

HARNESSING WAVEFRONT CURVATURE AND SPATIAL CORRELATION IN NONCOHERENT MIMO COMMUNICATIONS

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MOTIVATION

Noncoherent communication systems have regained interest due to increasing demand for low-latency applications. Most studies with large antenna arrays assume far-field propagation and locally plane wavefronts, but this becomes inaccurate at higher frequencies and shorter ranges where wavefront curvature and radiative near-field effects dominate.

Highlights

- Wavefront curvature is beneficial beyond the Fraunhofer limit.
- Large arrays can multiplex multiple users despite noncoherent processing.
- Noncoherent single-user detection is near-optimal with large arrays.

SYSTEM MODEL

We consider the uplink of a noncoherent MIMO system with K users and a BS equipped with an $N = N_H N_V$ element UPA. The system operates under NLoS conditions with only statistical CSI.

Channel Model

The channel of user k is modeled as

$$\mathbf{h}_k \sim \mathcal{CN}(\mathbf{0}, \mathbf{R}_{\mathbf{h}_k}), \quad \mathbf{R}_{\mathbf{h}_k} = \sum_{i=1}^L \beta_{ki} \mathbf{a}_{ki} \mathbf{a}_{ki}^H.$$

Near field: The array response \mathbf{a}_{ki} depends on exact distances, capturing spherical wavefronts.

Far field: Assumes planar wavefronts, leading to simplified responses depending only on angles.

Signal Model

The received signal is

$$\mathbf{y} = \sum_{k=1}^K \sqrt{p_k} \mathbf{h}_k x_k + \mathbf{z}, \quad \mathbf{z} \sim \mathcal{CN}(\mathbf{0}_N, \mathbf{R}_z),$$

with x_k belonging to a unipolar M -PAM constellation.

The optimal multiuser receiver is the ML detector

$$\hat{\mathbf{x}}_{\text{ML}} = \arg \min_{\mathbf{x} \in \mathcal{X}^K} \mathbf{y}^H \mathbf{R}_{\mathbf{y}|\mathbf{x}}^{-1} \mathbf{y} + \log |\mathbf{R}_{\mathbf{y}|\mathbf{x}}|. \quad (1)$$

A suboptimal receiver is the single-user detector that ignores the presence of other users:

$$\hat{x}_k = \arg \min_{x \in \mathcal{X}} \mathbf{y}^H \mathbf{R}_{\mathbf{y}|x,k}^{-1} \mathbf{y} + \log |\mathbf{R}_{\mathbf{y}|x,k}|. \quad (2)$$

CHANNEL STATISTICS DISCUSSION

Spatial Correlation Spectrum

- Both far-field and near-field models exhibit the same correlation spectrum.
- If two users are in the same scattering cluster the eigenvalues of their channel correlation matrices coincide, even if scatterers realizations differ.

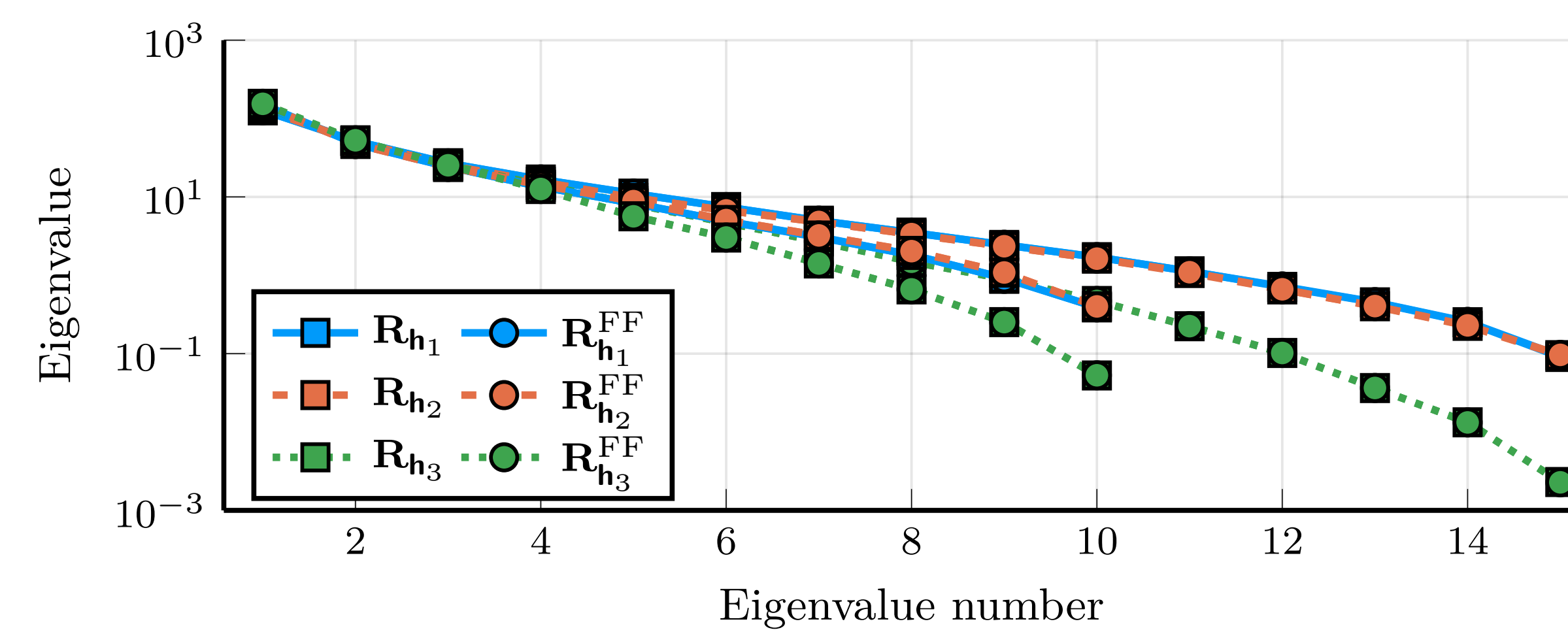


Figure 1. Non-zero eigenvalues of each UE's near-field and far-field channel correlation matrices for $L = 10$ and $L = 15$.

Distance Between Column Spaces

We measure the chordal distance between $\text{col}(\mathbf{R}_{\mathbf{h}})$ and $\text{col}(\mathbf{R}_{\mathbf{h}}^{\text{FF}})$ through the orthonormal eigenbases $\mathbf{U}_{\mathbf{h}}$ and $\mathbf{U}_{\mathbf{h}}^{\text{FF}}$:

$$d_{\text{ch}}(\mathbf{U}_{\mathbf{h}}, \mathbf{U}_{\mathbf{h}}^{\text{FF}}) = \text{tr}(\mathbf{I} - (\mathbf{U}_{\mathbf{h}}^{\text{FF}})^H \mathbf{U}_{\mathbf{h}} \mathbf{U}_{\mathbf{h}}^H \mathbf{U}_{\mathbf{h}}^{\text{FF}})^{\frac{1}{2}}.$$

- The chordal distance at the Fraunhofer limit is still significant (*i.e.*, 30% of its maximum value).
- $N \rightarrow \infty \Rightarrow d_{\text{ch}}(\mathbf{U}_{\mathbf{h}}, \mathbf{U}_{\mathbf{h}}^{\text{FF}}) = \sqrt{L} \Rightarrow \text{col}(\mathbf{R}_{\mathbf{h}}) \perp \text{col}(\mathbf{R}_{\mathbf{h}}^{\text{FF}})$, allowing large arrays to multiplex multiple users.

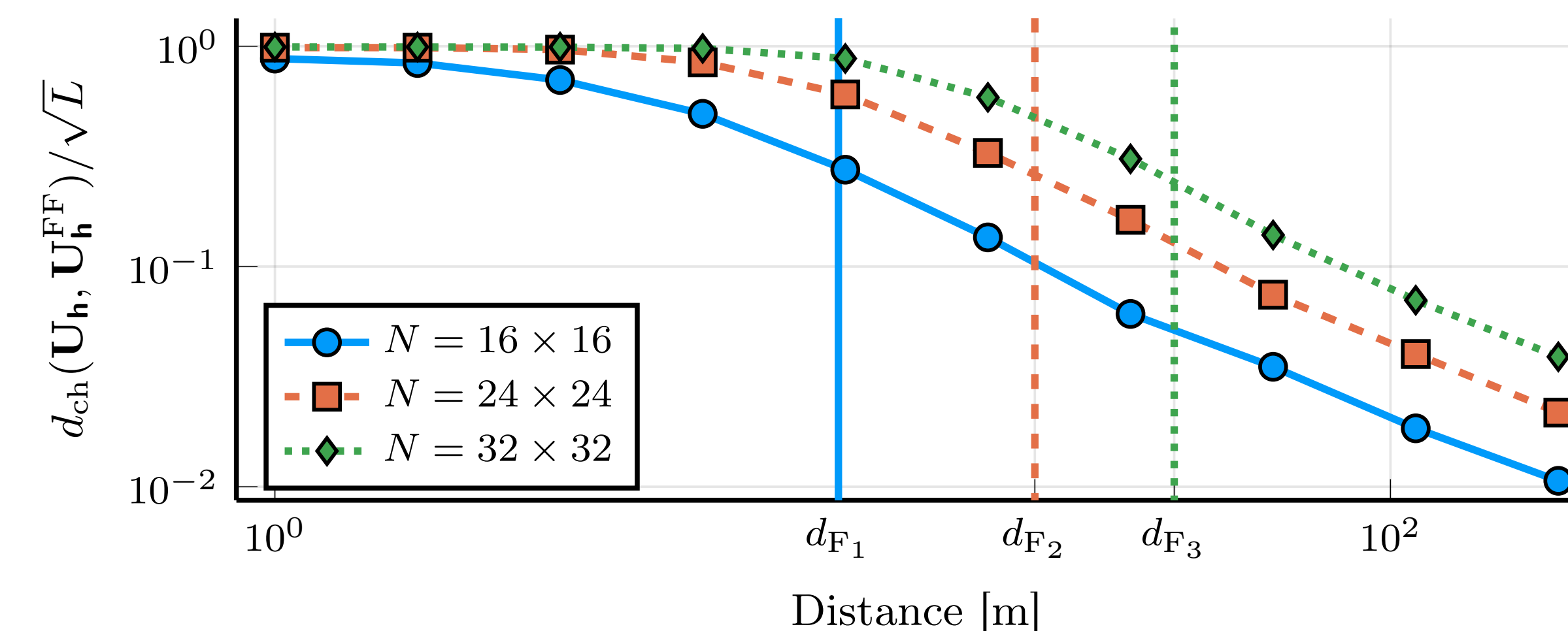


Figure 2. Chordal distance between $\text{col}(\mathbf{R}_{\mathbf{h}})$ and $\text{col}(\mathbf{R}_{\mathbf{h}}^{\text{FF}})$ for $N = 16 \times 16$, $N = 24 \times 24$ and $N = 32 \times 32$ with $L = 10$.

NUMERICAL RESULTS

Single-User Mismatched Mode

- Far-field model severely underestimates performance up to $10 d_F$.
- Higher SER at range due to lost spatial resolution between scatterers.

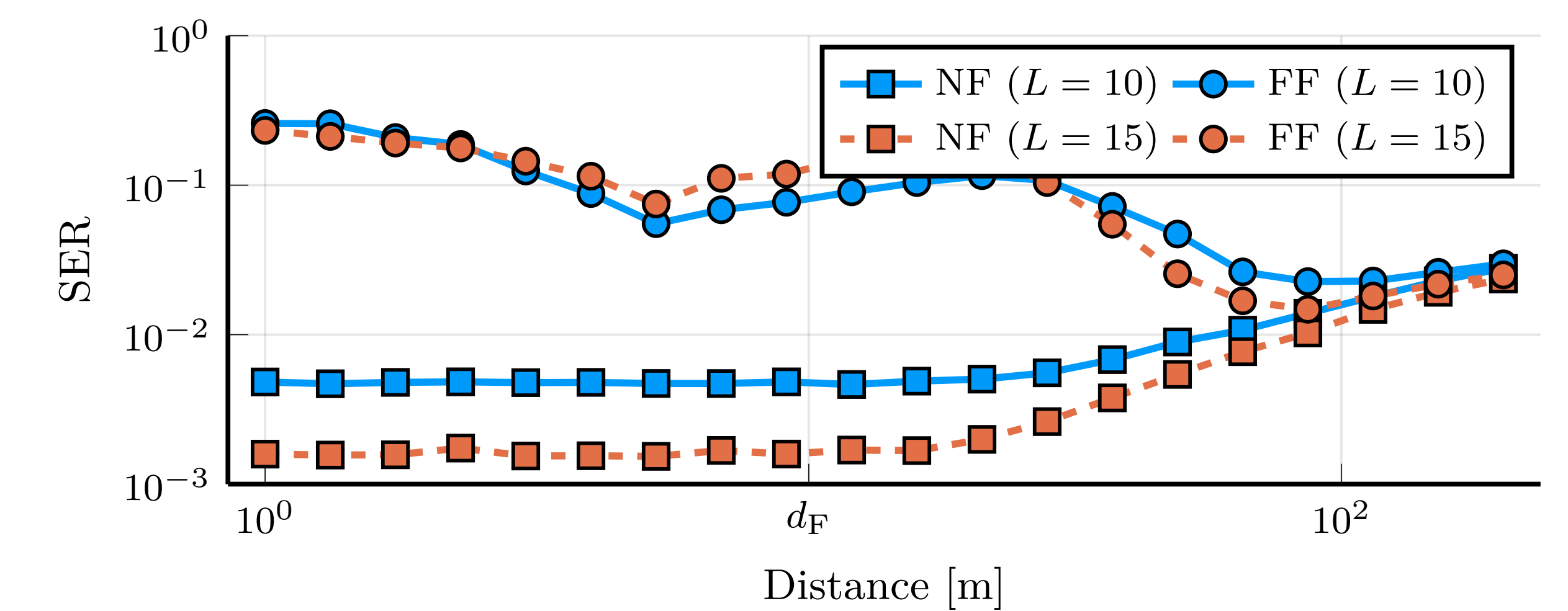


Figure 3. Error probability of a ML detector employing the exact or mismatched model at different distances. The simulation is performed for $\text{SNR} = 20$ dB.

Multiuser Detection

- Single-user SER converges to the optimal detector performance.
- Mismatched detector performs poorly regardless of the antenna count.

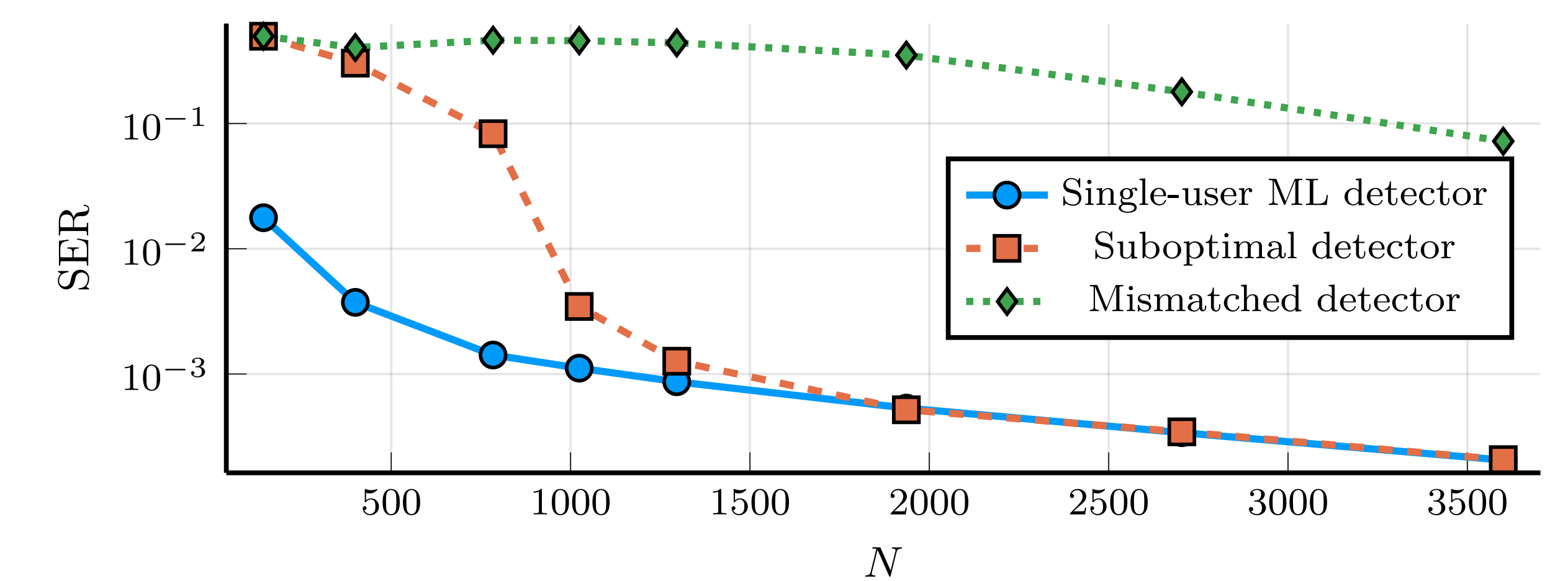


Figure 4. Error probability of the single-user detector in a five users environment for increasing number of antennas. The SINR is 20 dB.

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