Title：Fast Near-Field Beam Training for Extremely Large-Scale Array

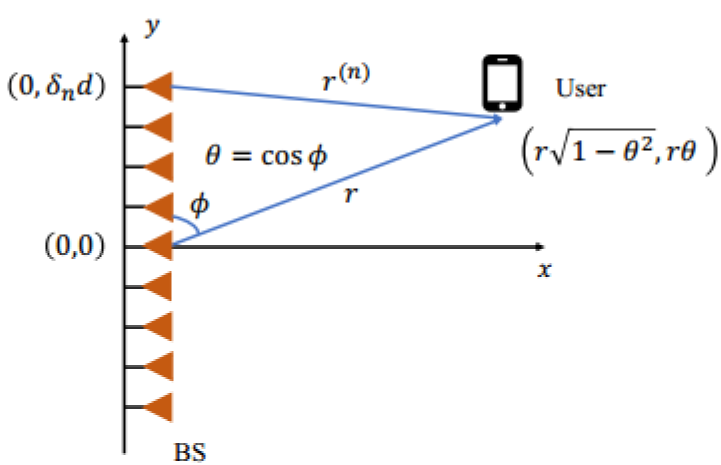
Background

Compared with the conventional far-field beam training method that searches for the best beam **angular** only, the near-field beam training is more challenging since it requires a beam search over **both the angular and distance** domains due to the spherical wavefront propagation model.

The existing near-field training methods for the narrow-band require a two-dimensional exhaustive search for all possible beam angular and distances, thus leading to prohibitively **high training overhead**.

Method

1、System model (N-antenna BS LOS channel)



Channel coefficient

$$\mathbf{h}_{\text{near}}^{H} = \sqrt{N} h \mathbf{b}^{H}(\theta, r)$$

where $h = \frac{\sqrt{\beta}}{r} e^{-\frac{j2\pi r}{\lambda}}$

Near-field steering vector

$$\mathbf{b}^{H}\left(\theta, r\right) = \frac{1}{\sqrt{N}}\left[e^{-j2\pi(r^{(0)}-r)/\lambda}, \cdots, e^{-j2\pi(r^{(N-1)}-r)/\lambda}\right]$$

Far-field steering vector

$$\mathbf{a}^{H}(\theta) \triangleq \frac{1}{\sqrt{N}}\left[1, e^{-j\pi\theta}, \cdots, e^{-j\pi(N-1)\theta}\right]$$

notice $\mathbf{a}^{H}(\theta) a(\theta) = 1$

The received signal at the user is given by

$$y_{\text{near}} = \mathbf{h}_{\text{near}}^{H} \mathbf{v} x + z_0 = \sqrt{N} h \mathbf{b}^{H}(\theta, r) \mathbf{v} x + z_0$$

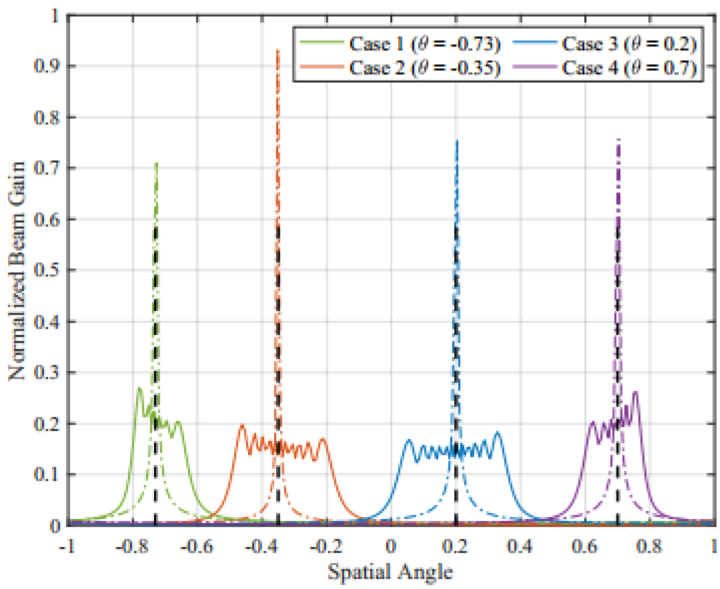
where v represents the transmit beamforming vector

2、 Two-phase near-field beam training method

Defination of the normalized beam gain

$$\mathbf{A}(\mathbf{u}^H, \mathbf{w}) = |\mathbf{u}^H \mathbf{w}|$$

where the beamforming vector w and the channel steering vector $\mathbf{u}^H$



对于MISO far field LOS channel， beamtraining就是将360度离散细分以后， 将每个steer vector的共轭转置作为transmit beamforming vector代入， 找个功率最大值，因为远场只与angular有关， 所以beam gain通常只有一个极窄角度处功率很高。而对于near field， steer vector同时与distance和angular有关就会有角度的扩散。

First phase

- we aim to estimate the spatial angle of the user in the first phase based on the far-field beam training method.
- we propose a new middle-K angle selection scheme that **selects K candidate spatial angles** in the middle of the quantized dominant-angle region rather than selecting one spatial angle only.

Second phase

a customized polar-domain beam training method is proposed for the second phase to

> estimate the effective user distance based on the **non-uniform distance sampling** method.

Conclusion

Last, it is worth mentioning that there exists a fundamental tradeoff between the beam training performance versus the number of candidate angles, K. Specifically, when K is larger, it incurs a larger training overhead, while leading to a higher beamforming gain due to the more accurate angle estimation.

Summary

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>
> - 能将近场beamtraining分两步来节省开销的主要原因在于：将远场的beamforming vector代入近场以后，虽然角度有扩散，但用户真实角度是近似位于角度扩散的中心区域，相当于确定了用户在一个窄角度内，方便后续距离处理。
> - 其次，这样做可以区分近场与远场，如果接收端功率比较集中，则位于远场，便不需要第二步了。