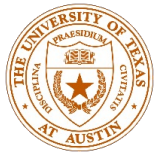
Association for Computing Machinery

MobiCom 2024



GPMS: Enabling Indoor GNSS Positioning using Passive Metasurfaces

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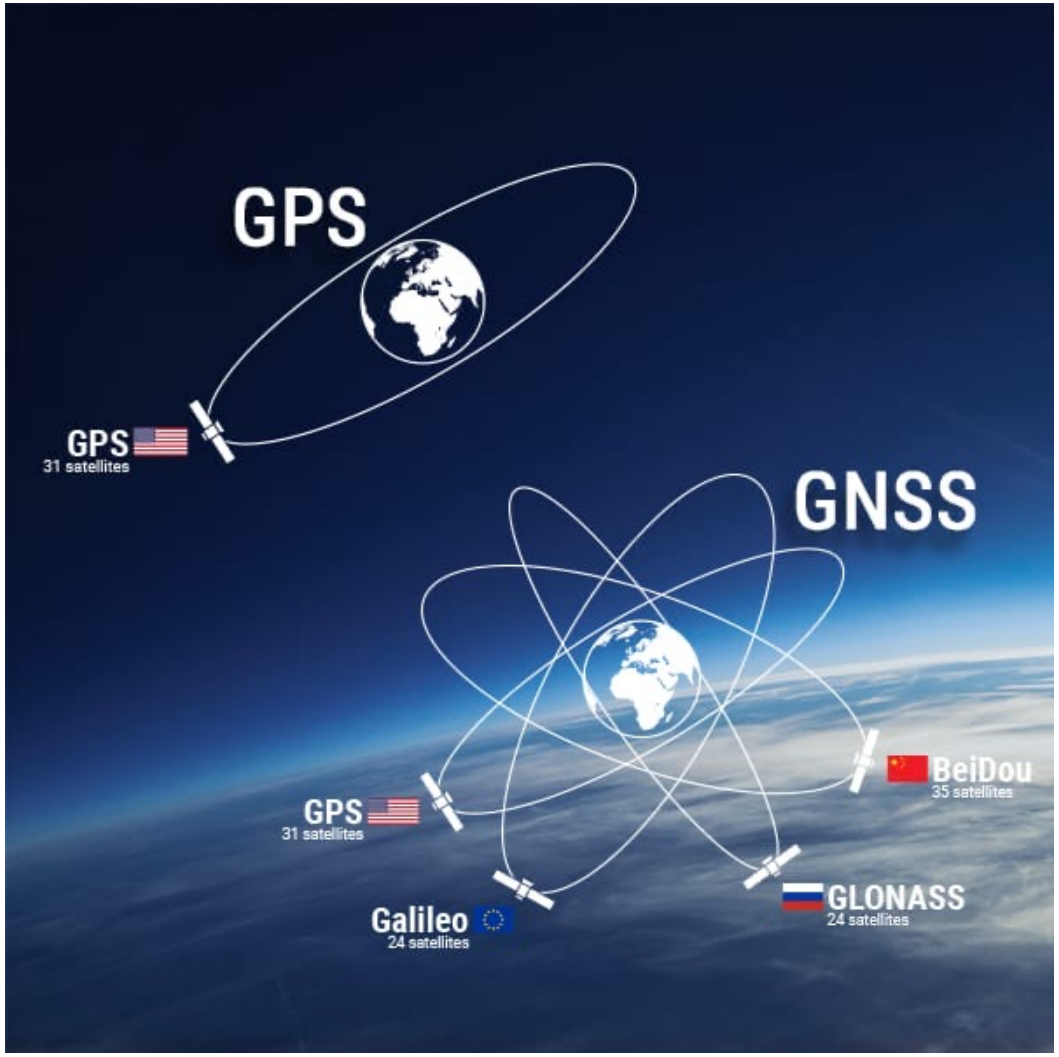
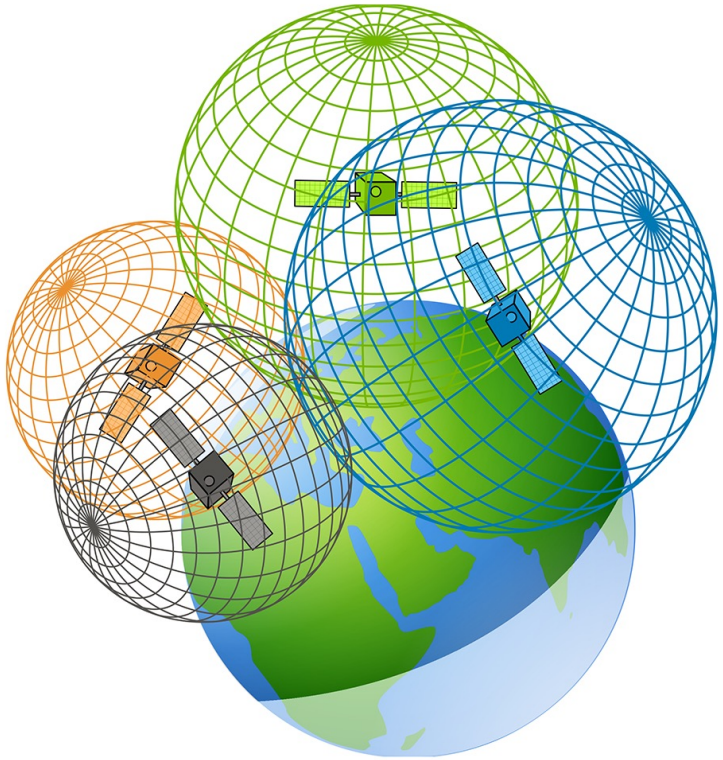
Shanghai Jiao Tong University[†] **Microsoft Research Asia[¶]** **UT Austin***

Central South University [‡] **Columbia University[♦]** **Yale University[₣]** **Tsinghua University[€]**

Global Navigation Satellite System (GNSS)





4 satellites -> (X,Y, Z, T)

Localization error (outdoor)
~1 meter

When GNSS comes to indoors

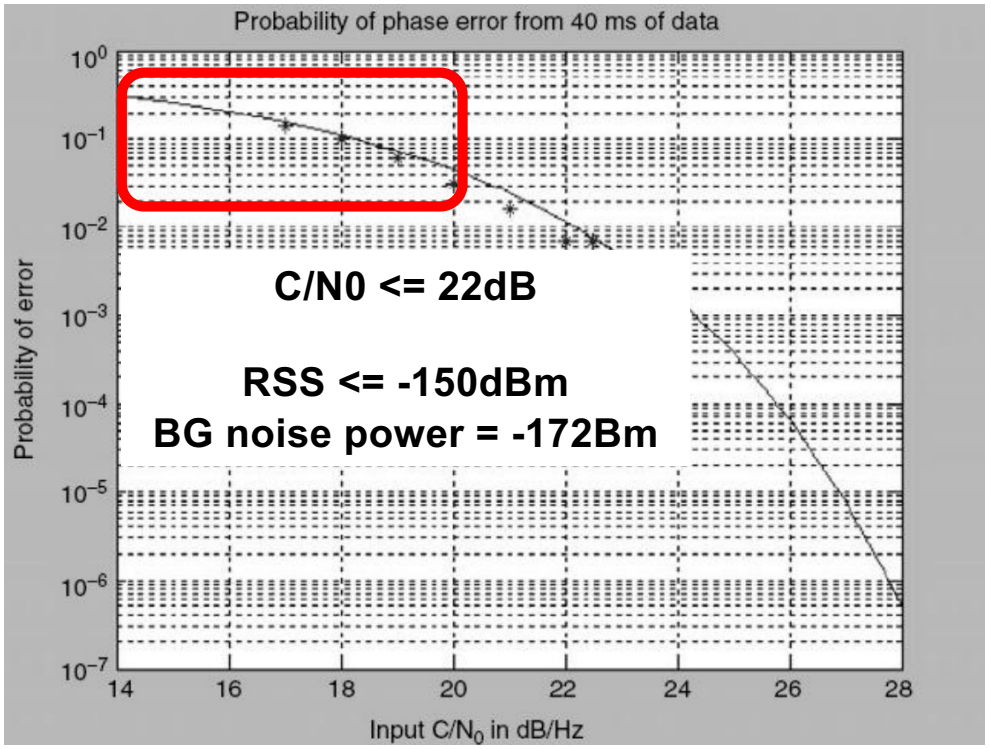
500 W

GPS signal outdoors:

~10^{-16} W ≈ -130 dBm

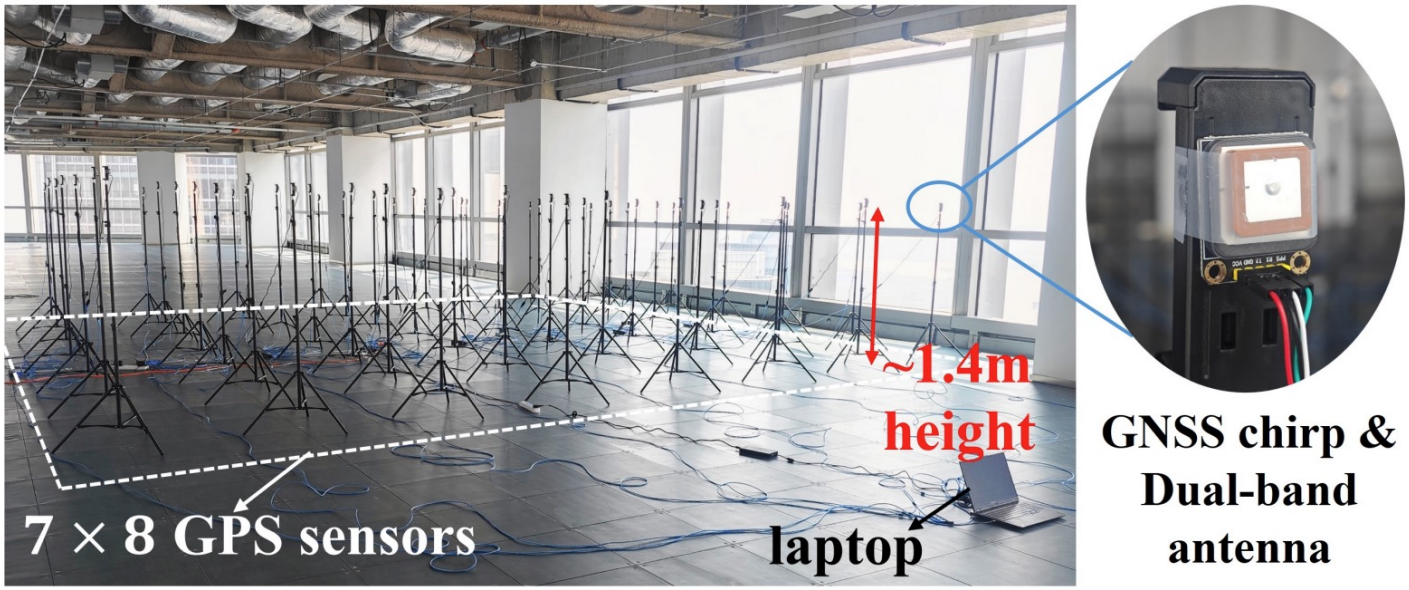
GPS signal indoors:

~10^{-18} W ≈ -150 dBm

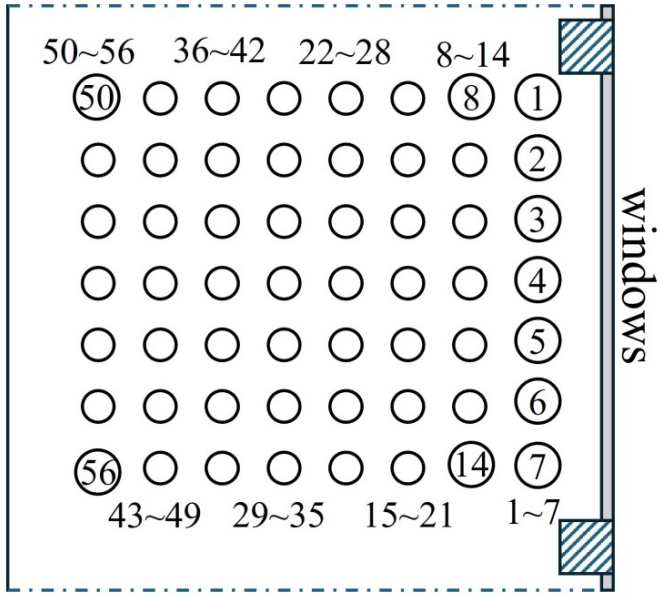


We CANNOT decode GNSS signals with such a low signal strength indoor.

Indoor GNSS measurements

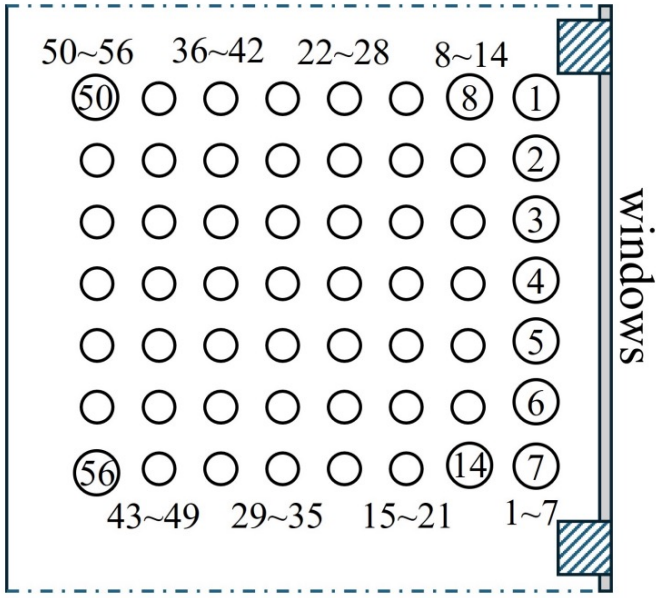


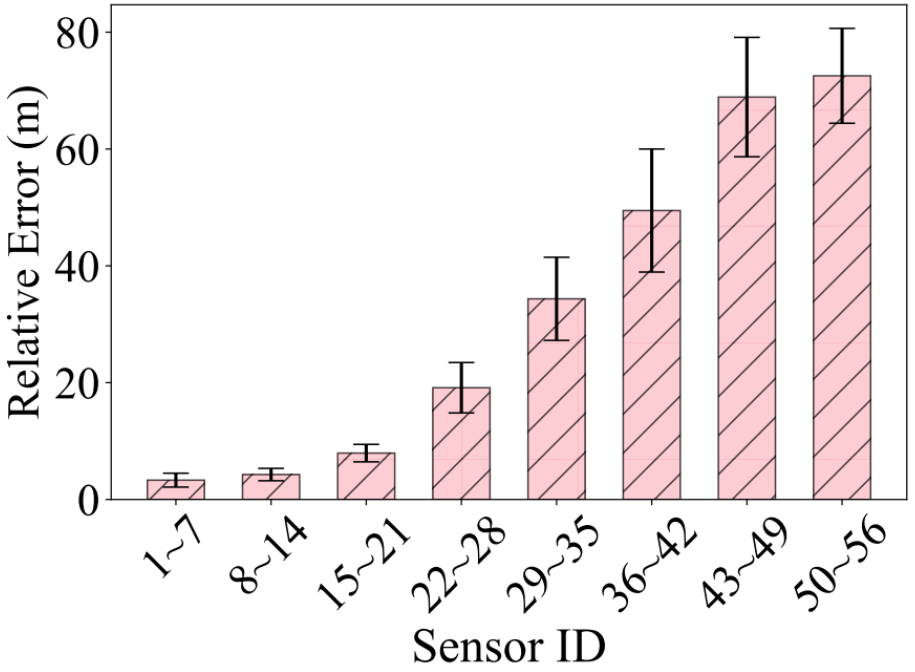
Real-world measurement setup



Top view

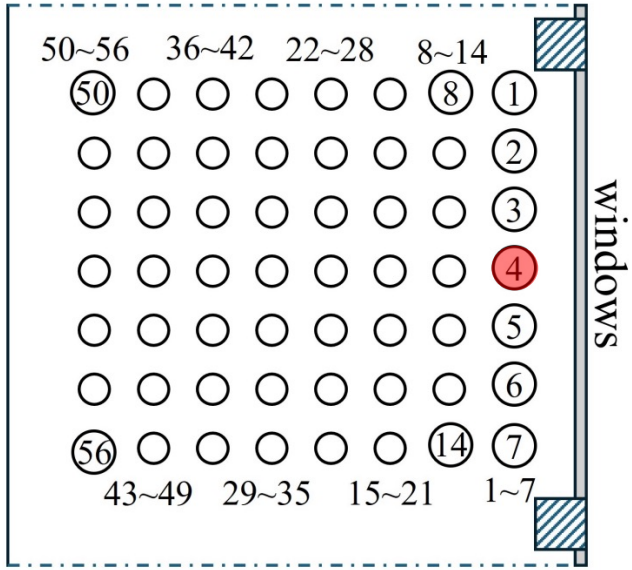
Indoor GNSS measurements



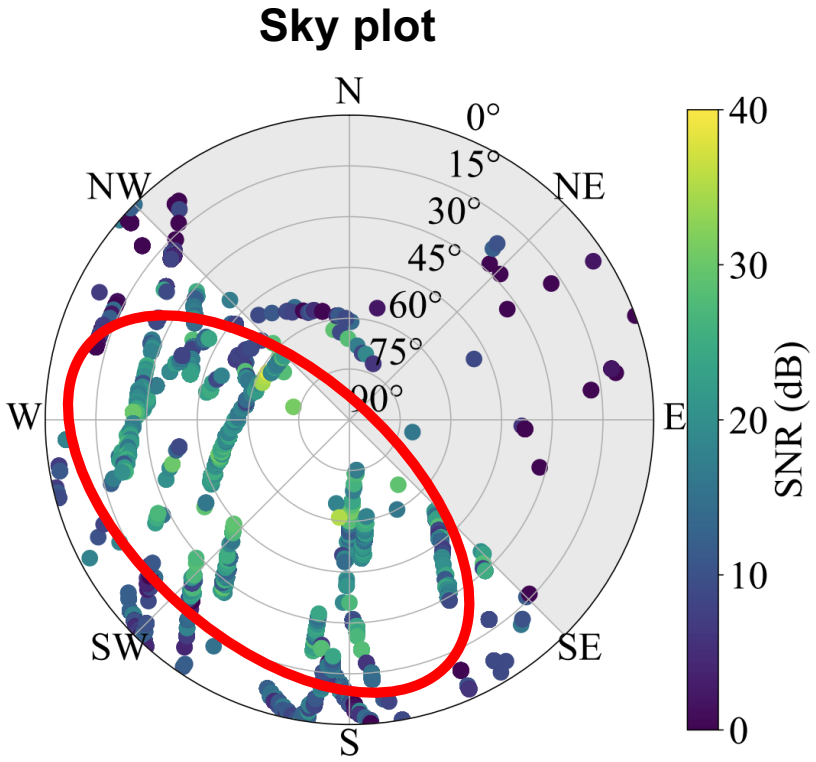


The closer to the window, the smaller the positioning error

Indoor GNSS measurements



All received GPS traces over 24 hours



At the position near the window, the greater the angle of incidence, the greater the SNR of the received signal.

Why low SNR of GNSS signals indoors

Shopping mall (indoor environment)

Two mainly reasons:

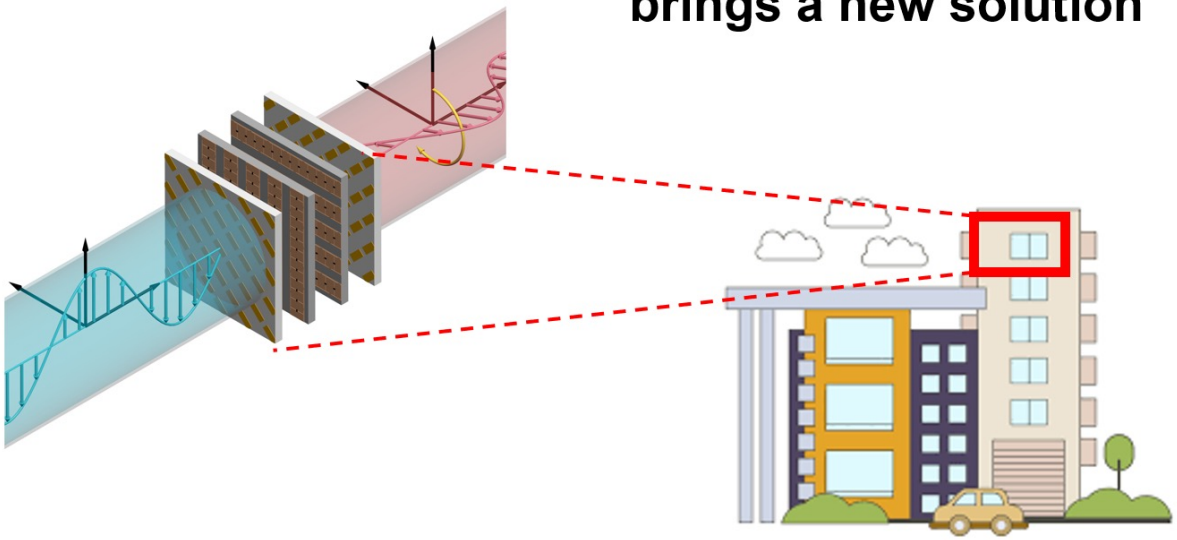
Can we make GNSS serve for indoor positioning?

2. Severe attenuation of GNSS signals by walls

Our idea: Design passive metasurface to enhance GNSS signals indoors

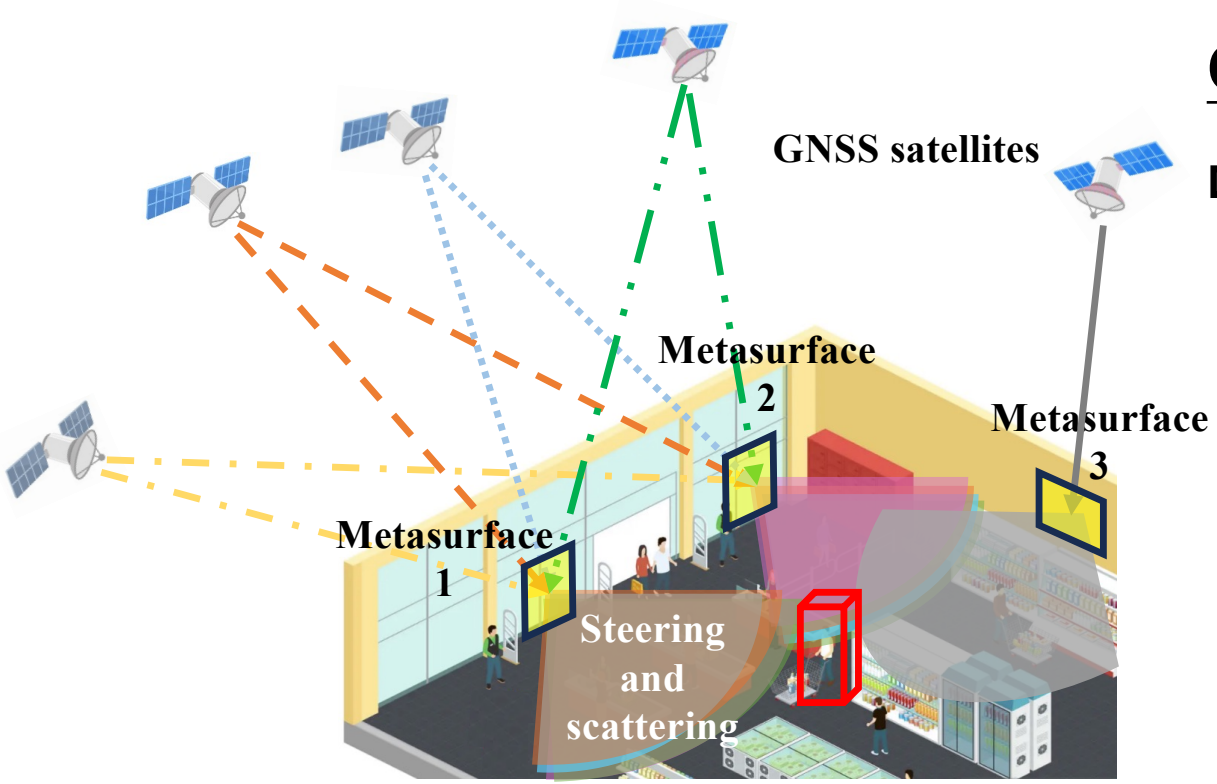
Shopping mall (indoor environment)

EM metasurface brings a new solution



- **Passive** (no power needed)
- **Easy to deploy**
- **Cheap** (martial cost of metasurface< $5/m^2)

Our idea: Effective steering and scattering



Deploy metasurfaces on the windows and walls

Challenges:

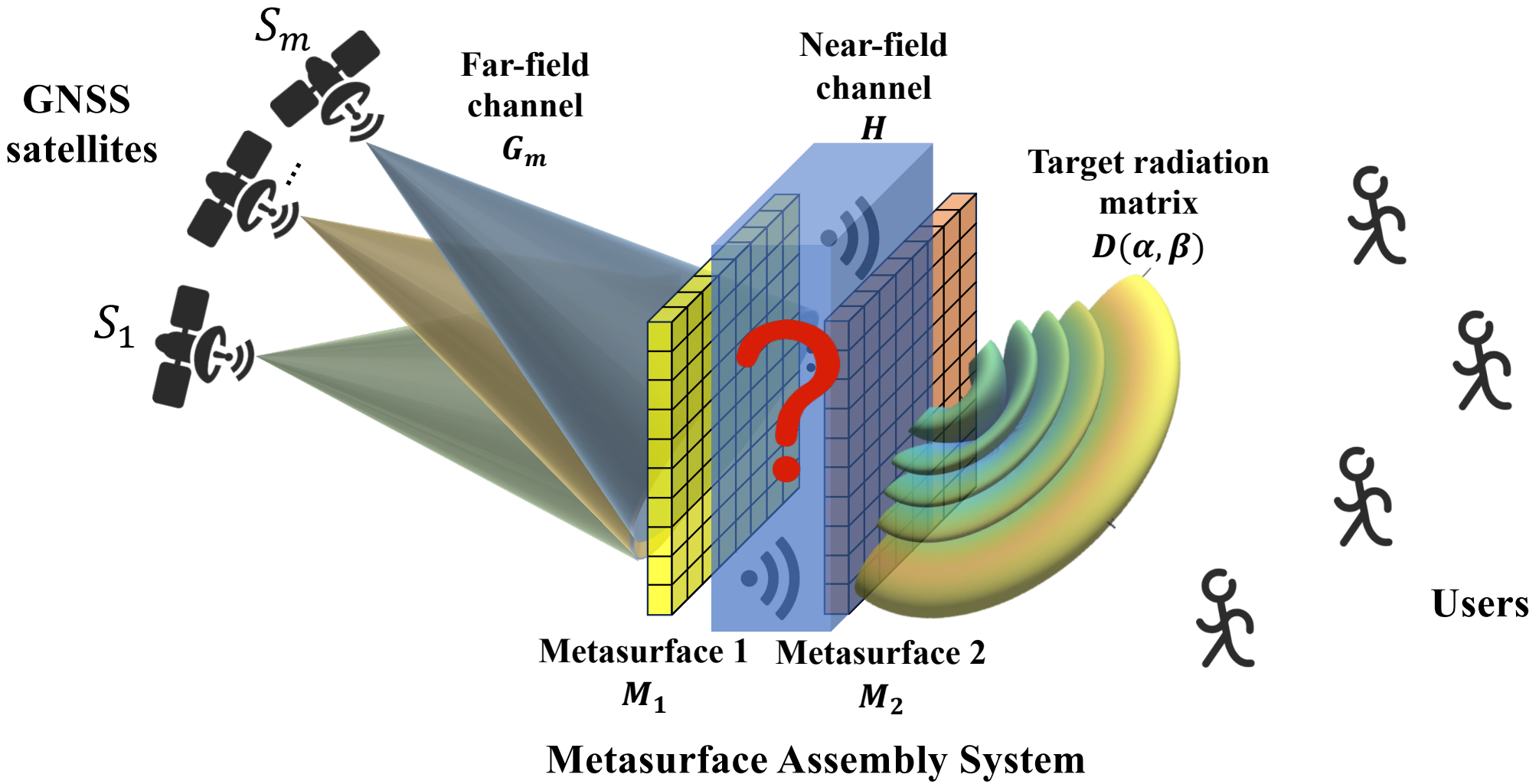
- **Metasurface design**
  - GNSS satellites are moving, and have different incident angles

    Powerful steering for any incident angles
  - Indoor users are also moving and everywhere

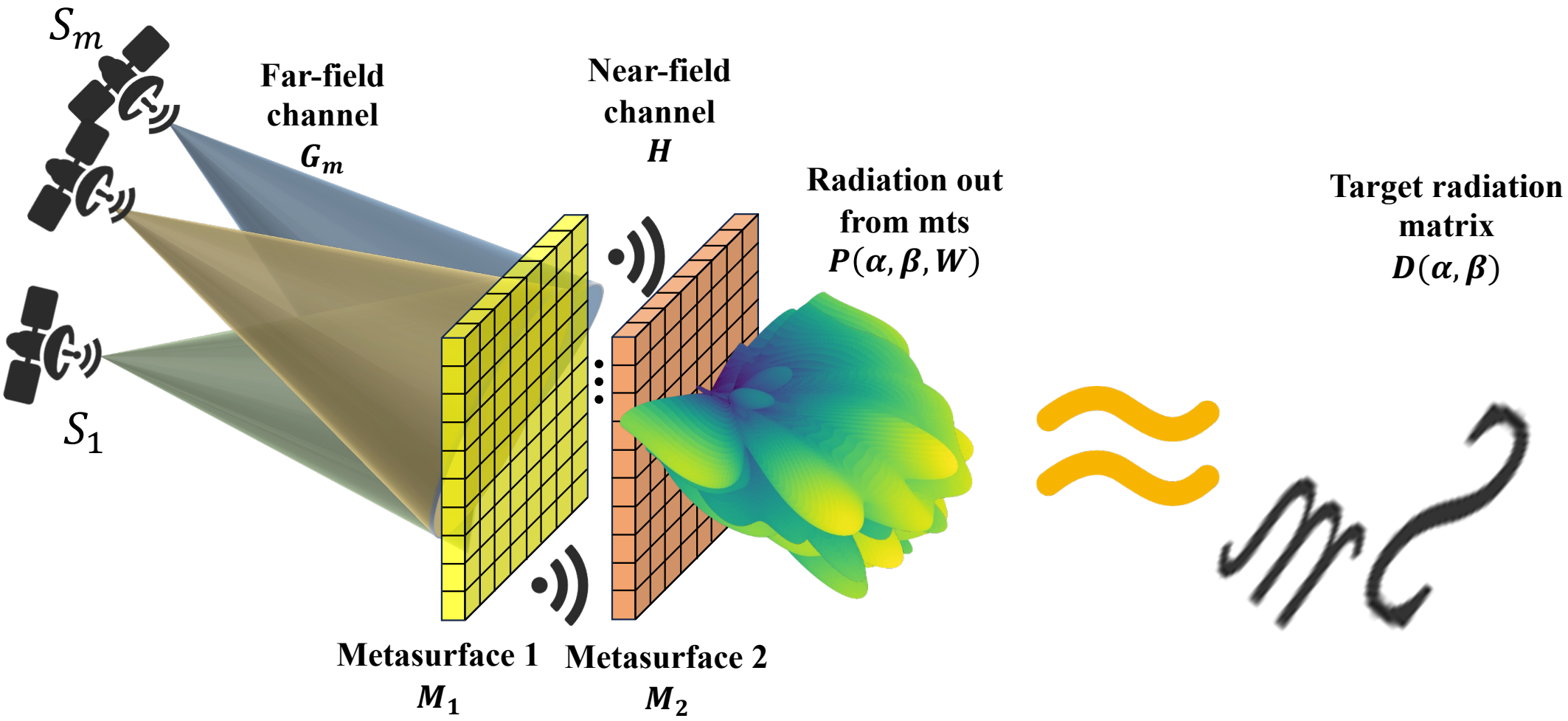
    Powerful scattering for maximum coverage
- **Indoor positioning algorithm design**
  - Satellite -> mts -> user

    Novel indoor positioning compatible with deployed metasurfaces

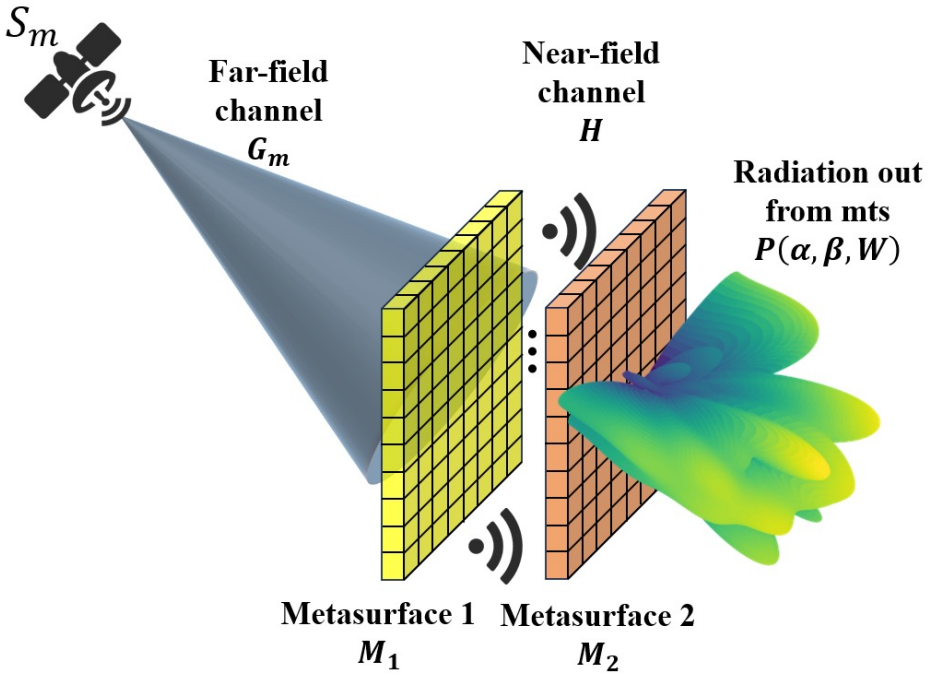
Macroscopic: Metasurface design (phase map) for GNSS



Macroscopic: Metasurface design (phase map) for GNSS



Macroscopic: Metasurface optimization model



Element weights radiated out from metasurface 2:

$$W = G_m M_1 H M_2$$

Radiation pattern radiated out from metasurface 2:

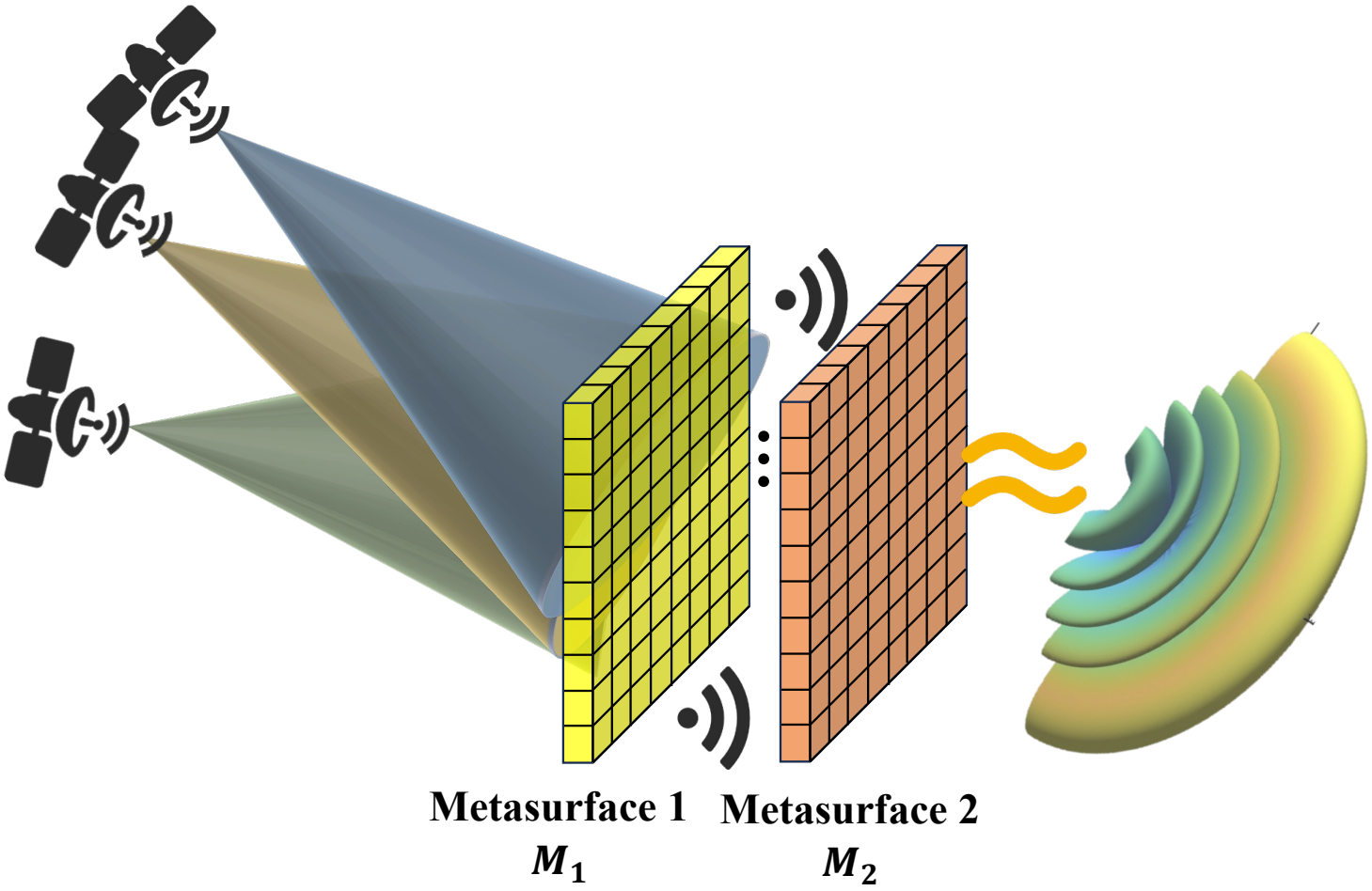
$$P(\alpha, \beta, W) = \frac{AF(\alpha, \beta, W)}{max(AF(\alpha, \beta, W))}$$

where $$AF(\alpha, \beta) = \sum_{i=1}^{N} \sum_{j=1}^{N} w_{i,j} \cdot e^{-j\left(2\pi \frac{d_x}{\lambda}(i-1)\sin\alpha\cos\beta + 2\pi \frac{d_y}{\lambda}(j-1)\sin\beta\right)}$$

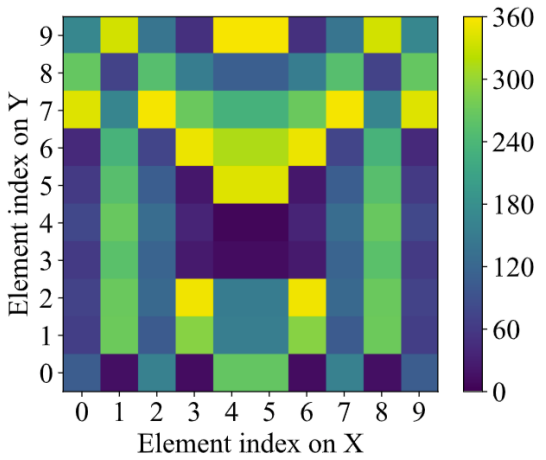
Optimization Problem: **for all GNSS satellite signals, we determine the optimal M_1 and M_2 to make the radiation patterns from the metasurfaces close to the target radiation pattern.**

$$\min \sum_{m=1}^{K} \iint \left(P(\boldsymbol{\alpha}, \boldsymbol{\beta}, \boldsymbol{W}) - D(\boldsymbol{\alpha}, \boldsymbol{\beta})\right)^2 d\alpha d\beta$$

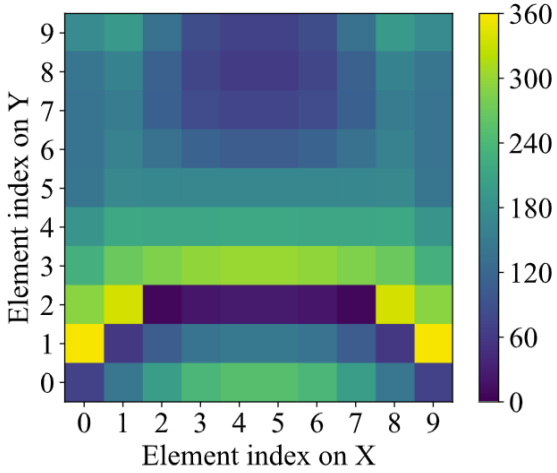
Optimized metasurface design



Metasurface 1's phasemap

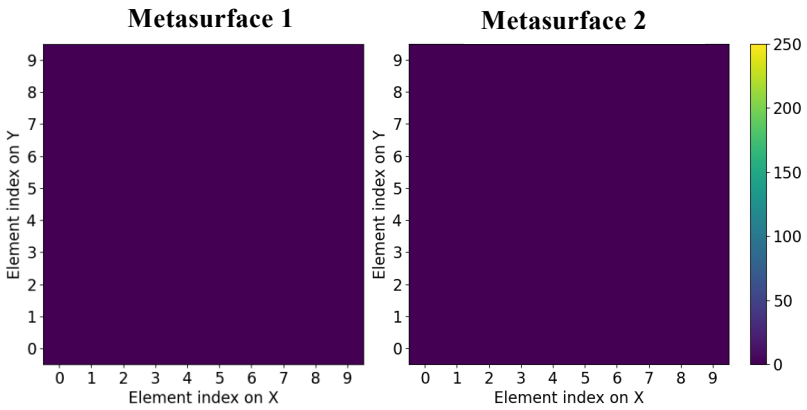


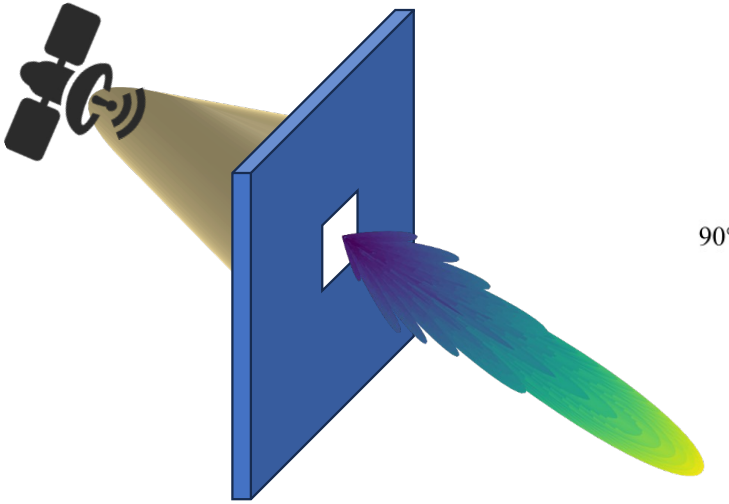
Metasurface 2's phasemap

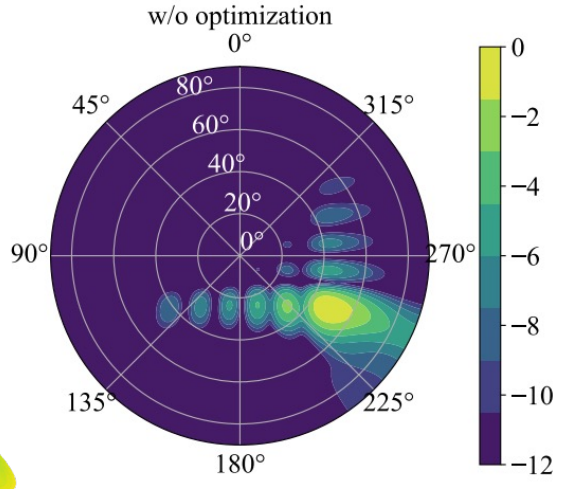


Comparison of not using optimized mts vs. using optimized mts

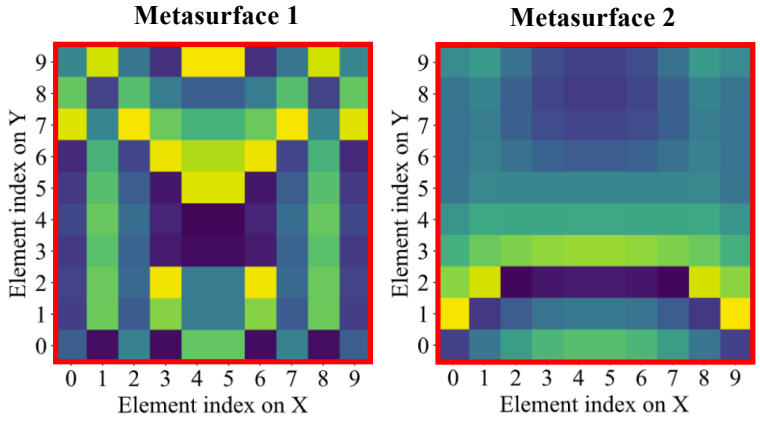
No optimization

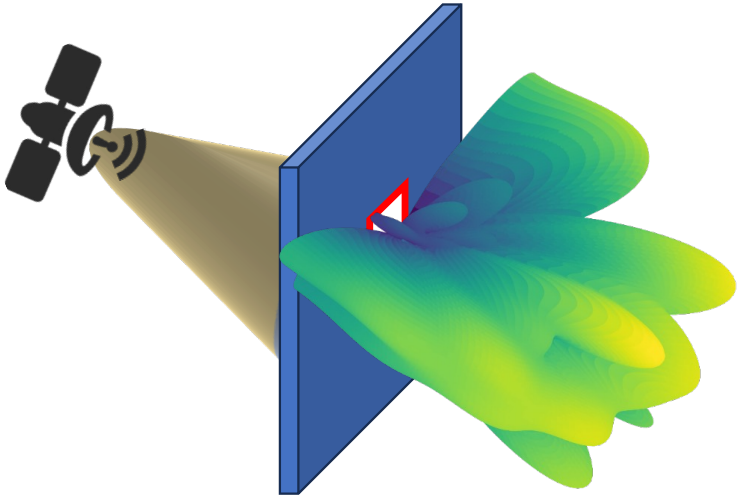


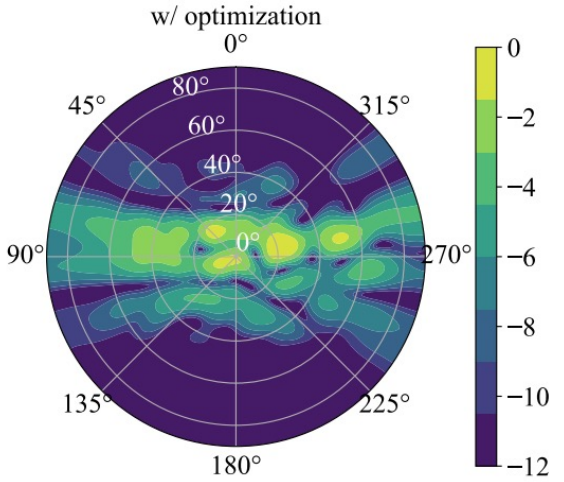




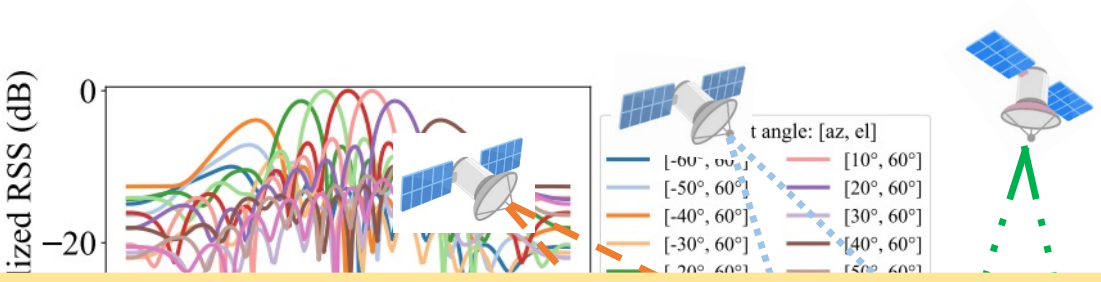
Optimization results



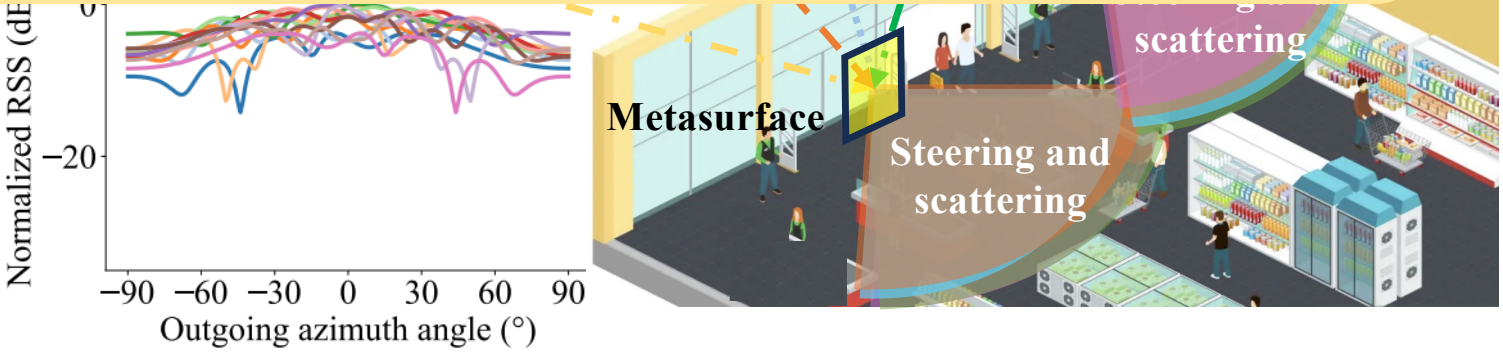




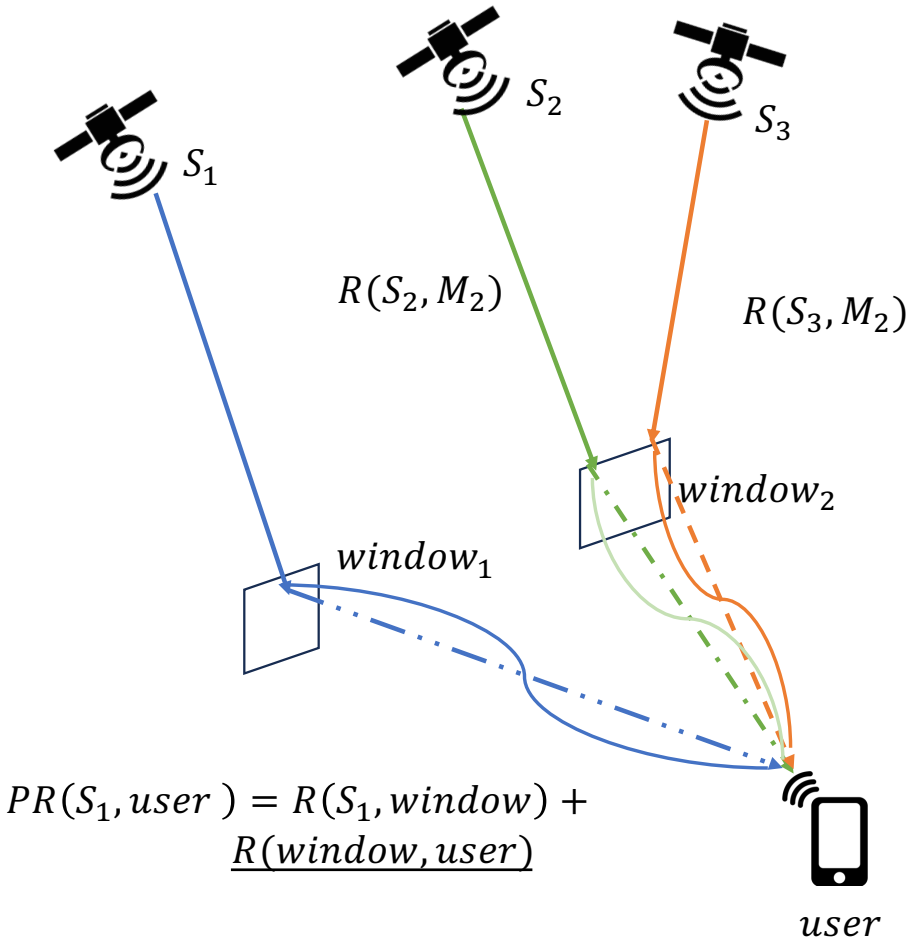
Simulation: scattering and steering performance

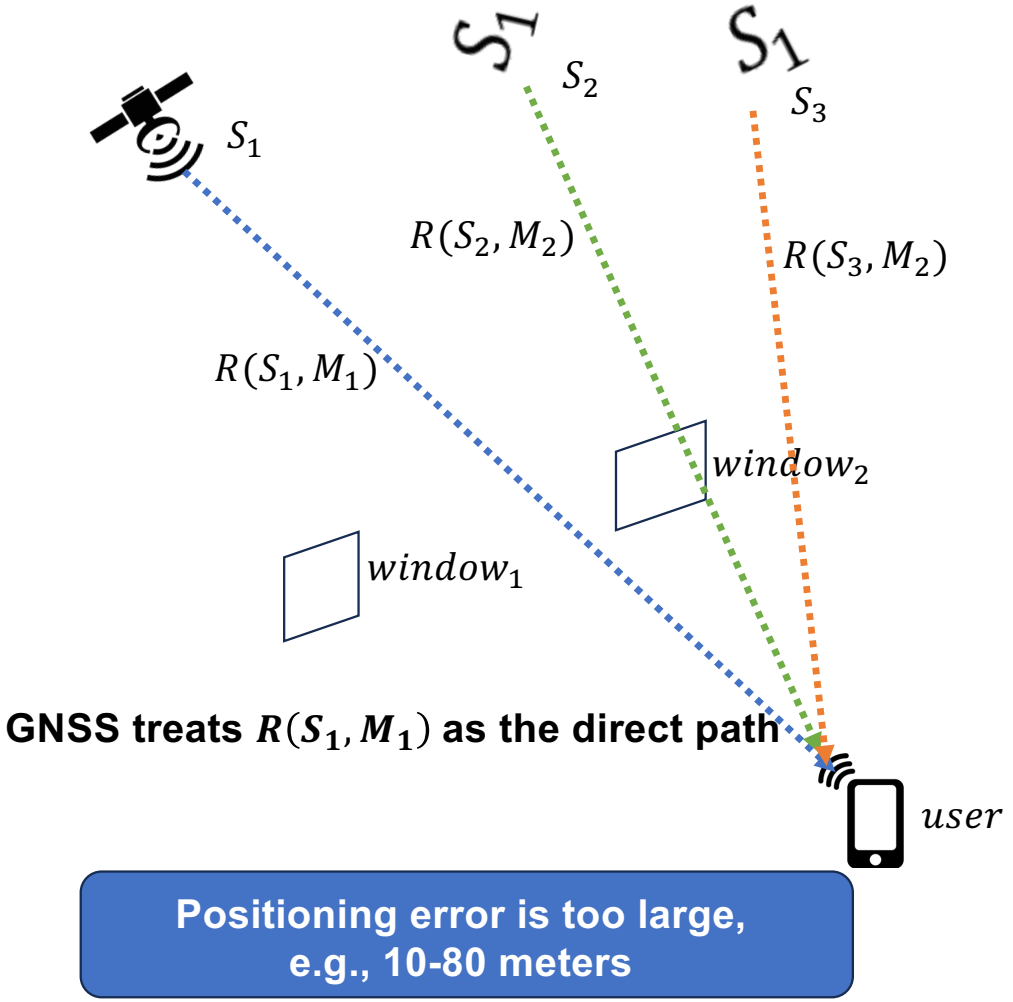


How to design an indoor positioning algorithm that is COMPATIBLE with metasurfaces?

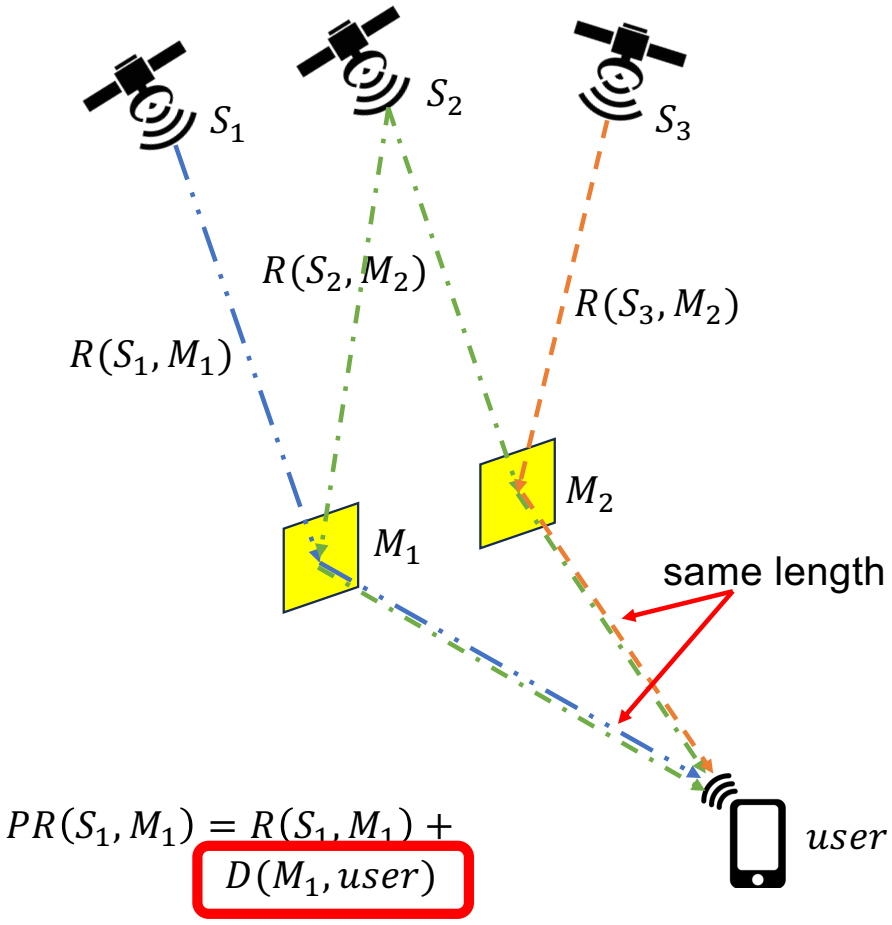


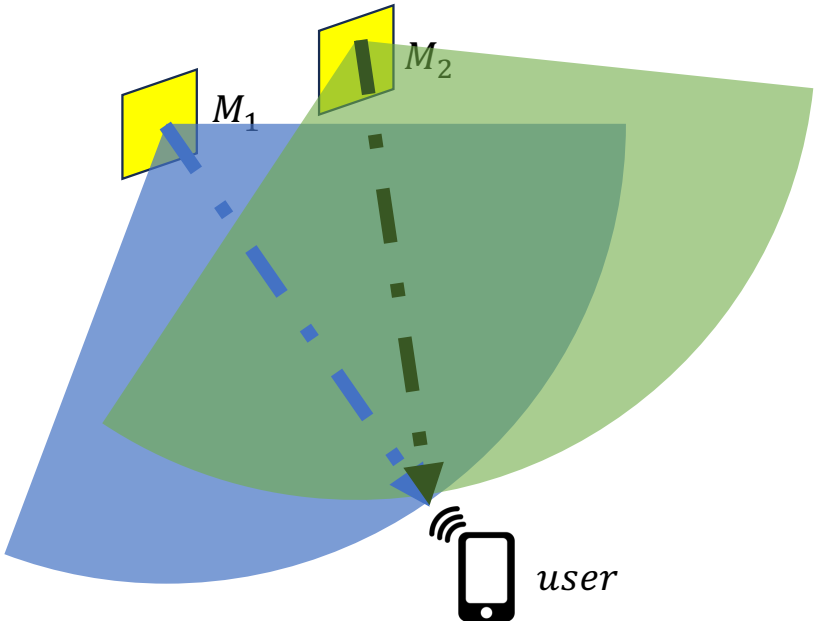
GNSS-based Indoor Positioning



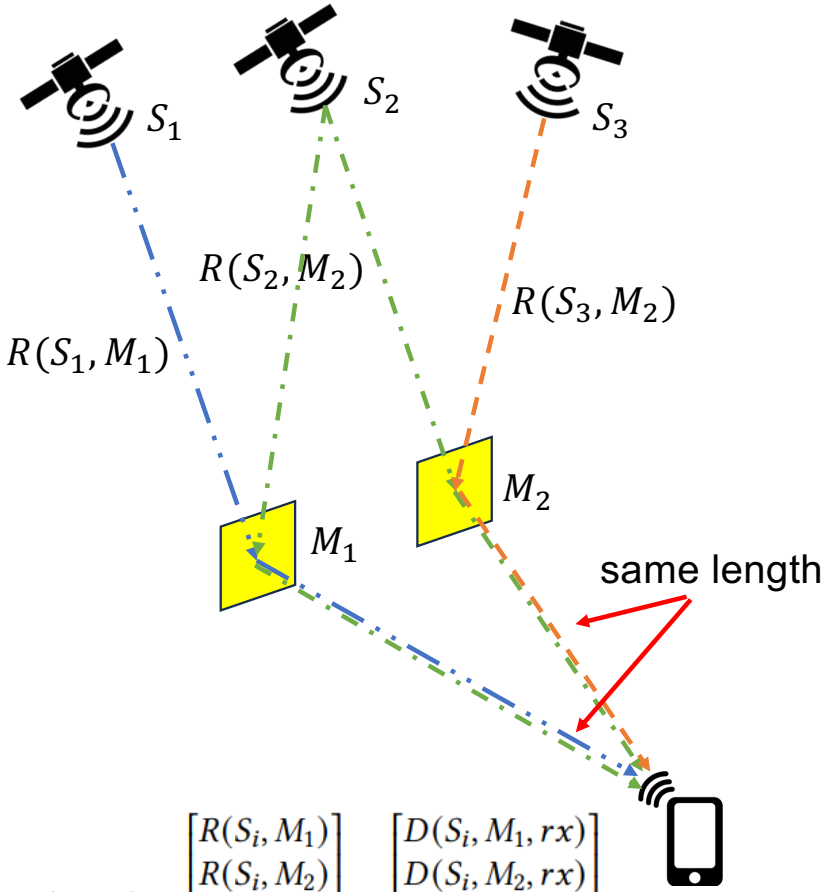


GNSS-based Indoor Positioning with Metasurfaces

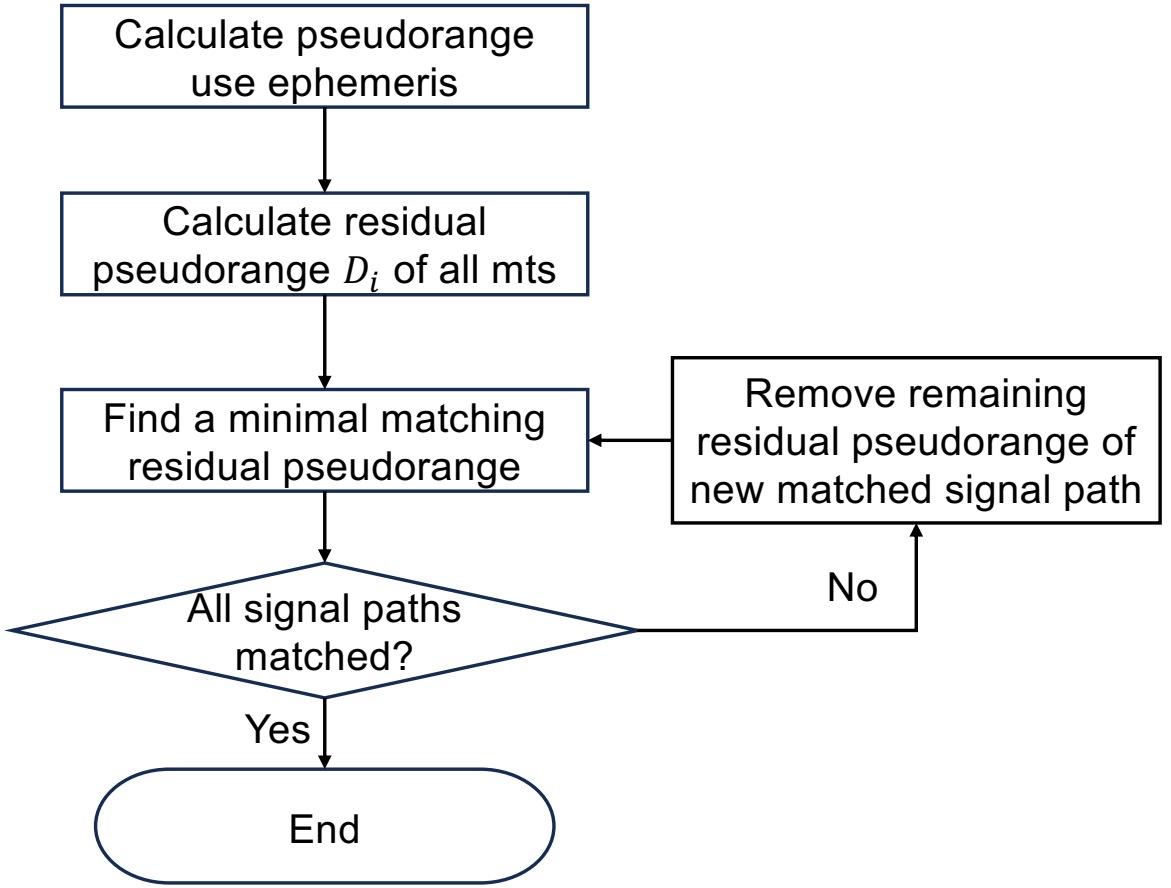




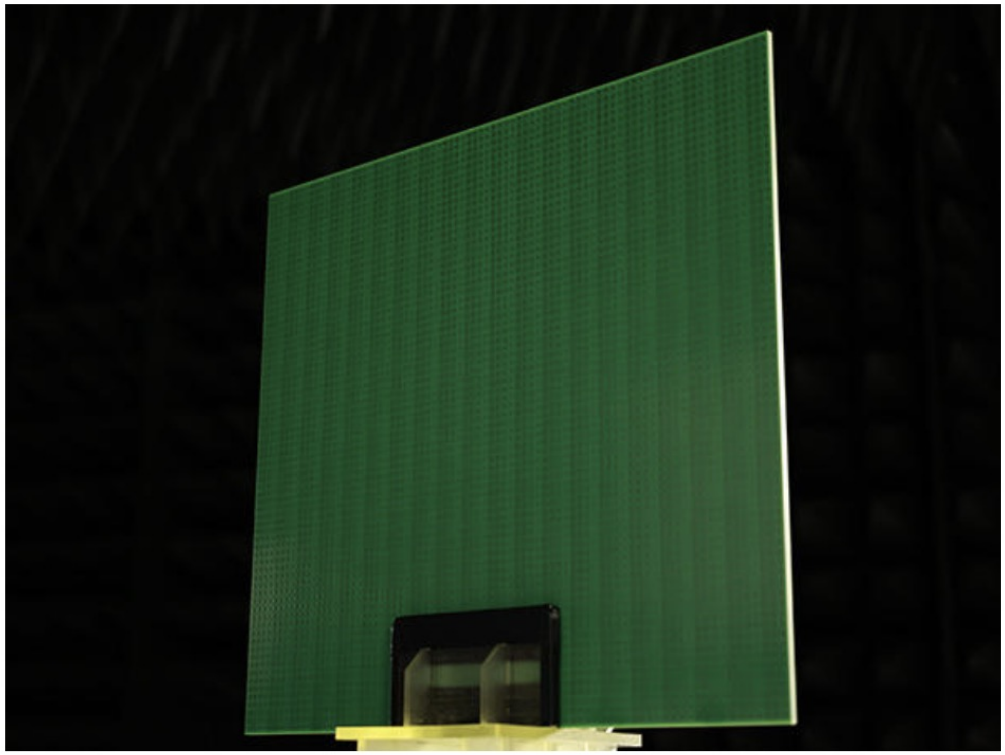
GNSS-based Indoor Positioning Alg. with Metasurfaces



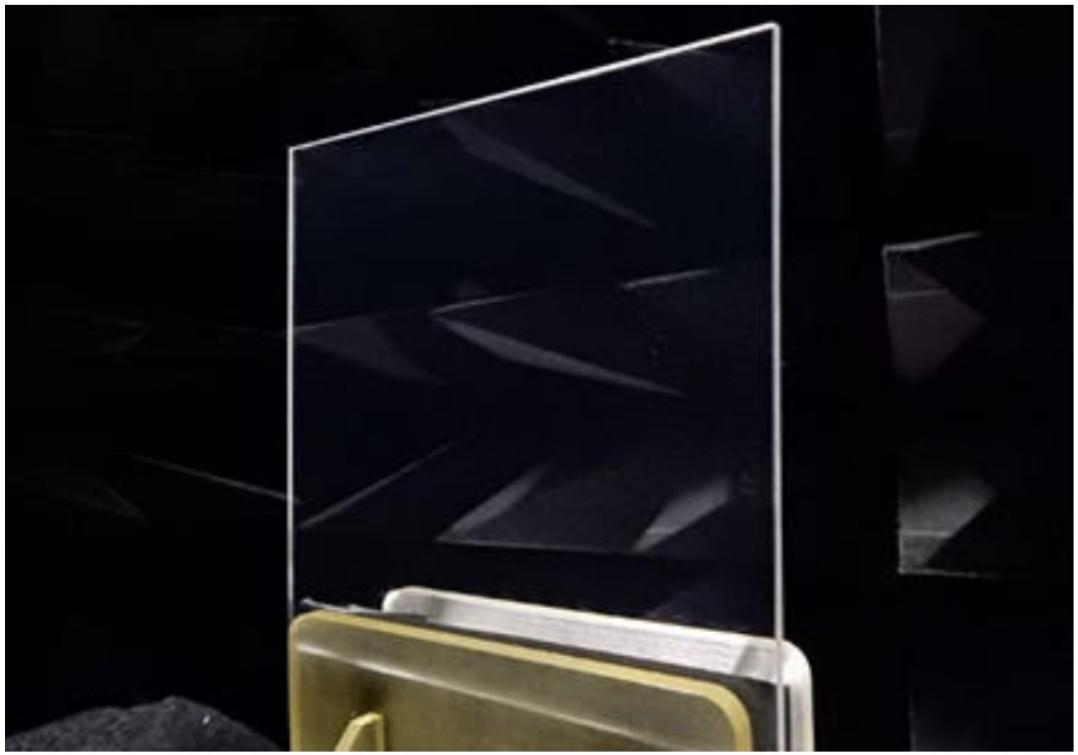
$$D_i = PR(S_i, rx) - \begin{bmatrix} R(S_i, M_1) \\ R(S_i, M_2) \\ \vdots \\ R(S_i, M_j) \end{bmatrix} = \begin{bmatrix} D(S_i, M_1, rx) \\ D(S_i, M_2, rx) \\ \vdots \\ D(S_i, M_j, rx) \end{bmatrix}$$



Experiment Setup and Metasurface Fabrication



Transmissive Metasurface (Prototype)

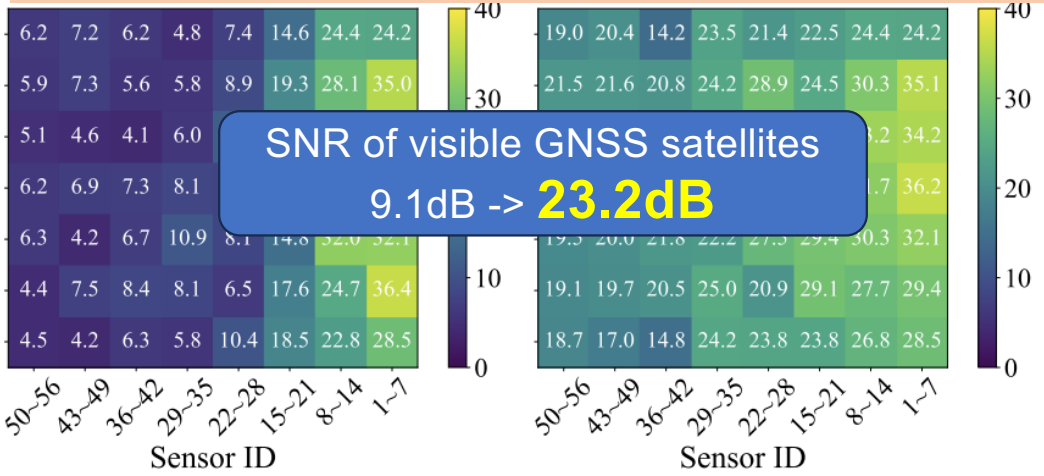


Transparent Transmissive Metasurface (Prototype)

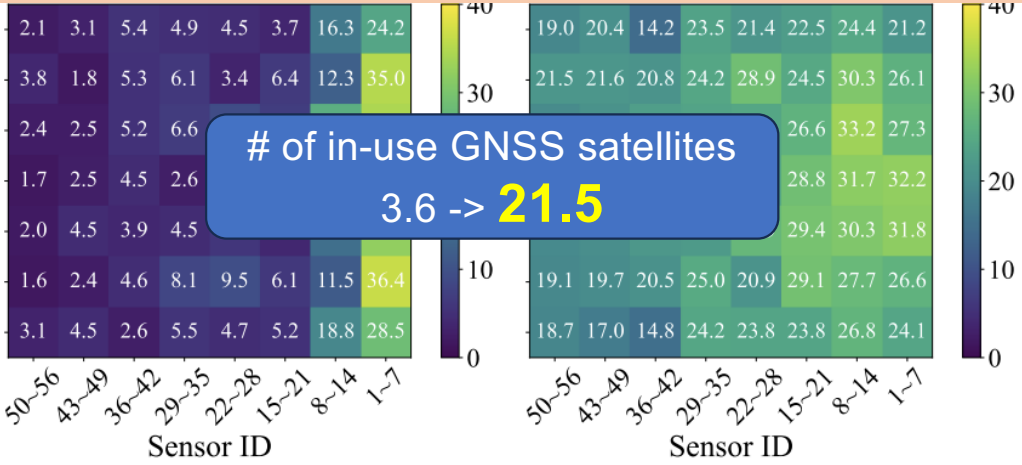
https://global.kyocera.com/newsroom/news/2022/000526.html

Metasurface performance on indoor coverage

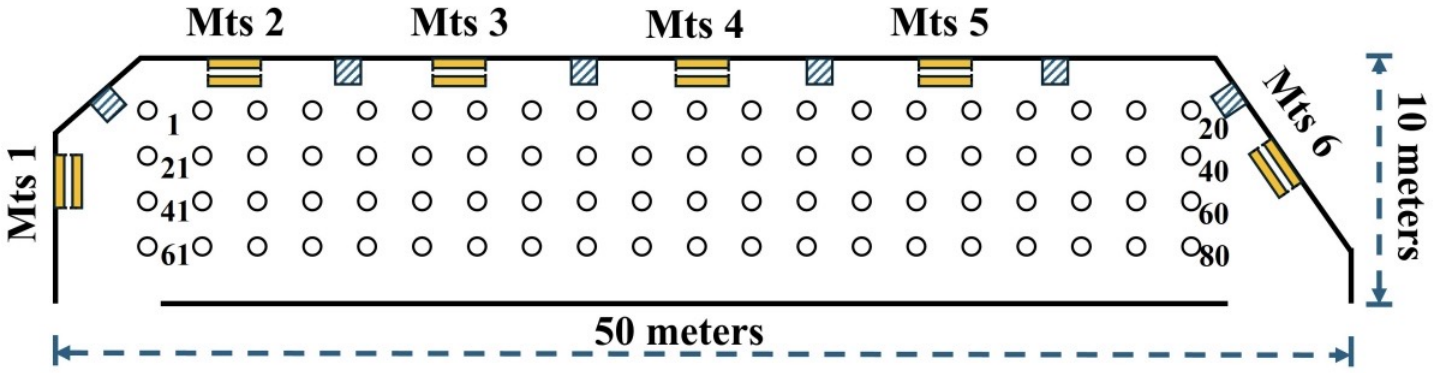
Comparison of the SNR of received GNSS satellites



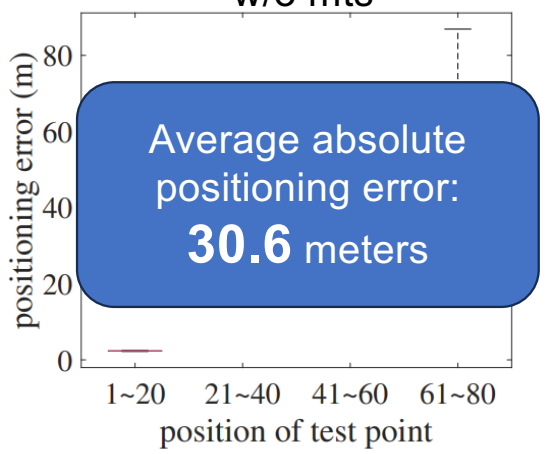
Comparison of the number of in-use GNSS satellites



Indoor positioning performance

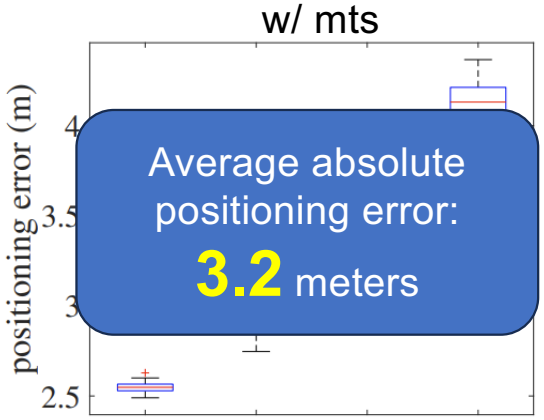


w/o mts



Average absolute positioning error: **30.6** meters

w/ mts



Average absolute positioning error: **3.2** meters

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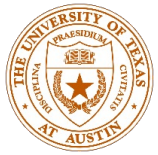

Thanks for listening!