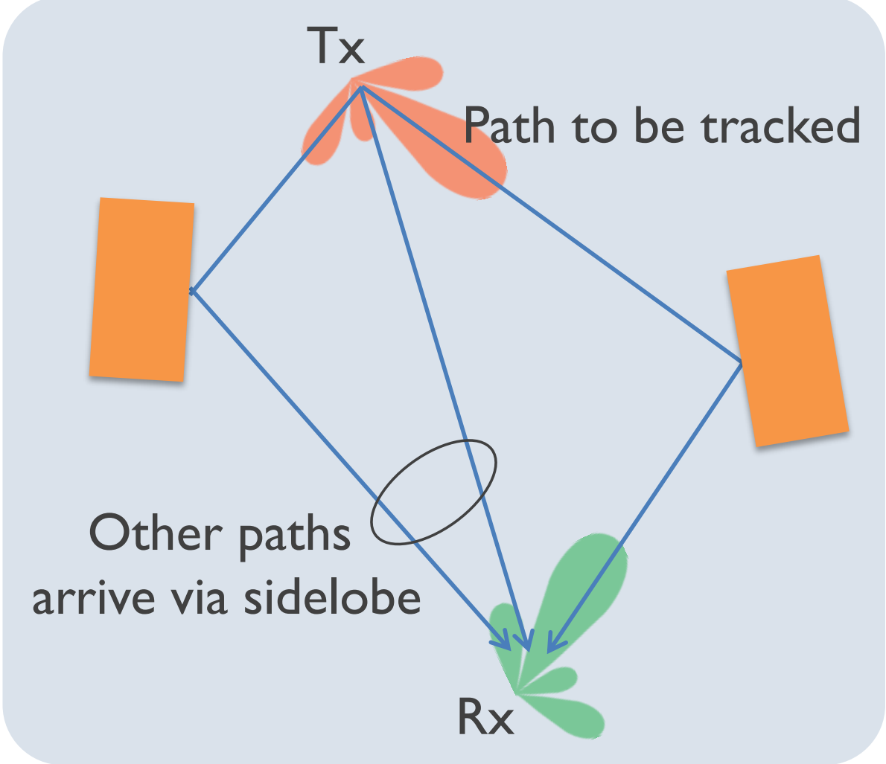
Angle of arrival

Angle of departure

$$\boldsymbol{G}[k]=\sum_{n=1}^{N[k]}\alpha_n[k]\boldsymbol{a}_{\mathrm{r}}(\phi_{n,\mathrm{A}}[k])\boldsymbol{a}_{\mathrm{t}}^*(\phi_{n,\mathrm{D}}[k])$$

Rx array response vector

Tx array response vector



State-space model:

$\mathrm{diag}([\rho,\rho,1,1])$ where ρ is the temporal correlation of $\alpha[k]$

State vector: $\left[\Re[\alpha[k]] \quad \Im[\alpha[k]] \quad \phi_{\mathrm{A}}[k] \quad \phi_{\mathrm{D}}[k]\right]^{\mathrm{T}}$

State evolution: $\boldsymbol{x}[k]=\boldsymbol{F}\boldsymbol{x}[k-1]+\boldsymbol{u}[k-1]$

Process noise assumed to be white Gaussian
$\boldsymbol{\Sigma}_{\boldsymbol{u}}=\mathrm{diag}([1-\rho^2,1-\rho^2,\sigma_{\mathrm{A}}^2,\sigma_{\mathrm{D}}^2])$

Measurement function: $y[k]=\alpha[k]\boldsymbol{w}^*\boldsymbol{a}_{\mathrm{r}}(\phi_{\mathrm{A}}[k])\boldsymbol{a}_{\mathrm{t}}^*(\phi_{\mathrm{D}}[k])\boldsymbol{f}+v[k]$

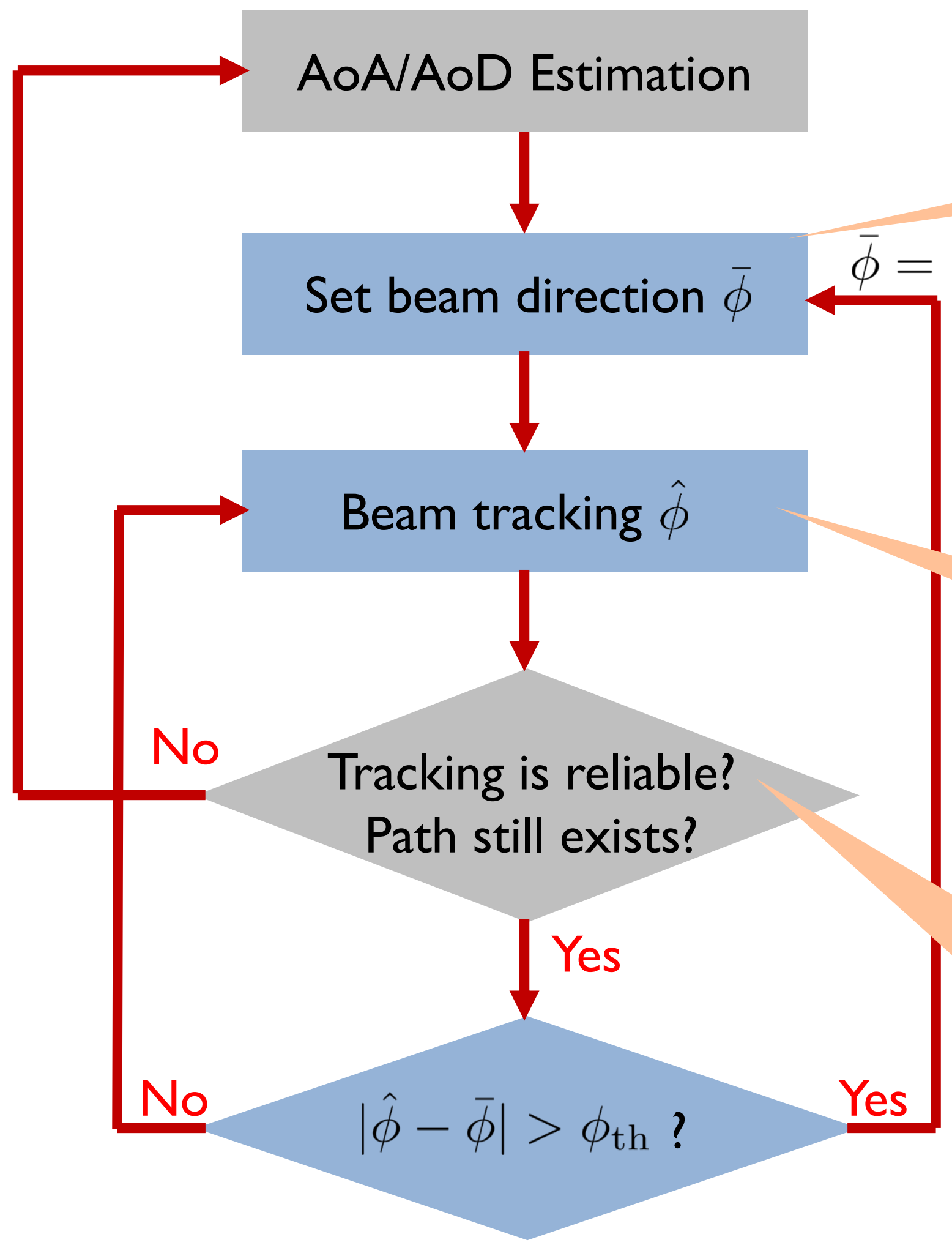
$$=\frac{\alpha[k]}{N_{\mathrm{r}}N_{\mathrm{t}}}\frac{1-e^{\mathrm{j}N_{\mathrm{r}}\frac{2\pi}{\lambda}d\Phi_{\mathrm{A}}}}{1-e^{\mathrm{j}\frac{2\pi}{\lambda}d\Phi_{\mathrm{A}}}}\frac{1-e^{\mathrm{j}N_{\mathrm{t}}\frac{2\pi}{\lambda}d\Phi_{\mathrm{D}}}}{1-e^{\mathrm{j}\frac{2\pi}{\lambda}d\Phi_{\mathrm{D}}}}+v[k]$$

Dot product of array steering vectors

Leveraging sparsity, focusing on only one path

Noise and interference from other paths via sidelobe are lumped up

III. Proposed beam tracking



Switch beam when the error exceeds the threshold

A natural choice for the threshold is 1/2 beamwidth

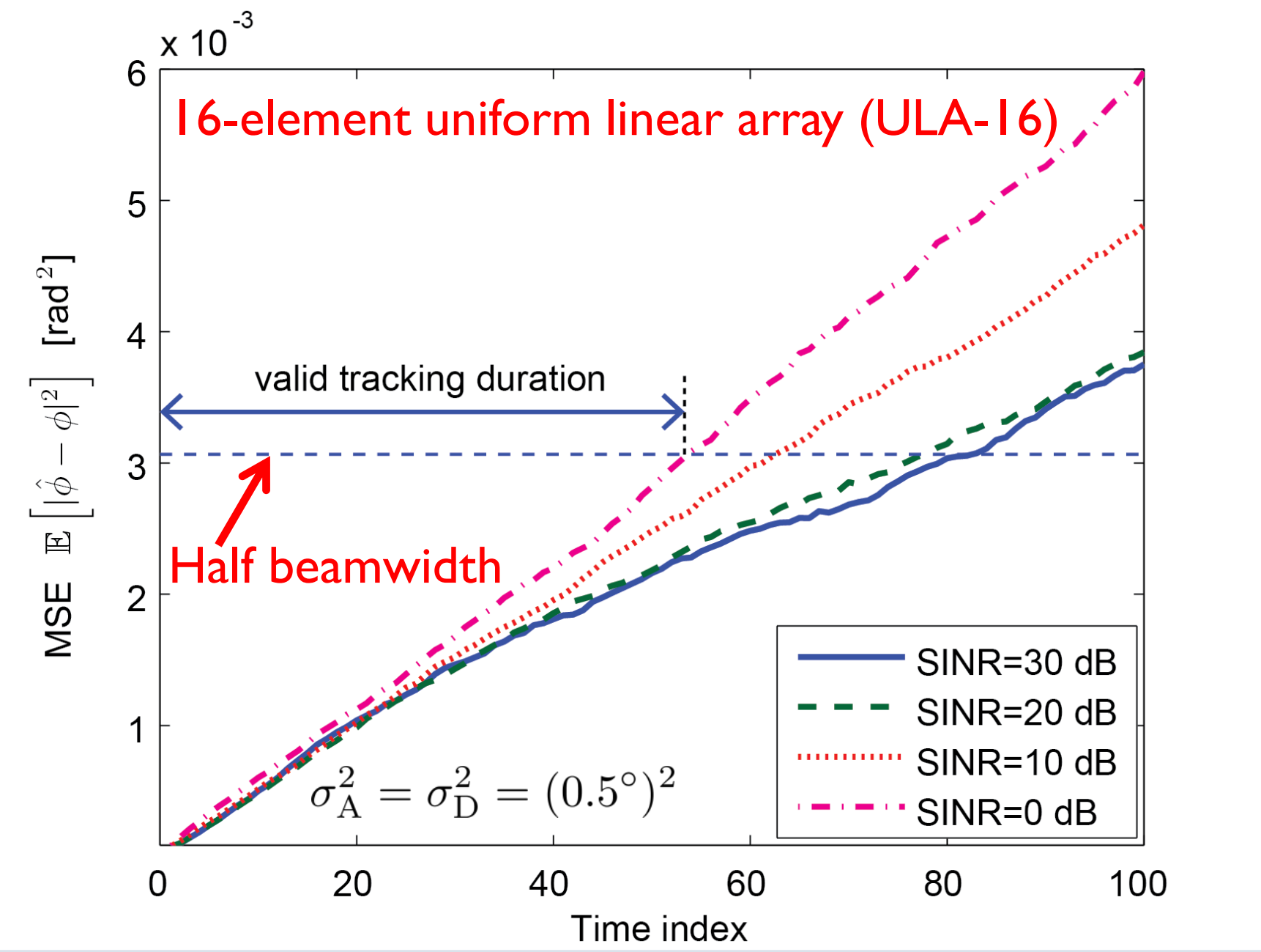
Extended Kalman filter (EKF) is applied on the state-space model

Path can disappear, e.g., due to blockage

▨ Not considered in this work

IV. Numerical results

Effect of SINR

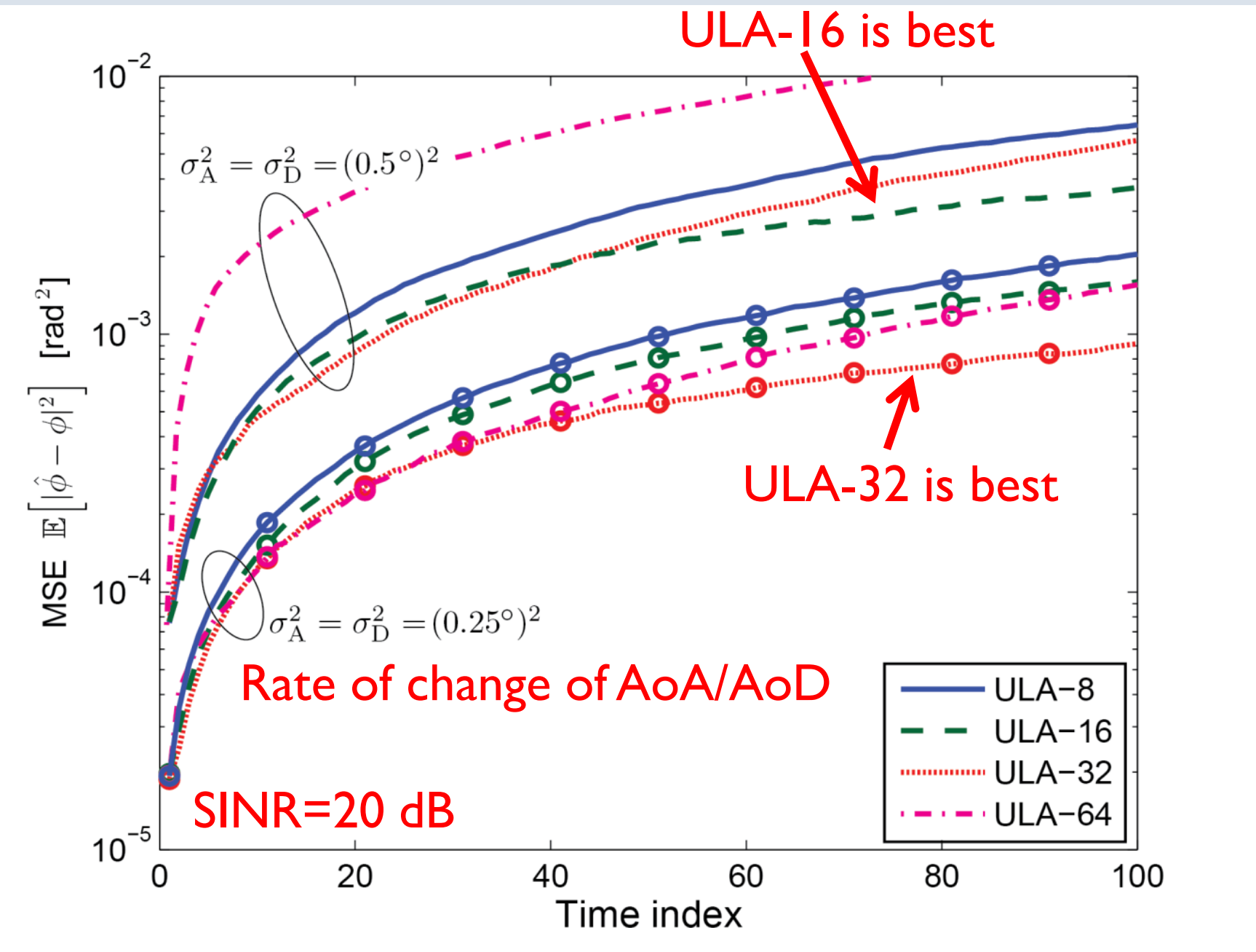


Large jump between 10 and 20 dB

Excessive SINR does not help much

Enough SINR is needed for good tracking performance

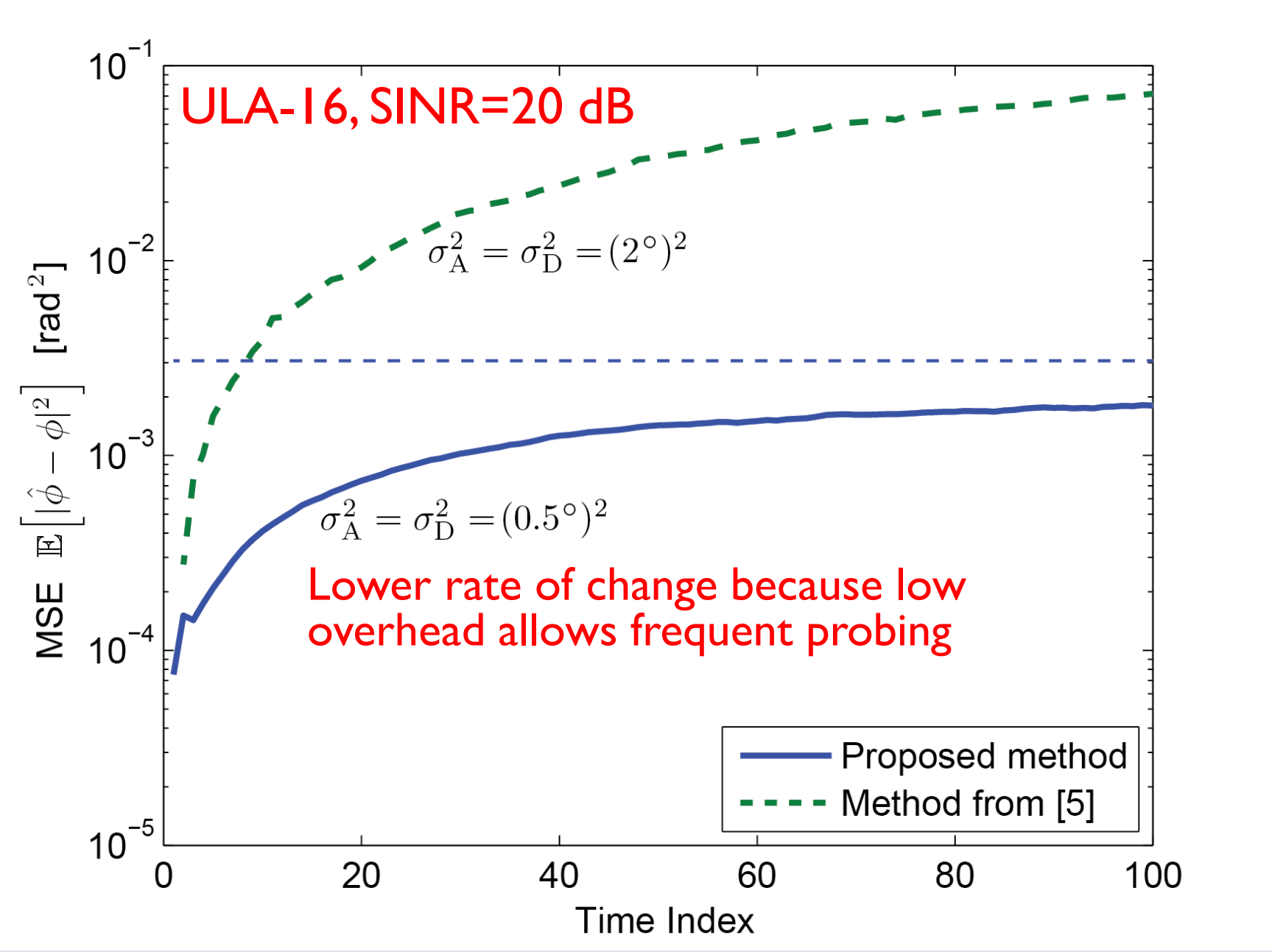
Effect of array size



Too narrow beams are too sensitive and too wide beams are not sensitive enough

Optimal array size depends on the rate of change of AoA/AoD

Comparison with prior work [5]



Method in [5] requires $N_{\mathrm{r}}N_{\mathrm{t}}$ times more measurement overhead

The low measurement overhead makes our method better for fast changing environments

V. Conclusions

- Proposed a beam tracking method with low overhead
- Tracking performance improvement saturates at high SINR
- Appropriate choice of array size needed for good tracking
  - Too small arrays are not sensitive enough
  - Too large arrays cannot keep up with changes in AoA/AoD

Future work

- Introduce more structure in evolution model to differentiate angle change due to linear displacement and rotation
- Propose solutions for all the gray blocks in Section III

References

[1] "IEEE std 802.11ad-2012," *IEEE Standard,* pp. 1–628, Dec. 2012.
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[3] V. Va, T. Shimizu, G. Bansal, and R. W. Heath Jr., "Millimeter wave vehicular communications: A survey," *Foundations and Trends in Networking*, vol. 10, no. 1, 2016.
[4] S. Sur, V. Venkateswaran, X. Zhang, and P. Ramanathan, "60 GHz indoor networking through flexible beams: A link-level profiling," in *Proc. of the ACM SIGMETRICS*, 2015.
[5] C. Zhang, D. Guo, and P. Fan, "Tracking angles of departure and arrival in a mobile millimeter wave channel," in *Proc. of the IEEE International Conference on Communications*, May 2016.

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