

**NYU****TANDON SCHOOL
OF ENGINEERING**

PRIMO: GPU-Accelerated Joint Beamforming and RIS Placement for Outdoor-to-Indoor Coverage at FR1(C) and FR3

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**NYU WIRELESS**

1. Background

> 80%of wireless traffic
is indoors [1]**> 20 dB**building penetration
loss [2, 3]**+8 dB**more loss at FR3
than FR1(C) [3]

❑ **New spectrum:** FR1(C) 6.425–7.125 GHz, FR3 7.125–24.25 GHz

❑ **Problem:** buildings block outdoor signals; indoor DAS is costly

❑ **Idea:** a passive RIS on a nearby building beams through **glass**

2. Research Gap

Gap in prior work

RIS position fixed [4]; placement models ignore wall loss

Classical solvers: slow, or weak under interference

Learning methods must be retrained per site [5]

RIS studies use statistical channels with no walls

This work

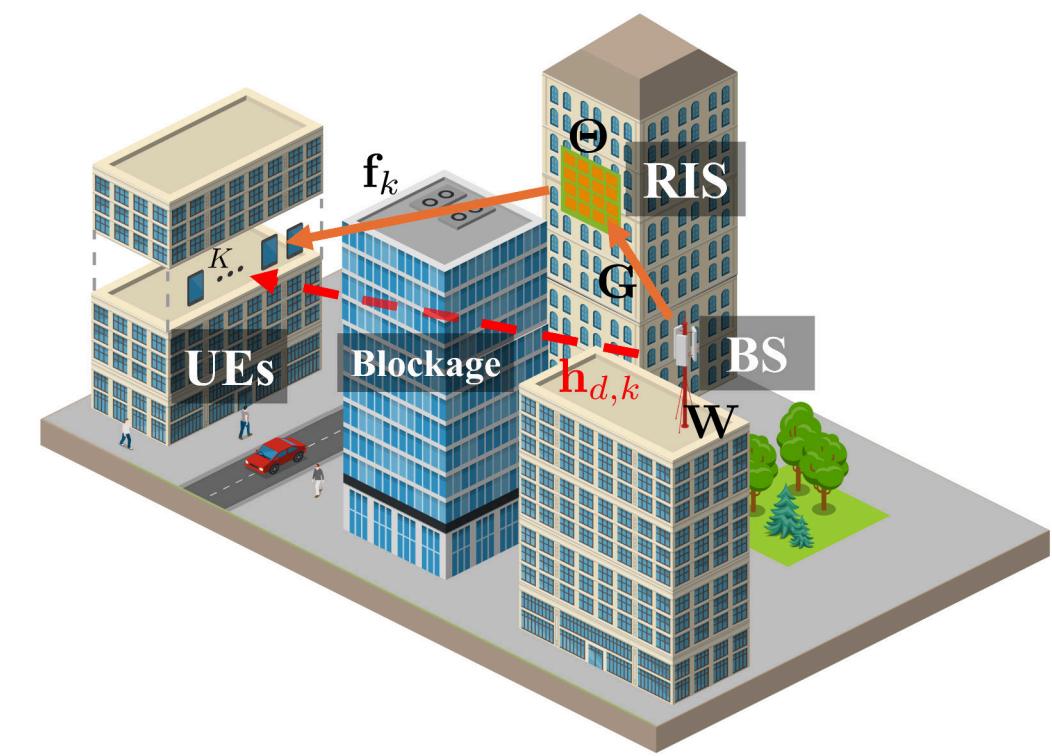
Joint precoding, RIS phases, and RIS position

PRIMO: GPU-parallel, **~100× faster** than AO-EW [4]

Training-free: no retraining

Site-specific ray tracing with measured walls, two bands

3. System Model and Problem



Optimization variables:

❑ **W:** BS precoder (M antennas)

❑ **θ :** RIS phases (N elements)

❑ **d :** RIS position (10 on a 40 m track)

❑ **Objective:** max-min user rate

$\mathbf{G} : \text{BS} \rightarrow \text{RIS}, \mathbf{f}_k : \text{RIS} \rightarrow \text{user}$

$\Theta = \text{diag}(e^{j\theta_1}, \dots, e^{j\theta_N})$

SINR

$$\gamma_k = \frac{|\mathbf{h}_{d,k}^H + \mathbf{f}_k^H \Theta \mathbf{G}|^2}{\sum_{j \neq k} |\mathbf{h}_{d,k}^H + \mathbf{f}_k^H \Theta \mathbf{G}|^2 + \sigma^2}$$

Shannon capacity

$$R_k = \log_2(1 + \gamma_k) \text{ bps/Hz}$$

Problem

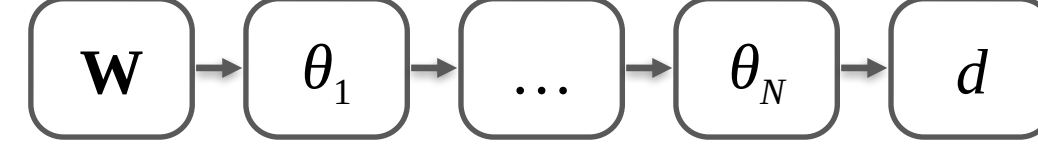
$$(P1) : \max_{\mathbf{W}, \theta, d} \min_k R_k(\mathbf{W}, \theta, d)$$

$$\text{s.t. } \text{tr}(\mathbf{W}^H \mathbf{W}) \leq P, \quad |e^{j\theta_n}| = 1, \quad 0 \leq d \leq L$$

4. Proposed Method: PRIMO

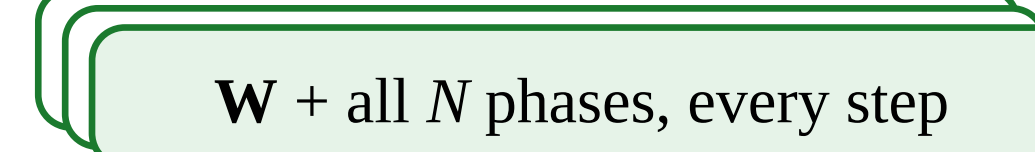
PRIMO = Parallel RIS Min-Rate Optimization

AO-EW [4]: one block at a time



N updates in sequence: slow

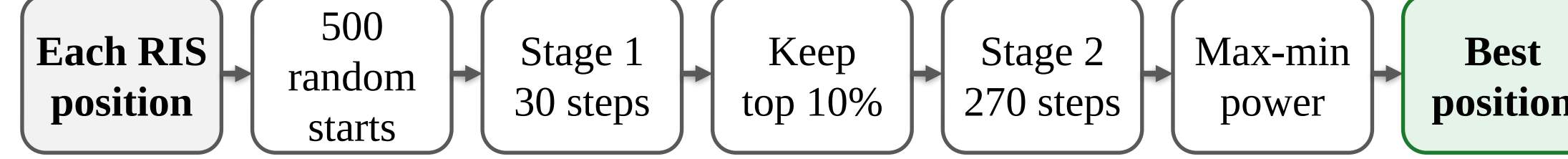
PRIMO: all at once, in parallel



500 random starts batched on one GPU

$$\mathcal{L}(\theta) = -\frac{1}{\alpha_{\text{sm}}} \log \left(\sum_{k=1}^K e^{-\alpha_{\text{sm}} R_k(\theta)} \right), \quad \min_k R_k - \frac{\log K}{\alpha_{\text{sm}}} \leq \mathcal{L} \leq \min_k R_k$$

Log-sum-exp: differentiable lower bound of the minimum user rate



❑ **Softmax weights:** gradient focuses on the worst user

❑ **Wirtinger gradient + Adam:** all N phases per step

❑ **RZF precoder W:** refreshed at every step

Joint
W, θ , d together

Scalable
6400 RIS elements

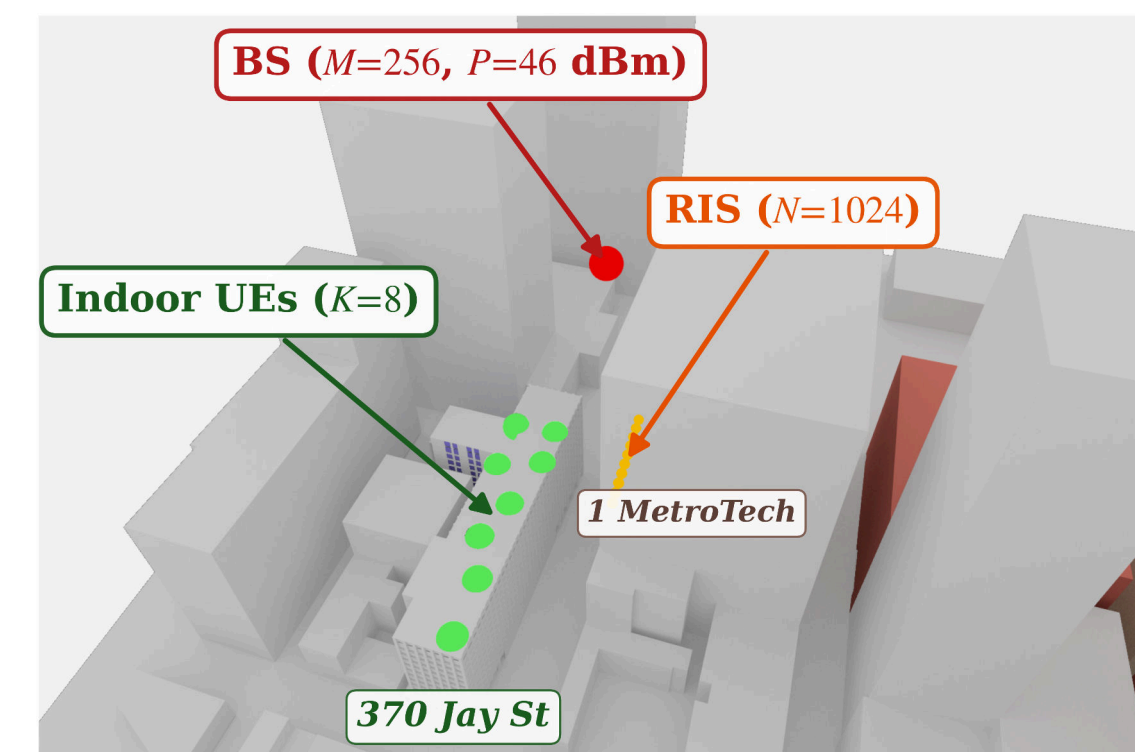
Fair
max-min user rate

Training-free
no retraining

100× faster
500 starts, one GPU

Real-time
2 ms warm start

5. Ray-Tracing Setup



❑ **Real geometry:** MetroTech 3D twin [7]

❑ **Measured walls:** concrete 20 cm, glass 12 mm [2, 3]

❑ **Calibrated RT [6]:** reflection, refraction, diffraction, ≤ 4 bounces

❑ **Real heights:** BS 38 m, RIS 45 m, users 44.5 m

❑ **Same aperture:** BS M 256 $\rightarrow$ 1600, RIS N 1024 $\rightarrow$ 6400 (6.25×)

❑ **Parameters:** BS 46 dBm; 20 MHz + 7 dB NF $\rightarrow$ noise $\sigma^2 = -94$ dBm; $K = 4-20$

❑ **Assumed:** perfect CSI, continuous phases, ideal coding (no link-level sim)

6. Results

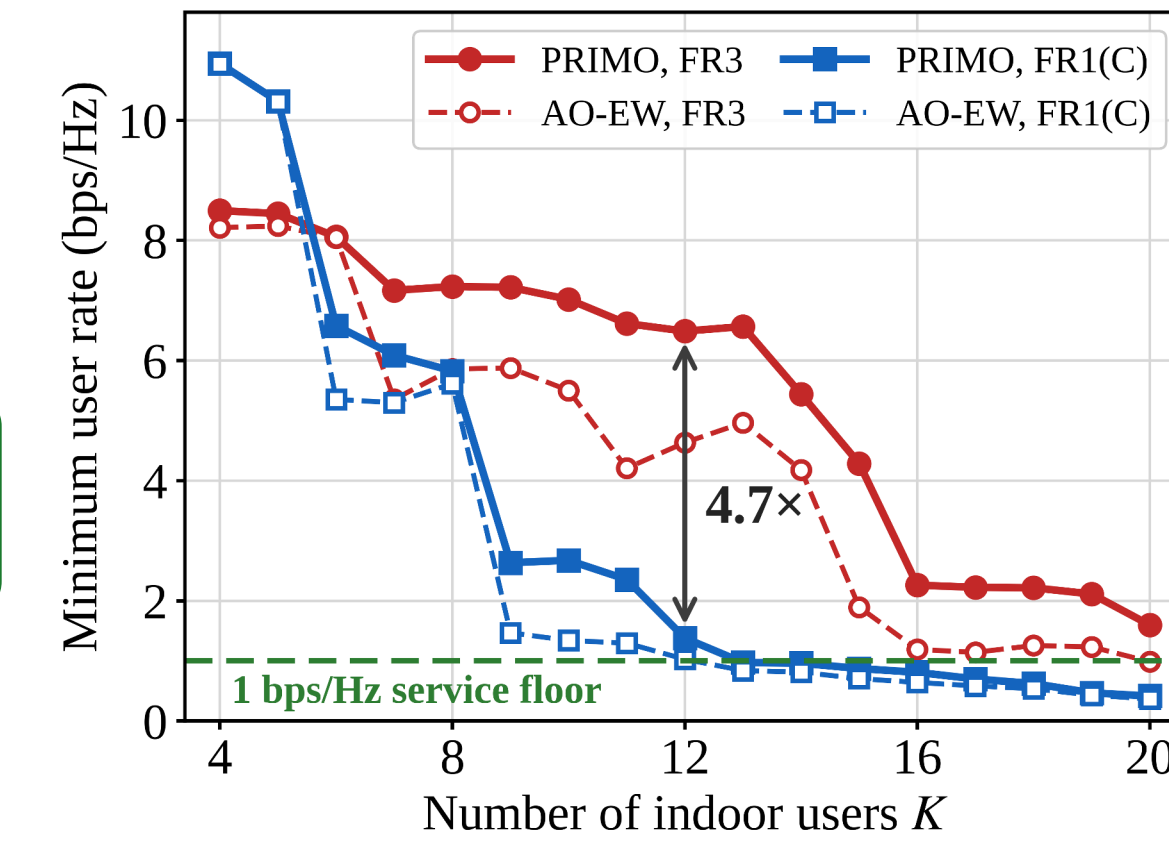
Evaluation protocol

❑ **Users:** K served at once; the K strongest of a 9th-floor pool

❑ **All methods:** optimize $\mathbf{W}, \theta, d$ on the same ray-traced channels

❑ **Metric:** worst user's spectral efficiency, $\log_2(1 + \text{SINR})$ bps/Hz

❑ **Runs:** PRIMO mean of 5 trials; baselines 30 random starts; RTX 4090

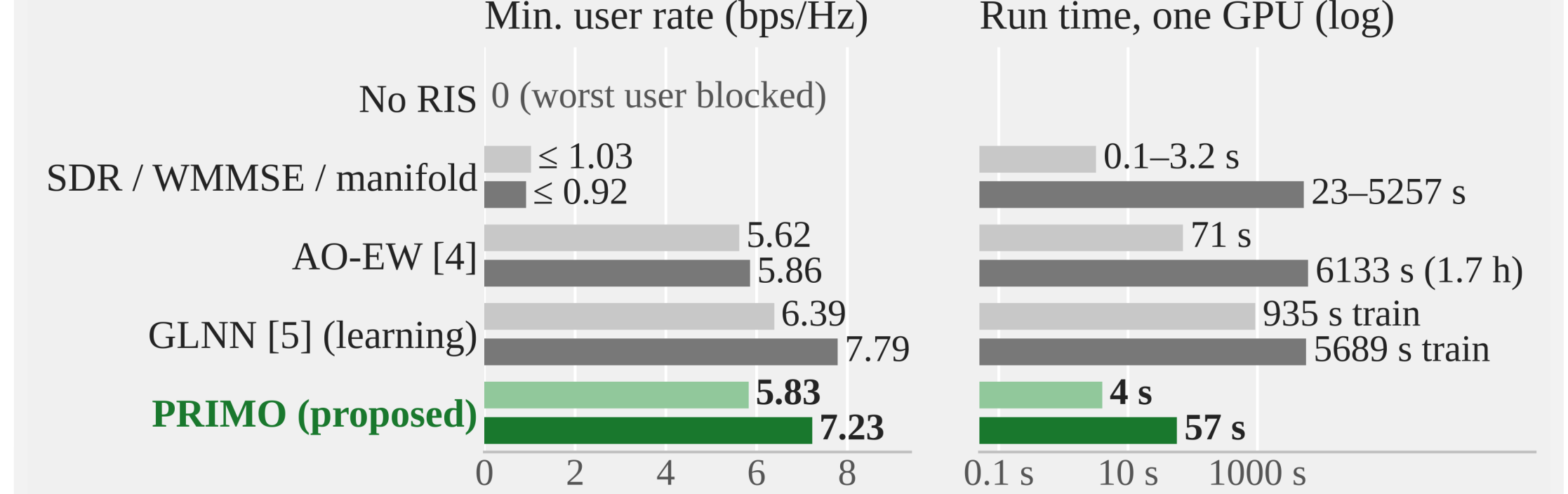
**100× faster**

than AO-EW: 57 s vs. 6133 s

1.9× ratemin. rate vs. AO-EW, FR3, $K = 16$ **4.7× rate**FR3 vs. FR1(C), $K = 12$ **+92% users**

served above 1 bps/Hz: 23 vs. 12

All methods, $K = 8$



7. Conclusion and Impact

Key finding

PRIMO: **1.9×** higher minimum rate, **100× faster**

FR3 serves **92%** more indoor users than FR1(C)

Phase tuning cannot compensate a poor RIS position

Impact

Real-time RIS control: no training, 2 ms updates

FR3 pays off in densely occupied buildings

Optimize RIS placement once per building

A low-cost outdoor RIS + PRIMO brings FR3 coverage to indoor users

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