

2023/09/23

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# Performance Analysis for RIS Assisted Wireless Sensing

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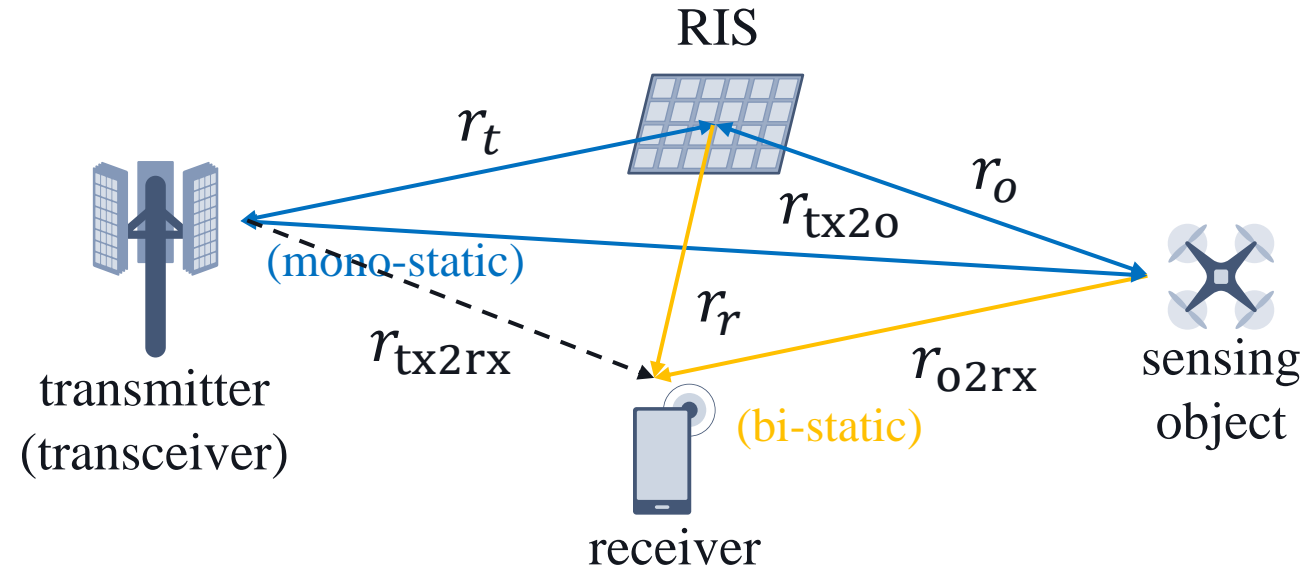
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# Outline

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- System model
- Pathloss and SNR analysis
- Evaluation

# System Model

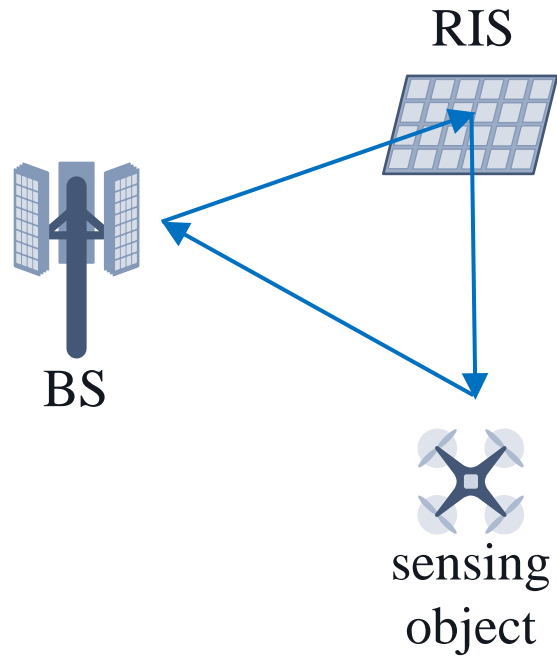


- RIS-assisted communications
  - RIS enhances the communication link btw Tx and Rx.
- RIS-assisted sensing: mono-static and bi-static
  - Enhancing power of indirect links which are reflected by RISs, to exceed power of direct link.
  - Bypassing blockage in direct links.

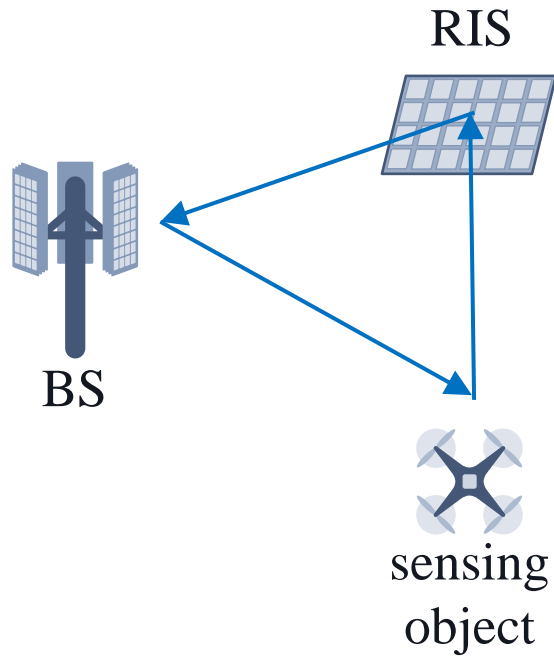
# System Model

- Paths of RIS-assisted mono-static sensing

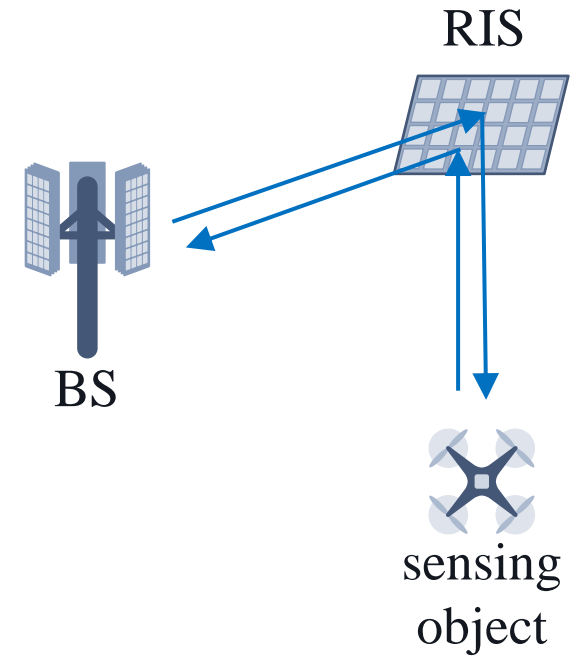
$BS \rightarrow RIS \rightarrow \text{object} \rightarrow BS$



$BS \rightarrow \text{object} \rightarrow RIS \rightarrow BS$



$BS \rightarrow RIS \rightarrow \text{object} \rightarrow RIS \rightarrow BS$



# Receive Power of Sensing Assisted by RIS

[Ref] W. Tang et al., "Wireless Communications With Reconfigurable Intelligent Surface: Path Loss Modeling and Experimental Measurement," in IEEE Transactions on Wireless Communications, vol. 20, no. 1, pp. 421-439, Jan. 2021. (SEU)

Monostatic Sensing: BS  $\rightarrow$  RIS  $\rightarrow$  object  $\rightarrow$  RIS  $\rightarrow$  BS

- Reflected power at the object: BS  $\rightarrow$  RIS  $\rightarrow$  object

$$P_{\text{object,rf}} = P_t G_t G_{\text{cell}} \frac{l_M l_N \text{RCS}}{(4\pi)^2} \left| \sum_{m=1}^M \sum_{n=1}^N \sqrt{F(\theta_{m,n}^{\text{BS}}) F(\theta_{m,n}^{\text{object}})} \frac{a_{m,n} e^{j\left(\phi_{m,n} - 2\pi \frac{r_{m,n}^{\text{BS}} + r_{m,n}^{\text{object}}}{\lambda}\right)}}{r_{m,n}^{\text{BS}} r_{m,n}^{\text{object}}} \right|^2$$

Unit cell radiation pattern

- Received power at BS: object  $\rightarrow$  RIS  $\rightarrow$  BS

- General model:

$$P_{\text{BS,rx}} = P_{\text{object,rf}} G_r G_{\text{cell}} \frac{l_M l_N \lambda^2}{(4\pi)^3} \left| \sum_{m=1}^M \sum_{n=1}^N \sqrt{F(\theta_{m,n}^{\text{object}}) F(\theta_{m,n}^{\text{BS}})} \frac{a_{m,n} e^{j\left(\phi_{m,n} - 2\pi \frac{r_{m,n}^{\text{object}} + r_{m,n}^{\text{BS}}}{\lambda}\right)}}{r_{m,n}^{\text{object}} r_{m,n}^{\text{BS}}} \right|^2$$

Maximize (RIS beam forming):  $\phi_{m,n} = 2\pi \frac{d_{m,n}^{\text{BS}} + d_{m,n}^{\text{object}}}{\lambda}$

Far field approximate

$P_{\text{BS,rx}}^{\text{max, farField}}$

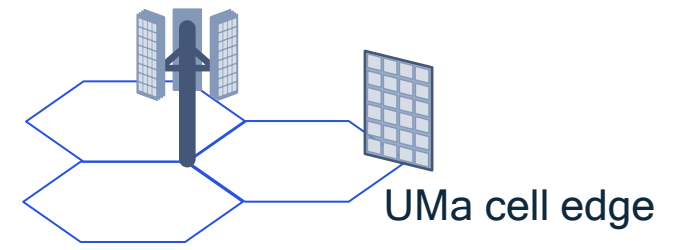
$$= P_t G_t G_r \frac{\text{RCS} \left( G_{\text{cell}} \lambda l_M l_N F(\theta^{\text{BS}}) F(\theta^{\text{object}}) \right)^2 (aK)^4}{(4\pi)^5 (r^{\text{BS}} r^{\text{object}})^4}$$

$K = MN$

Receive power increases with the fourth power of the number of RIS unit cells

# Power Gain of RIS in Monostatic Sensing

## Comparison of RIS in Communications and Sensing



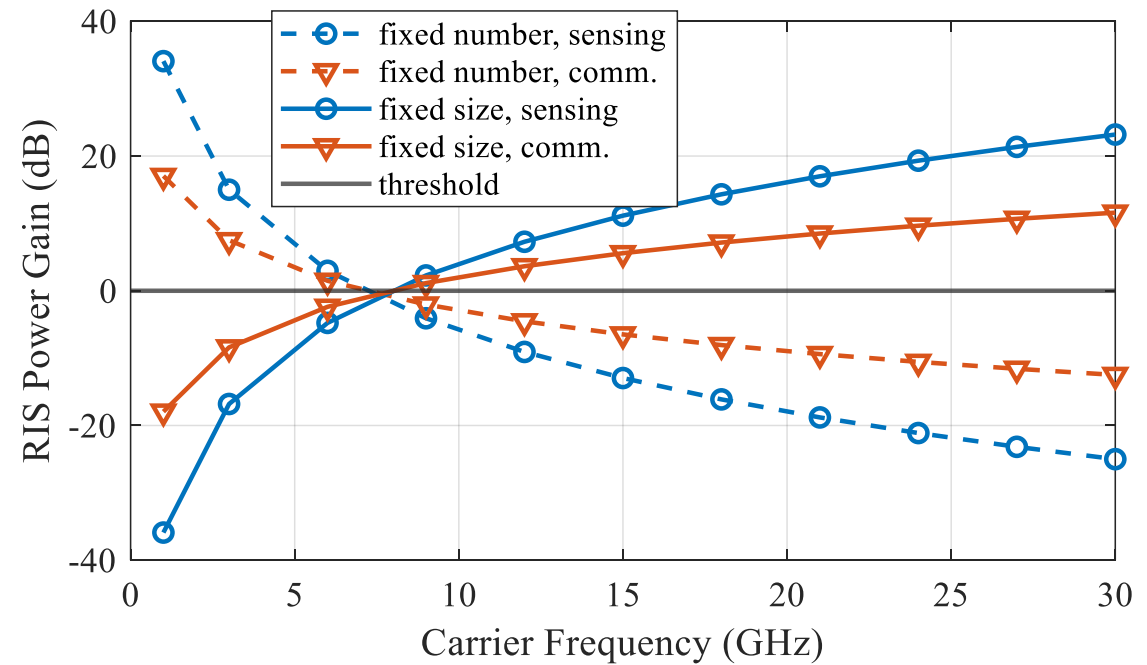
$$\eta_{\text{sens}} = \frac{(GF^{\text{sens},t})^2 (ar_{\text{tx}2\text{o}})^4}{(4\pi F^{\text{tx}}(\theta_{\text{tx}2\text{o}})\beta)^2 (r_t r_o \lambda)^4} A_{\text{RIS}}^4,$$

$$\eta_{\text{comm}} = \frac{GF^{\text{comm}}(ar_{\text{tx}2\text{rx}})^2}{4\pi F^{\text{tx}}(\theta_{\text{tx}2\text{rx}})\beta(r_t r_r \lambda)^2} A_{\text{RIS}}^2,$$

$$A_{\text{RIS}} = MNA_{\text{cell}} = MN\beta\lambda^2, \quad \beta = 1/16$$

Amplitude of RIS reflection coefficient  $a = 0.7$

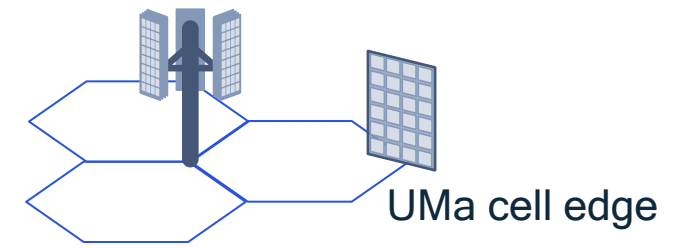
Power gains brought by RISs in sensing and communications with the **fixed unit cell number** (100x100) or the **fixed RIS size** (1 m<sup>2</sup>)



- Higher carrier frequency

- Fixed unit cell number: the advantage of RIS assisted sensing over communications reduces
- Fixed RIS size: the advantage of RIS assisted sensing over communications grows

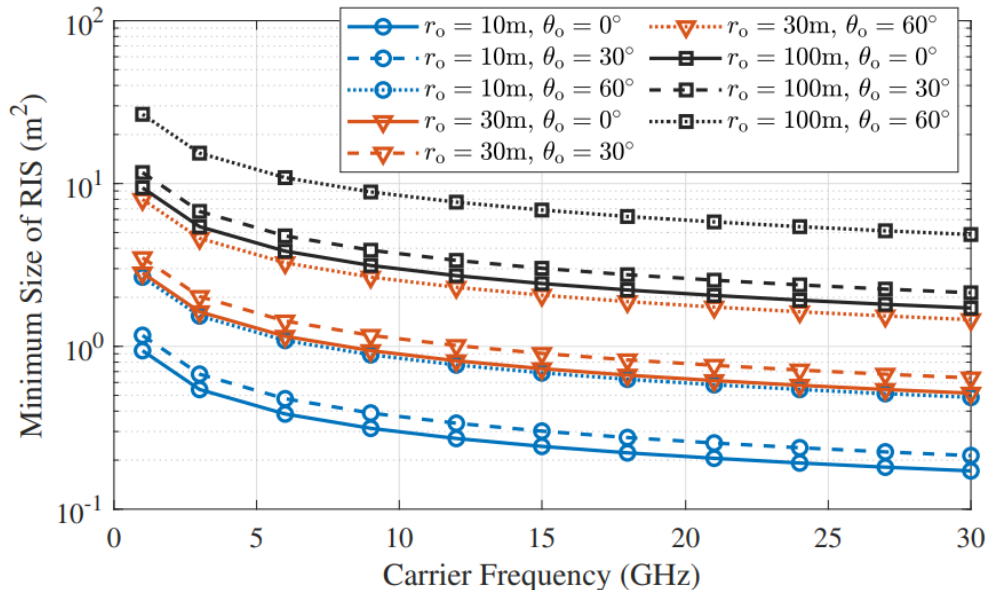
# Required RIS Size in Monostatic Sensing



The **minimum size** of RIS in mono-static sensing to achieve the receiver **sensitivity**

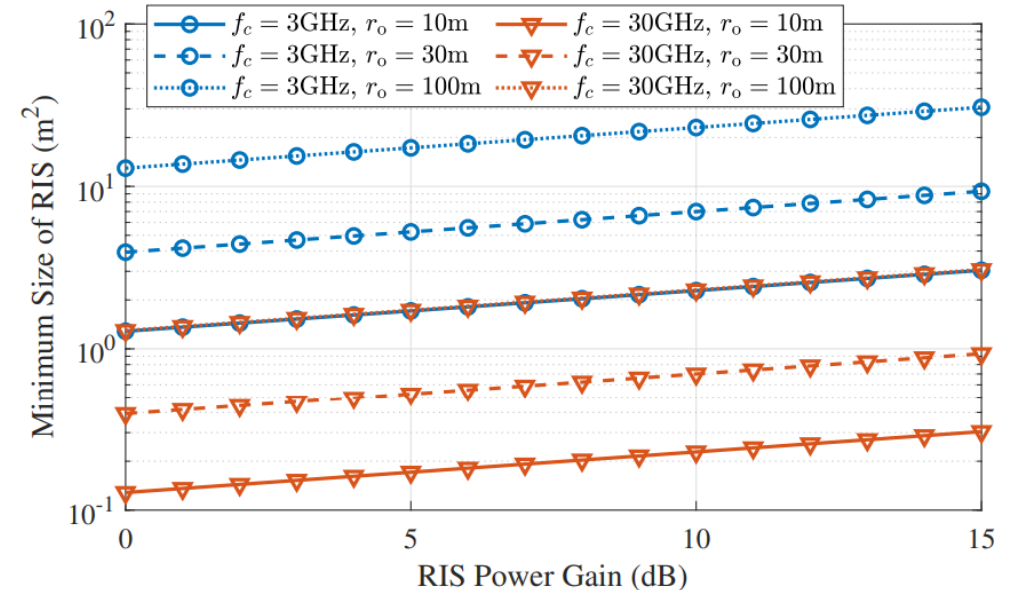
$$A_{\text{RIS}} \geq \left( \frac{\rho_0 P_n (4\pi)^5 \beta^2 \lambda^2}{P_t G_t G_r \sigma (GF^{\text{sens},t})^2} \right)^{\frac{1}{4}} \frac{r_t r_o}{a}.$$

SNR sensitivity  $-16.5$  dB



The **minimum size** of RIS in mono-static sensing to achieve a **given power gain**

$$A_{\text{RIS}} > \frac{(4\pi F^{\text{tx}}(\theta_{\text{tx}2\text{o}})\beta)^{\frac{1}{2}} r_t r_o \lambda}{(GF^{\text{sens},t})^{\frac{1}{2}} a r_{\text{tx}2\text{o}}} \eta_{\text{sens}}^{\frac{1}{4}}.$$



- Higher carrier frequency → Smaller required RIS size
- RIS size grows slowly with the increasing of target power gain

# SNR for Sensing Assisted by RIS

Monostatic Sensing: BS  $\rightarrow$  RIS  $\rightarrow$  object  $\rightarrow$  RIS  $\rightarrow$  BS

- System Parameters

- Carrier frequency = 3.5 GHz, BW = 100MHz, comb 4 RS

- BS:

- $P_t = 49$  dBm (TR 38.855),  $G_t = G_r = 8$  dBi,
- Antenna uptilt  $0^\circ$ , beamforming gain = 12 dB
- Noise figure = 8 dB, noise density -174 dBm/Hz

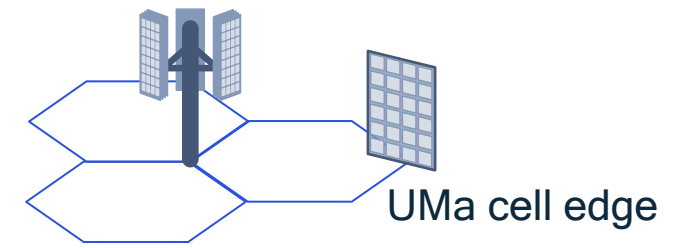
- RIS:

- Surface size  $M = N = \sqrt{K}$
- Unit cell size  $l_M = l_N = \lambda/4$ , amplitude of coefficient  $\alpha = 0.7$
- Varactor-diode or 2-bitquantized PIN-diode

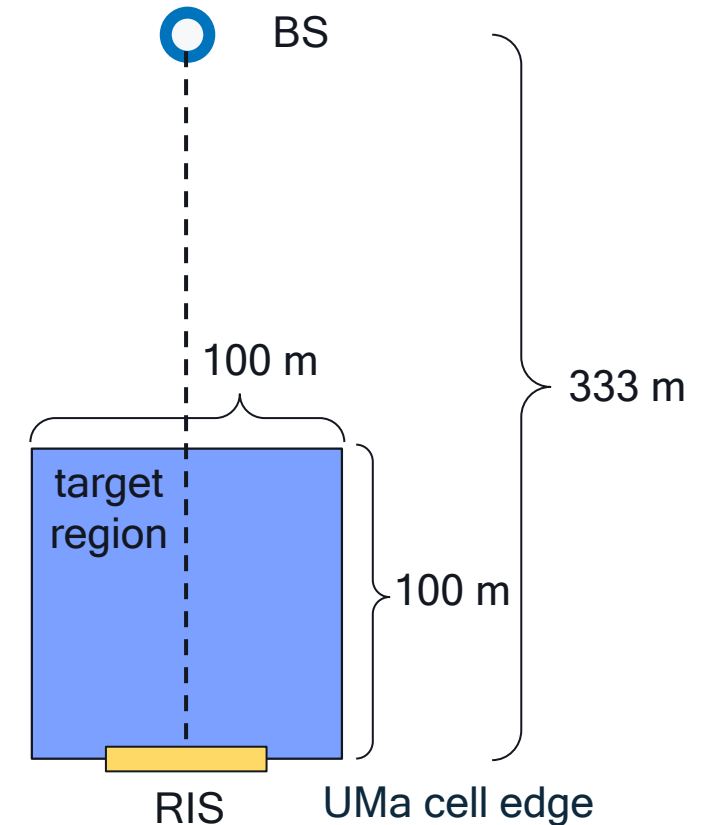
- $$\text{SNR} = \frac{P_{\text{BS},\text{rx}}}{kT_0 B F_n}$$

- Paths other than the direct link can be neglected

- Non-target reflections assumed removed by radar processing
- TR36.777 (target UAV): 15 dB for the target LOS/NLOS ratio over Rician channels



Geometry (top view):

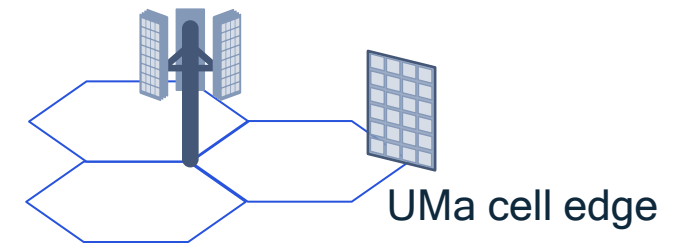


Assume BS, RIS and objects are same in height for in the initial analysis



# SNR for Sensing Assisted by RIS

Comparison RIS size and quantization



- Color shows SNR of BS  $\rightarrow$  RIS  $\rightarrow$  object  $\rightarrow$  RIS  $\rightarrow$  BS minus SNR of BS  $\rightarrow$  object  $\rightarrow$  BS

Unit Cell Number K:

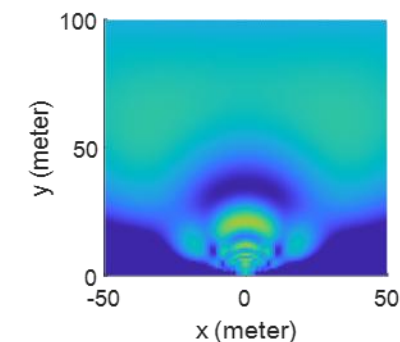
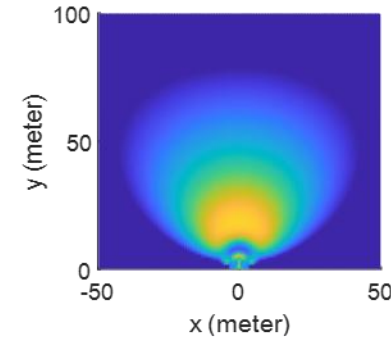
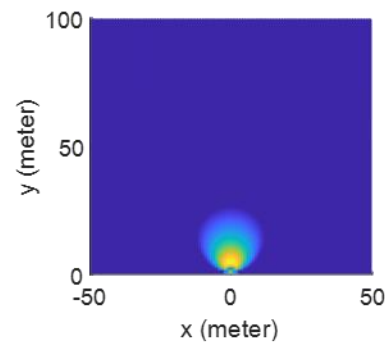
**50x50** (1mx1m)

**100x100** (2.1mx2.1m)

**200x200** (4.3mx4.3m)

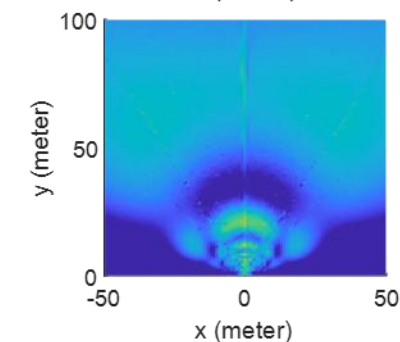
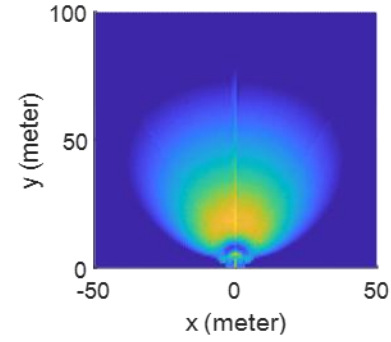
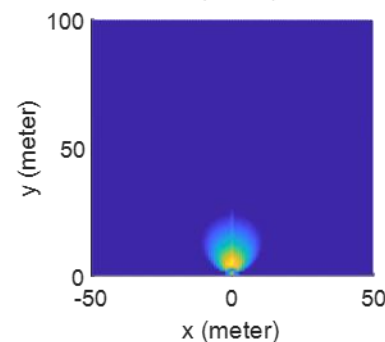
- 2D beamforming

- Coefficients by the far field model
- Varactor-based RIS



- 2-bit quantized 2D beamforming

- Coefficients by the far field model
- PIN-diode RIS



SNR gain (dB)



- Impact of the quantization of two bits and more on the RIS beamforming gain could be neglected.

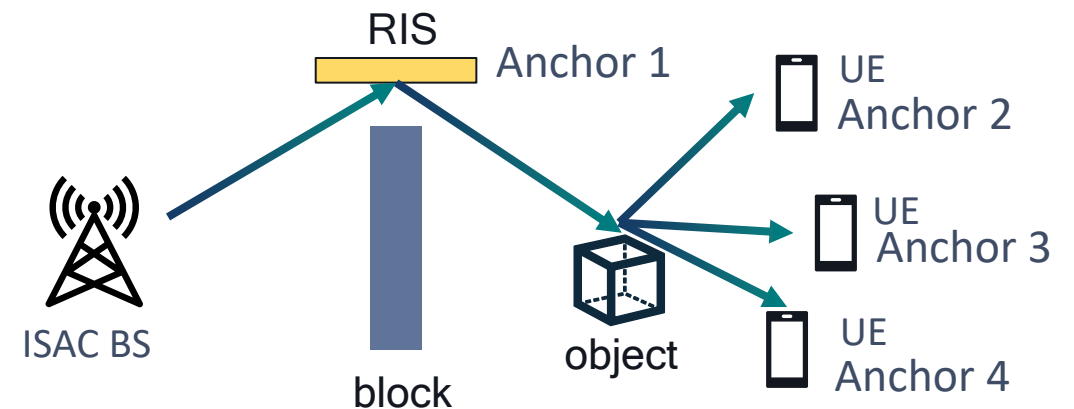
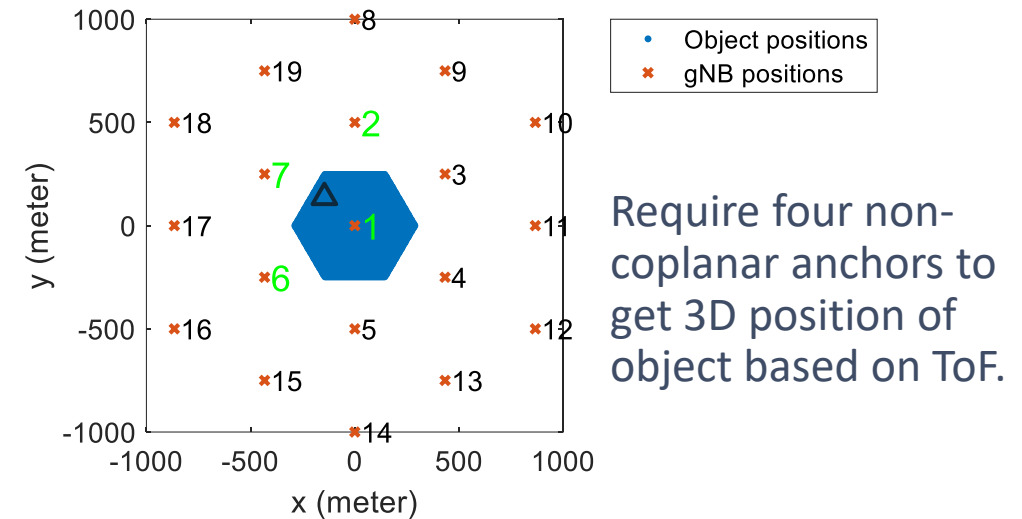
# Utilization of RIS in Sensing

- New anchor node

- New anchor by RIS to replace the 4<sup>th</sup> largest SNR BS in the object 3D locating with higher SNR
  - For the object position denoted by the triangle, the four largest SNR BS is BS 1, 2, 6 and 7, where the 4<sup>th</sup> largest SNR BS is BS 6.
  - RIS can reflect signals from BS 1 to exceed the SNR of BS 6 at the object position.

- RIS to provide additional sensing/positioning RS

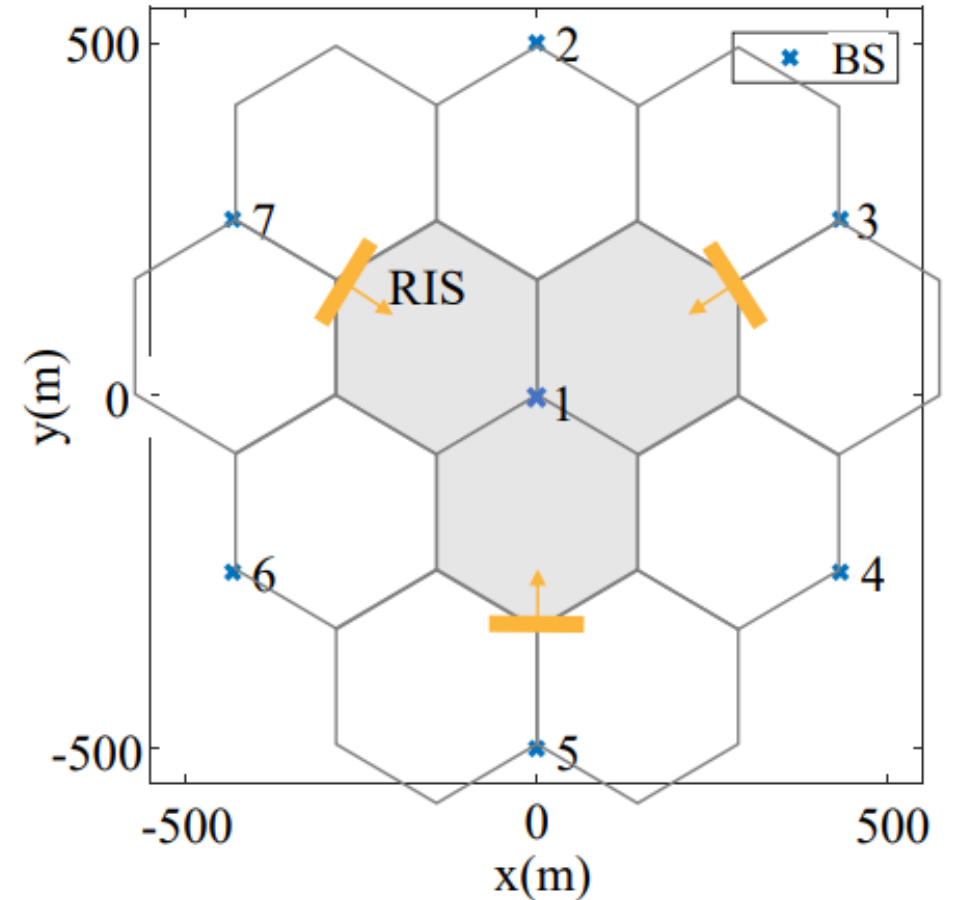
- RIS can extend the coverage to the area with LOS blockage between the BS
- UEs in the blockage can be served by RIS for communications and serve as sensing RS receivers.



# System Setup

## Four-Point Localization in 3D

- **Baseline: BS monostatic**
  - Require four reference **BSs not in the same plane**
    - Height of the 19 BSs is uniformly distributed in [20,50] m (38.855 UMa outdoor)
    - **Four reference point:** Select the four largest SNR BSs, not in the same plane.
- **RIS-based: BS + RIS**
  - **RIS provide a new reference point**
    - Height of all RISs is 10 m
    - **Four reference point:** Select the three largest SNR BSs and RIS



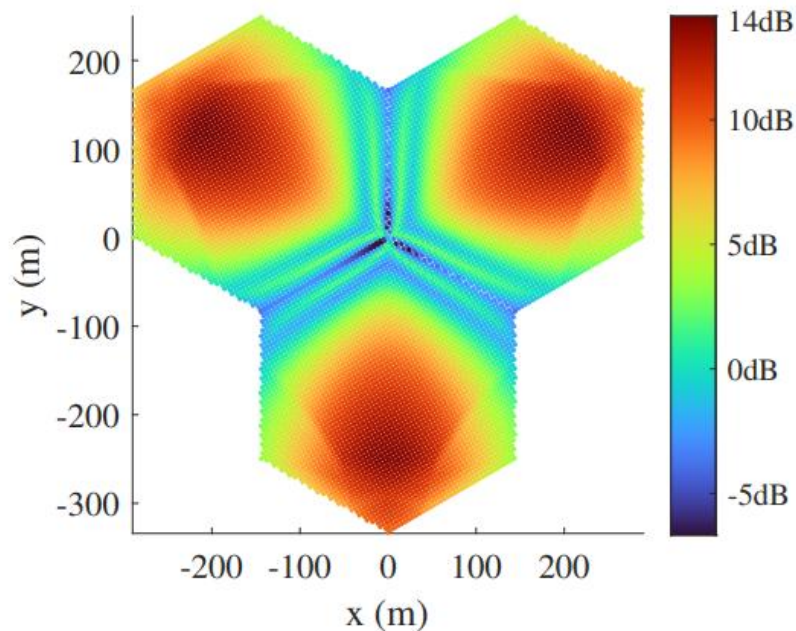
# Simulation Results

## UAV Sensing as an Example

- SNR Gain by RIS

- Achieve an average SNR gain of 6.7 dB compared to the 4th-highest SNR BSs.

SNR Gain by RIS in the coverage of a BS



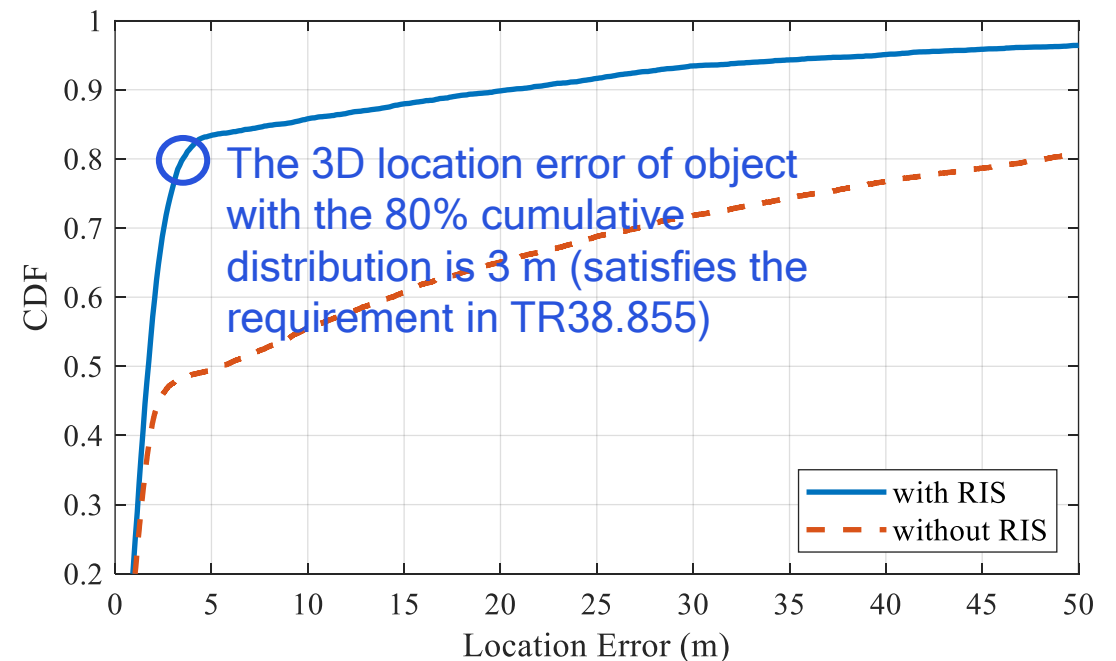
## Simulation settings

- Carrier frequency is 3.5 GHz
- RIS size is  $M = N = 100$ ,  $\alpha = 0.7$ , RISs adopt far-field beamforming and the BSs have a beamforming gain of 12 dB
- Sensing object is assumed as drones with RCS  $\sigma = 0.01 \text{ m}^2$  at the height of 120 m
- RIS-based sensing: RIS height is 10 m with uptilting of  $20^\circ$ , and the BS height is 25 m with uptilting of  $0^\circ$
- Sensing w/o RIS: BS height is uniformly distributed in the range of 20~50m
- Algorithm: Gauss-Newton

- Localization Error





- Bottleneck is the 4th-highest-SNR device  $\rightarrow$  much smaller error in sensing assisted by RISs

CDF of Localization Error





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