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The Rumble in the Millimeter Wave Jungle: Obstructions Vs RIS

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[Developing the Science of Networks]

Outline

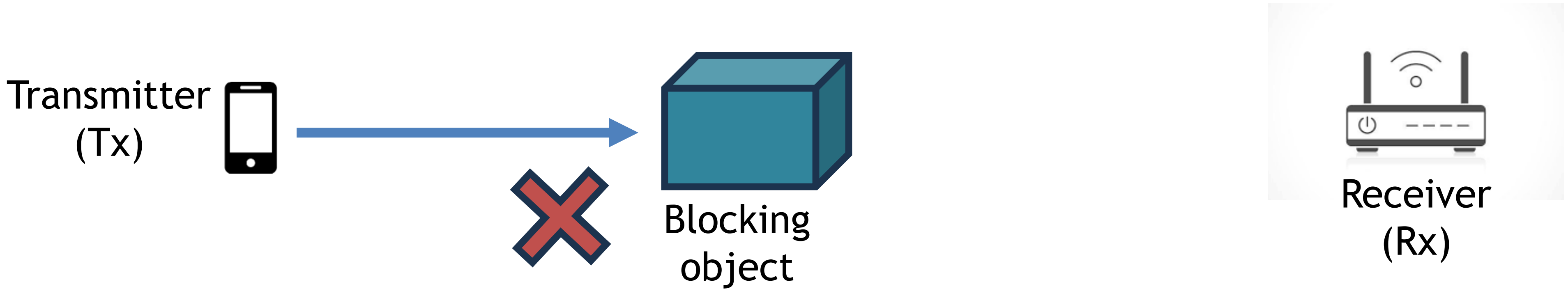
- Background and Motivation
- Reconfigurable Intelligent Surfaces
- Path Loss Model
- Probability of Outage
- Numerical Simulations
  - 2D Indoor Case
  - Beamsteering Cases
  - 3D Indoor Case
- Conclusions and Future Work

Background and Motivation

- **Sub-6 GHz Congestion:** The rapid growth in traffic is causing congestión problems in sub-6 GHz frequency bands.
- **mmWave and THz frequency bands:**
  – Provide abundant spectrum and high data transfer rates for supporting 6G technology.

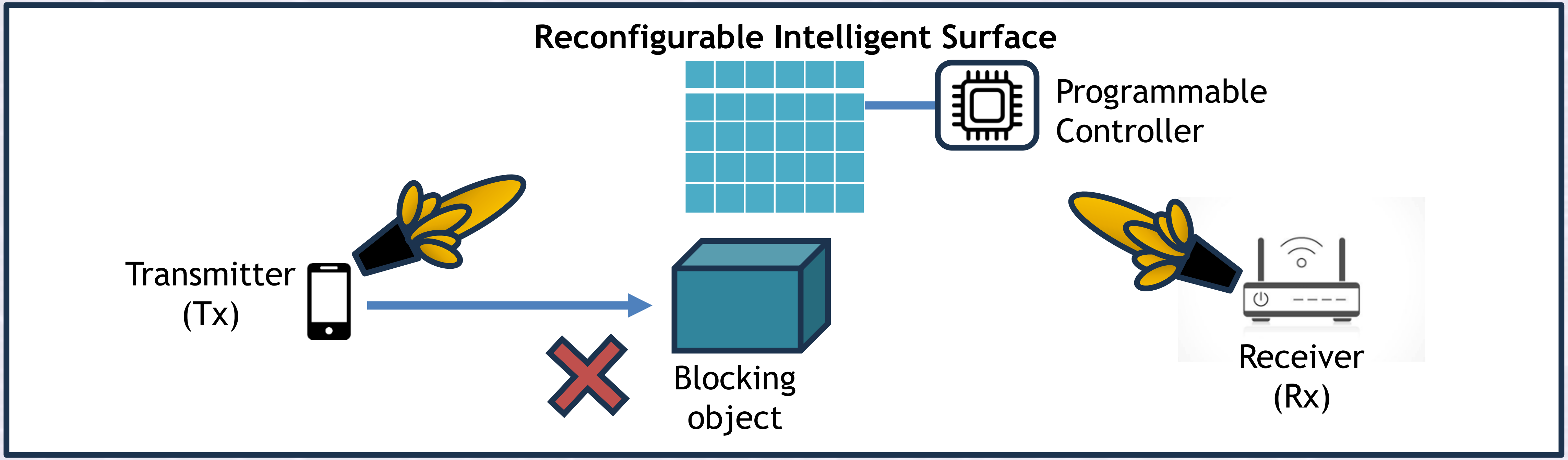
Background and Motivation

Challenge: Any object can block the link path



- **Sub-6 GHz Congestion:** The rapid growth in traffic is causing congestion problems in sub-6 GHz frequency bands.
- **mmWave and THz frequency bands:**
  - Provide abundant spectrum and high data transfer rates for supporting 6G technology.
  - Exhibit large path losses, especially when the LOS path is blocked by obstacles.

A Solution: Reconfigurable Intelligent Surfaces (RIS)

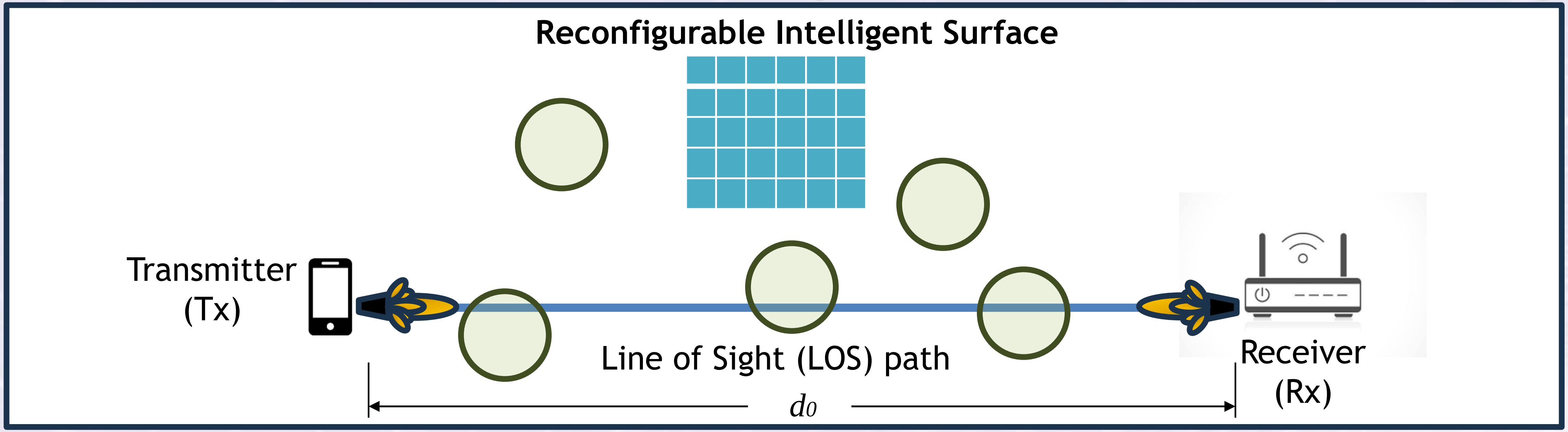


- **Essential Supporting Technology:** for 6G wireless communications
- **RIS:** are (2D) arrays of reflecting elements, allowing phase and magnitude responses to be manipulated via a programable controller.
- **Smart Radio Environments:** RIS can provide control on wireless environment.

State of the Art

- **Path Loss Modeling:** a crucial research area for enhancing RIS-assisted wireless communication systems.
- Introduction of various path loss models [1-7].
- **Limitations of Current Models:**
  - Exclude the transmission medium effects.
  - Discard the attenuation induced by obstructing objects.
- **Importance of Comprehensive Path Loss Models:**
  - Signal-to-Noise Ratio (SNR) Calculation.
  - Outage Probability Estimation: to evaluate reliability and performance of the link in the presence of obstructions.

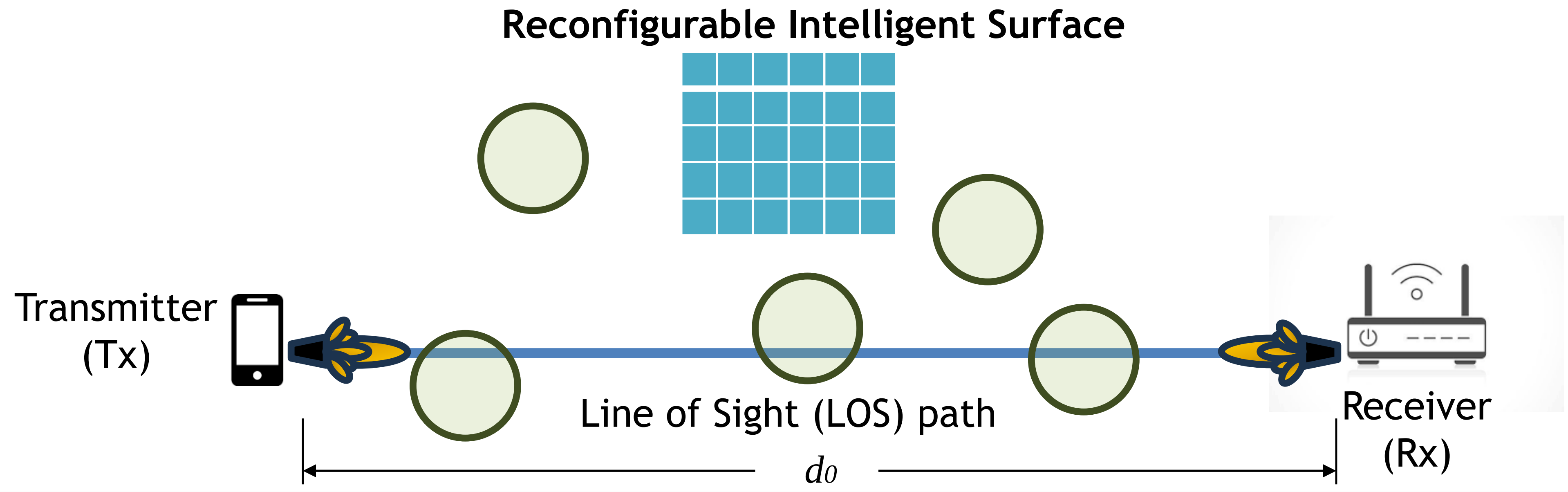
Line of Sight (LOS) Path Loss Modeling



Line of Sight Path Loss Model in dB [8] ⟶

$$\mathcal{L}_0 = L_0 + 10\log_{10}\mu_0 + \zeta X_0, \qquad (1)$$

Line of Sight (LOS) Path Loss Modeling



Line of Sight Path Loss Model in dB →

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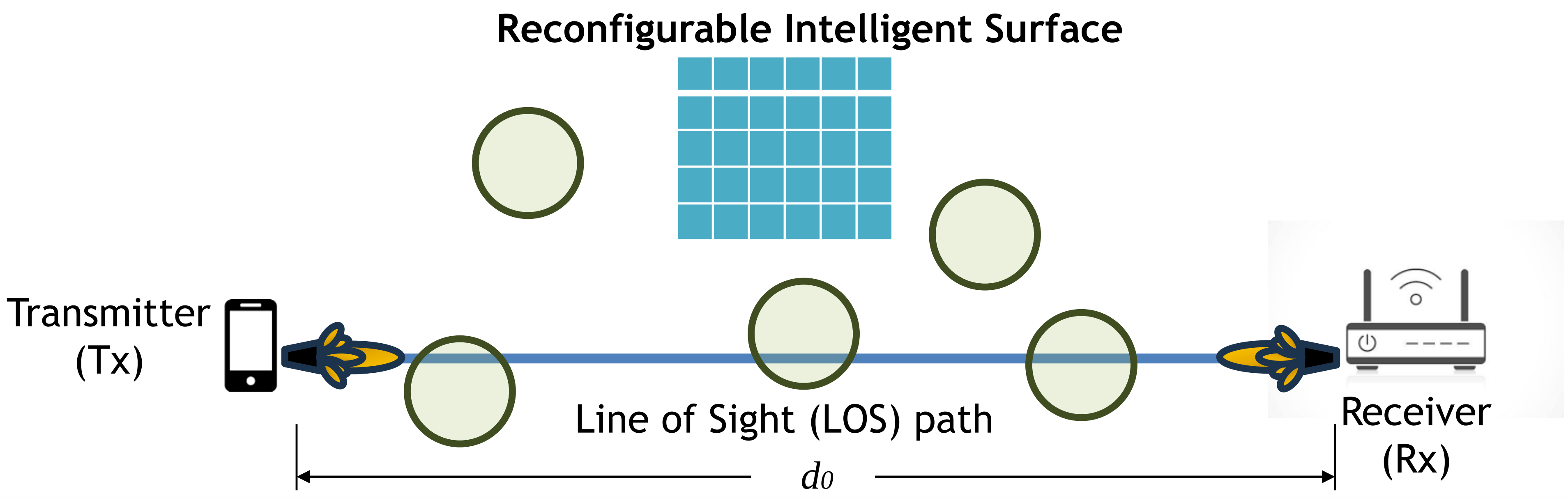
Free-Space Path Loss

Line of Sight (LOS) Path Loss Modeling



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Term related to the average fading depht

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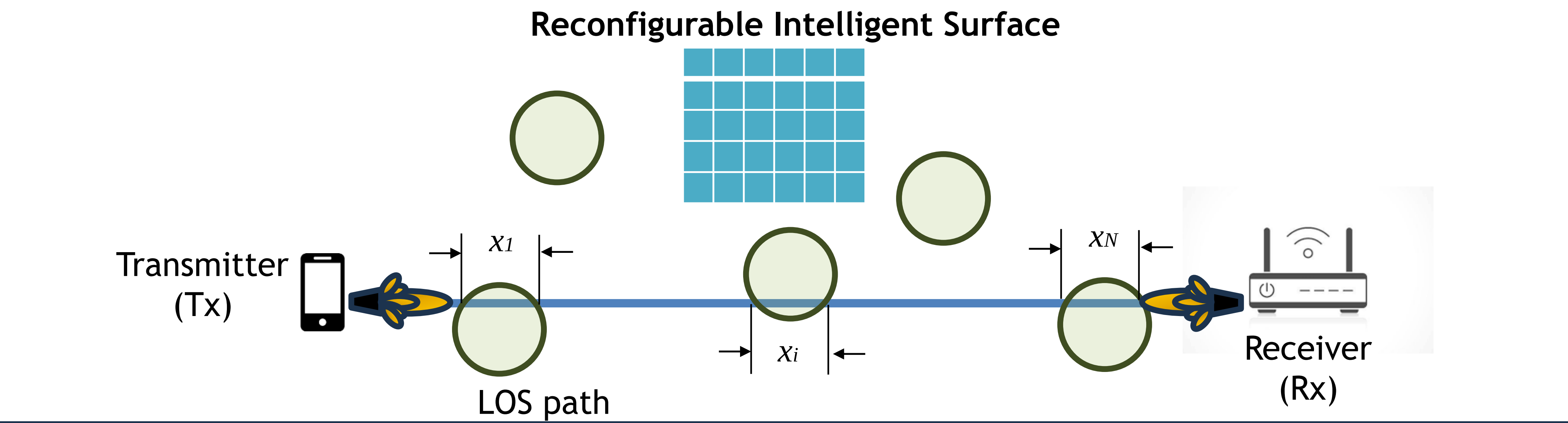

Line of Sight Path Loss Model in dB →

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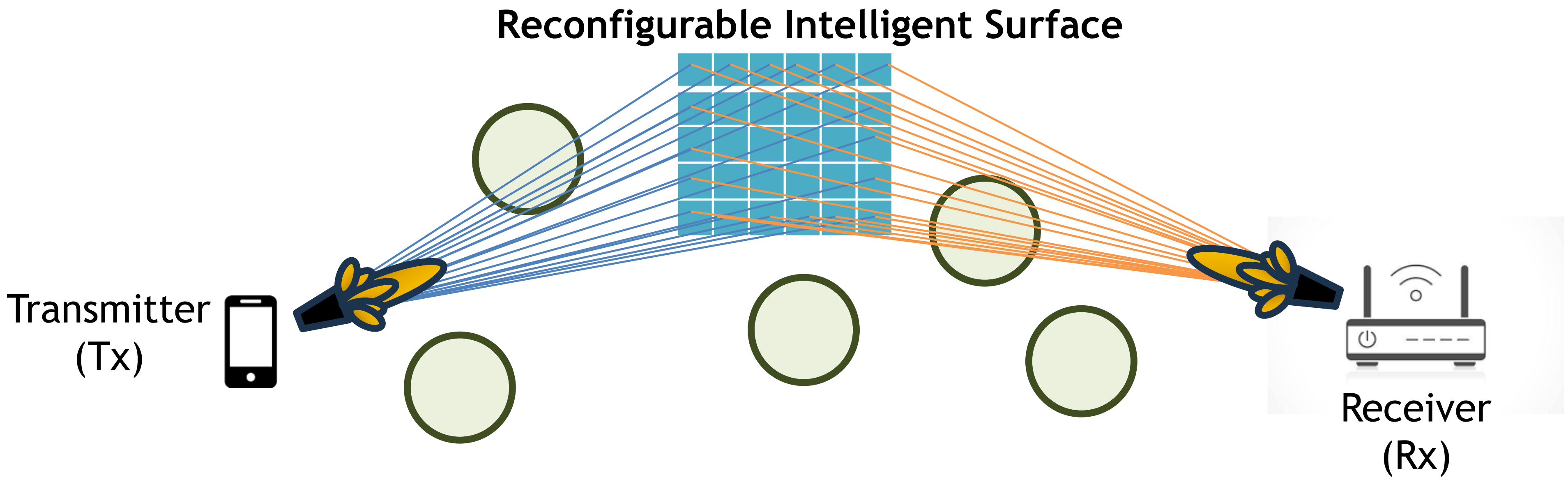
Obstruction attenuation

- ζ - Attenuation of the obstructing object in dB/m
- X_0 - Total obstruction length for the LOS path

$$X_0 = \sum_{i=1}^{N} x_i$$

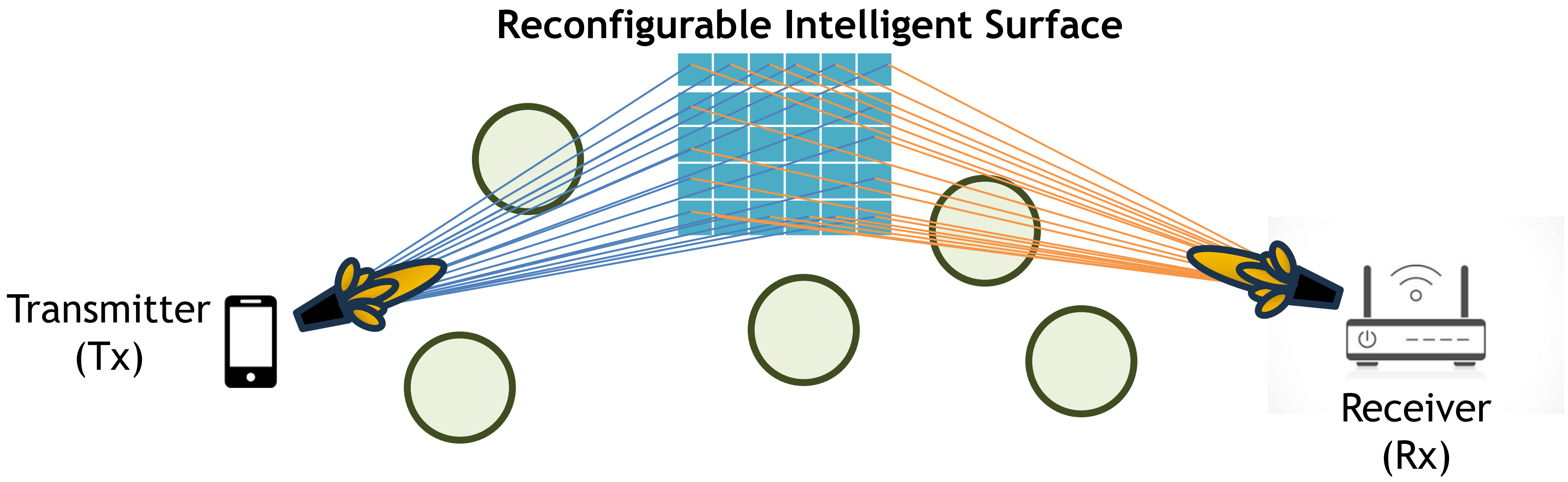
RIS Path Loss Model



$$\mathcal{L}_{RIS} = 20\log_{10}\left(\frac{4\pi}{\delta_x\delta_z}\right) - 10\log_{10}(G_tG_rB) - 20\log_{10}\left|\sum_{m=1}^{M}\sum_{n=1}^{N}\sqrt{\frac{F_{m,n}^{(eq)}}{D_{m,n}^{(eq)}}}\frac{1}{r^t{}_{m,n}r^r{}_{m,n}}\right|. \qquad (2)$$

- **Based on the Tang Path Loss Model [3]**

RIS Path Loss Model



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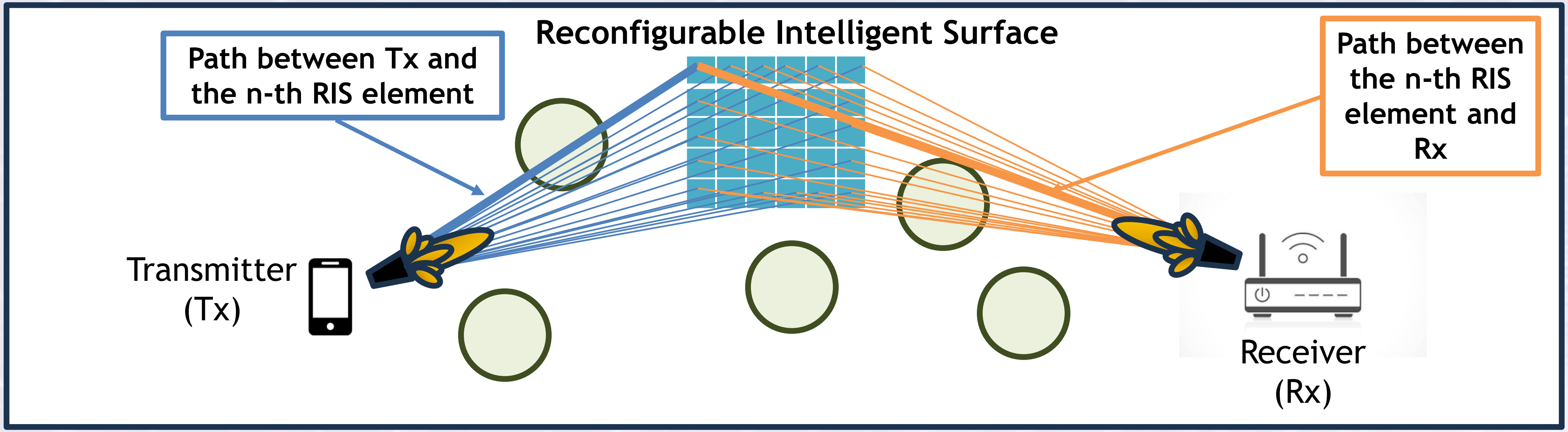
Free-Space Path Loss

RIS Path Loss Model



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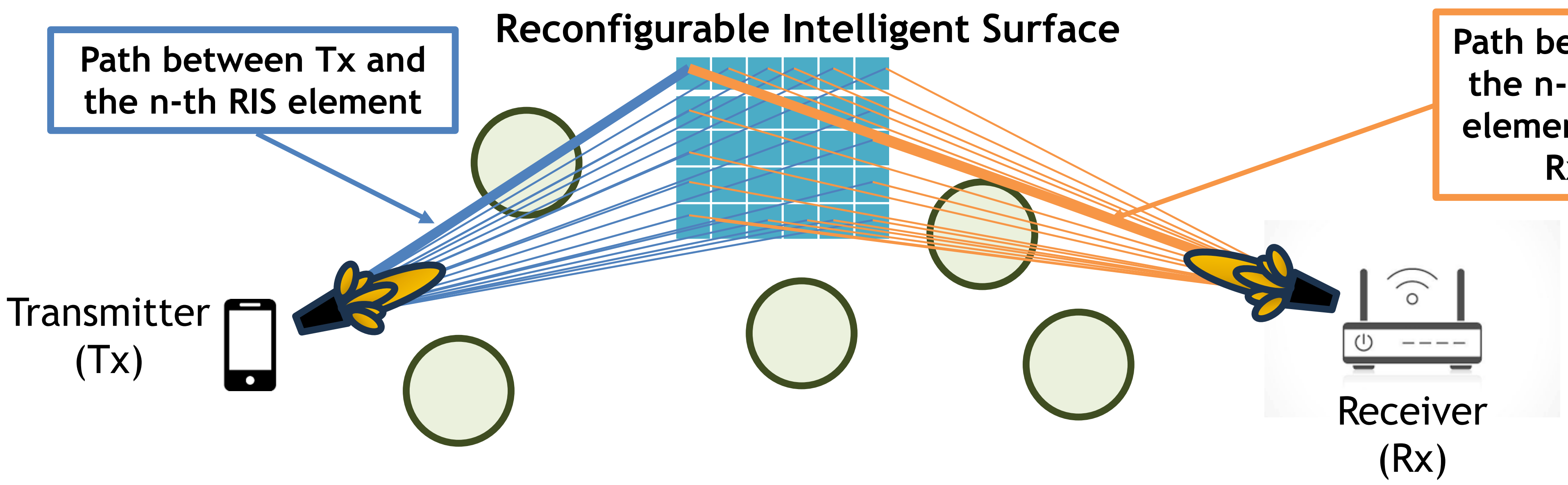
- Consider the contribution of each path Tx-(RIS element)-Rx.
- Subsequently, each the model combine the individual contributions.

RIS Path Loss Model



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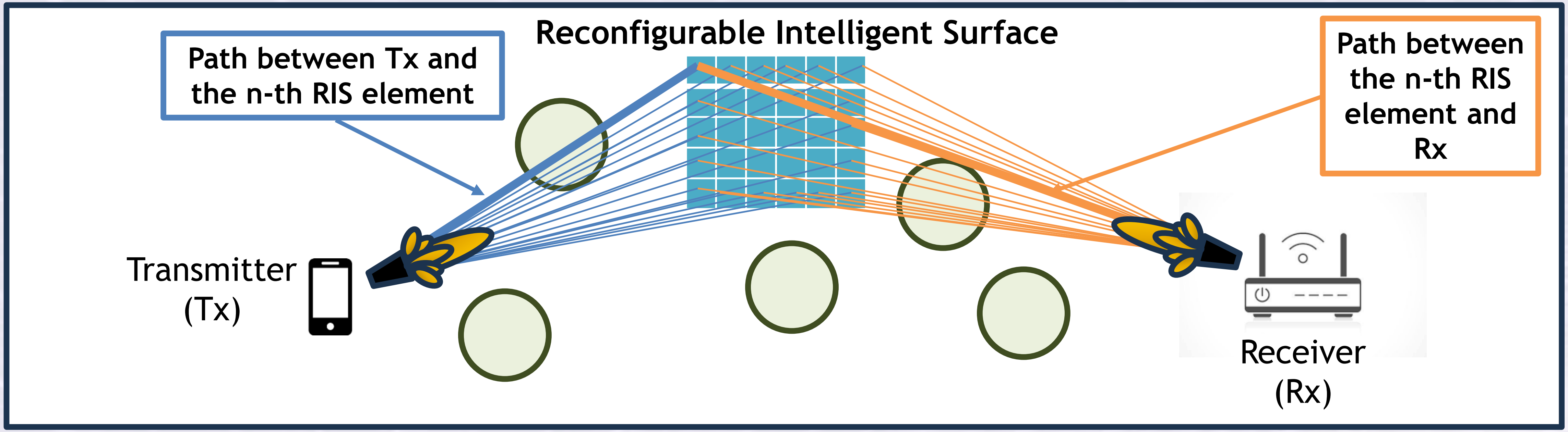
- Each contribution includes the effects of the antennas' power radiation patterns.

$$\boxed{F^{(eq)}_{m,n} = F(\theta^t_{m,n}, \varphi^t_{m,n})F(\theta^{m,n}_t, \varphi^{m,n}_t)F(\theta^{m,n}_r, \varphi^{m,n}_r)F(\theta^r_{m,n}, \varphi^r_{m,n})}$$

RIS Path Loss Model



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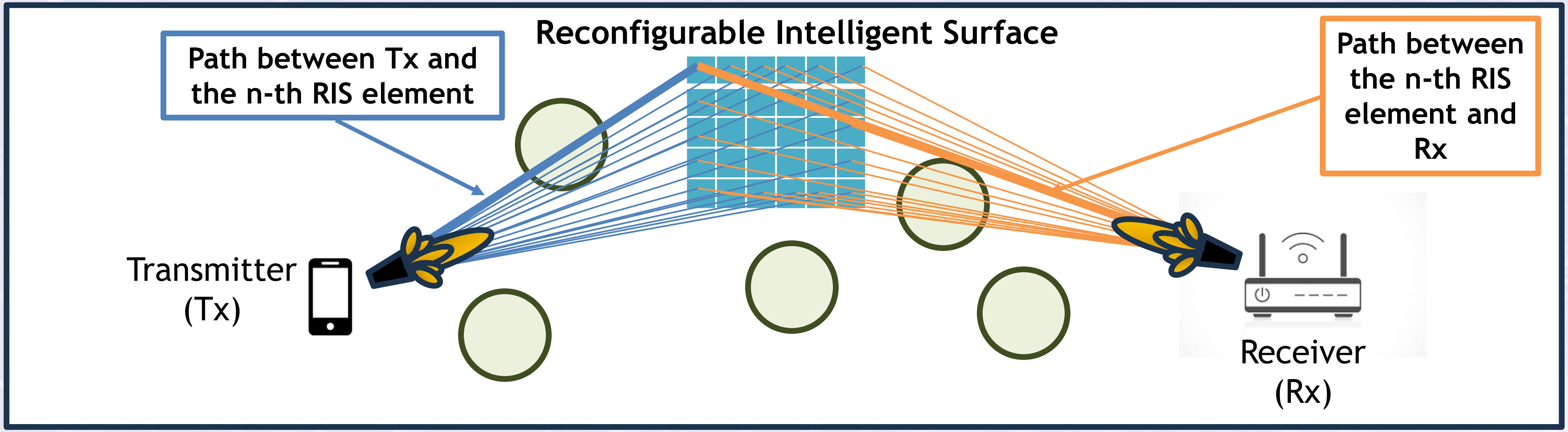
- Our model incorporates the effects of transmissions medium and attenuation due to obstructions on each path Tx-(RIS element)-Rx.

$$D_{m,n}^{(eq)} = 10^{\frac{A_0\left(r_{m,n}^{t}+r_{m,n}^{r}\right)}{10}}10^{\frac{\varsigma\left(X_{m,n}^{t}+X_{m,n}^{r}\right)}{10}}.$$

RIS Path Loss Model



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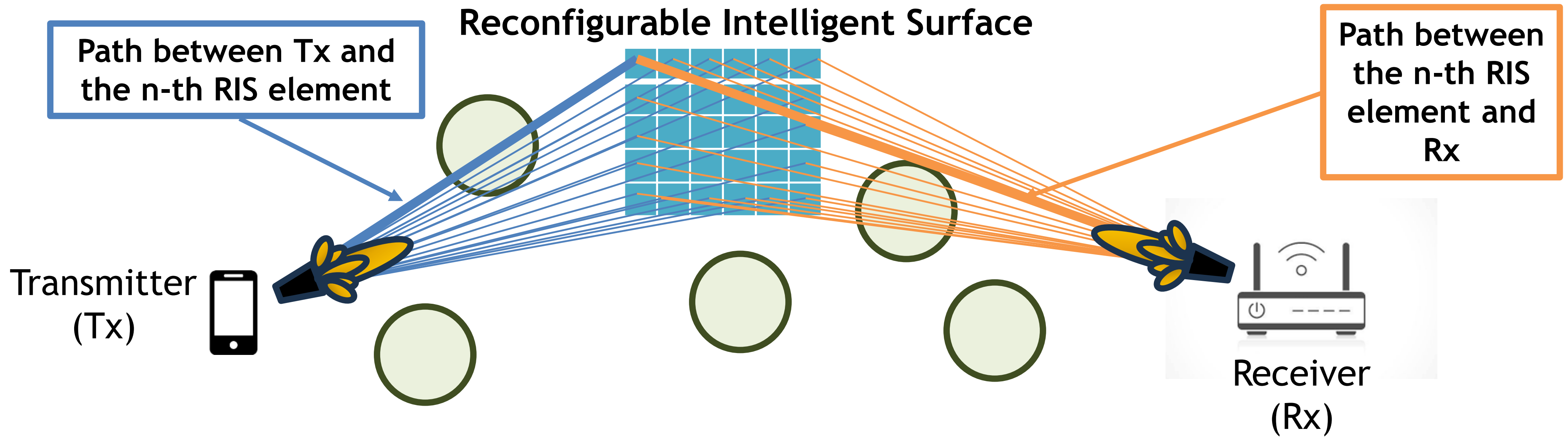
Attenuation due to transmission medium PATH LENGTH

$$D^{(eq)}_{m,n} = 10^{\frac{A_0\left(r^t_{m,n}+r^r_{m,n}\right)}{10}}10^{\frac{\varsigma\left(X^t_{m,n}+X^r_{m,n}\right)}{10}}.$$

RIS Path Loss Model



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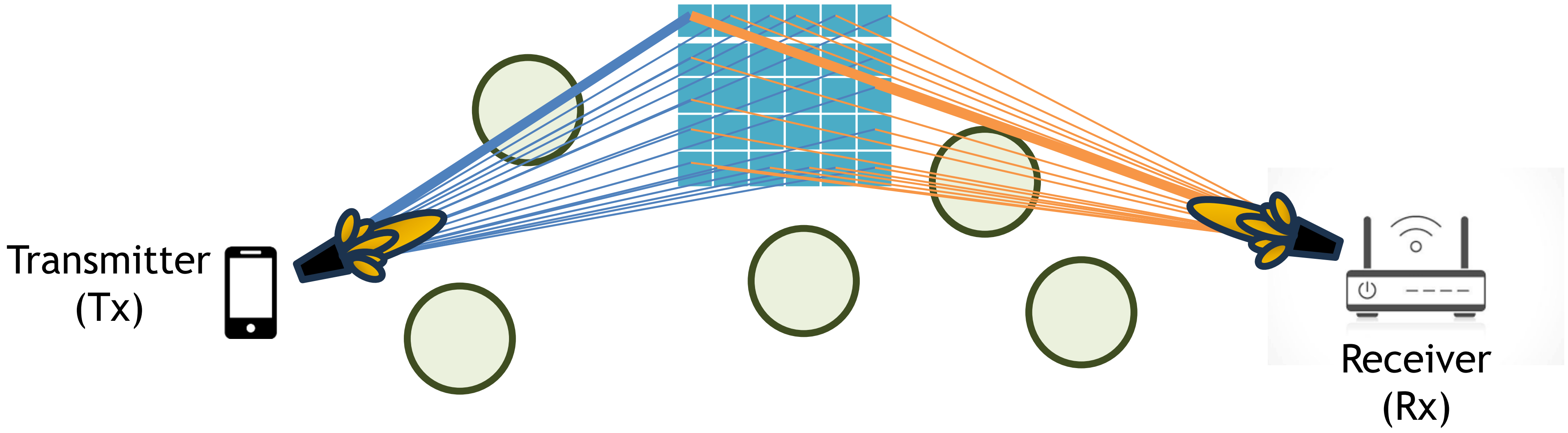
Attenuation due to obstructions
OBTRUCTION LENGTH

RIS Path Loss Model



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- **Assumptions:**
  - All RIS elements have the same amplitude response.
  - Phase responses of RIS elements are adjusted to maximize power at the receiver.

SNR and Outage Probability

- Tx and Rx are aligned through **beamsteerning.**
- The aligment is optimal in terms of **signal-to-noise ratio (SNR)**

$$\boxed{\gamma_k = \frac{P_t |h|^2}{\sigma^2} 10^{-\frac{\mathcal{L}_k}{10}}.}$$

SNR of the k-th path

- The system selects the **least attuenuated path:** between LOS path and RIS-path

$$\boxed{\gamma = \frac{P_t |h|^2}{\sigma^2 \Upsilon},}$$

where

$$\boxed{\Upsilon = \min_k \left\{ 10^{\frac{\mathcal{L}_k}{10}} \right\}.}$$

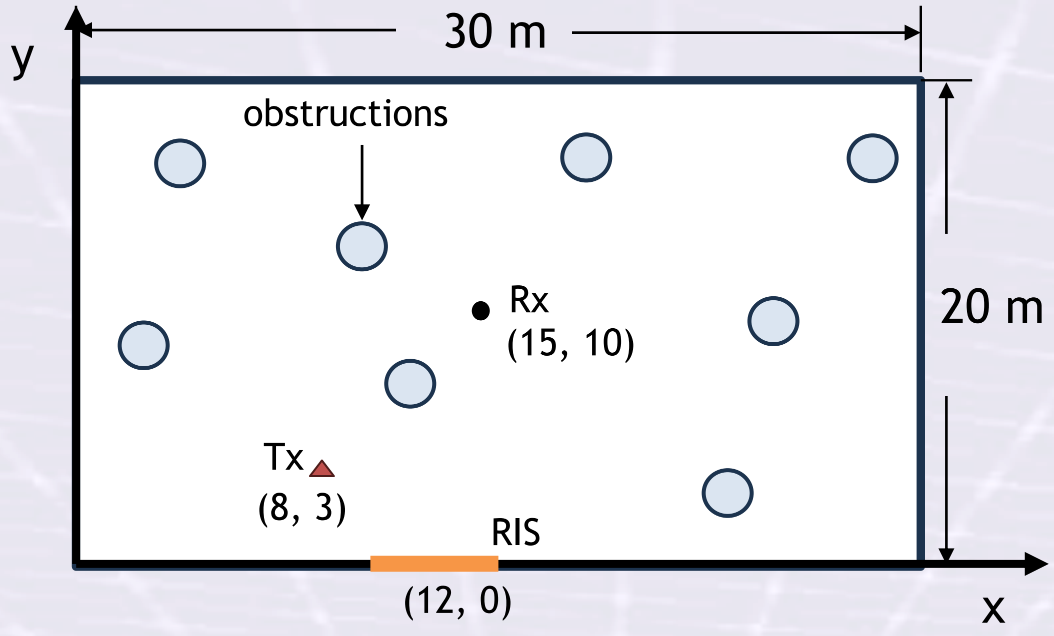
- **Probability of Outage:**
  - Key Performance Indicator (KPI)
  - Determine whether the SNR is less than a given threshold.

$$\boxed{\mathrm{P}_{\mathrm{out}}(\gamma_{\mathrm{th}}) = \Pr(\Upsilon \leq \gamma_{\mathrm{th}}).}$$

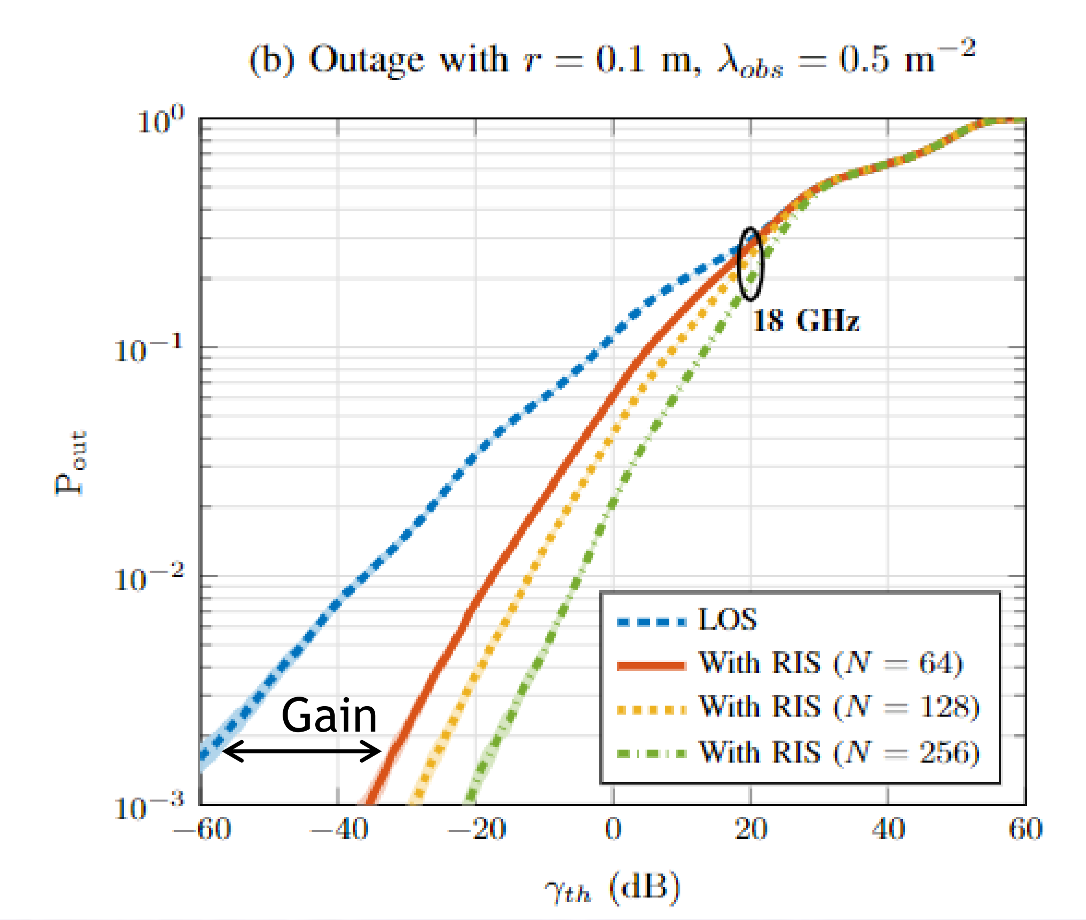
Numerical Simulations

- **Objective:** Estimation of the outage probability in the presence of randomly located obstructions.
- **Path Loss Model:** considering
  - The effects of the transmission medium.
  - Attenuation of obstructing objects.
- Each data point is averaged over 100,000 realizations of the corresponding experiment.
- **Poisson Point Process (PPP):**
  - Each trial generates a different PPP with a specified density λ_{obs} to position object centers.
- **Obstruction shapes:**
  - **2D case:** circular obstructions.
  - **3D case:** spherical obstructions.

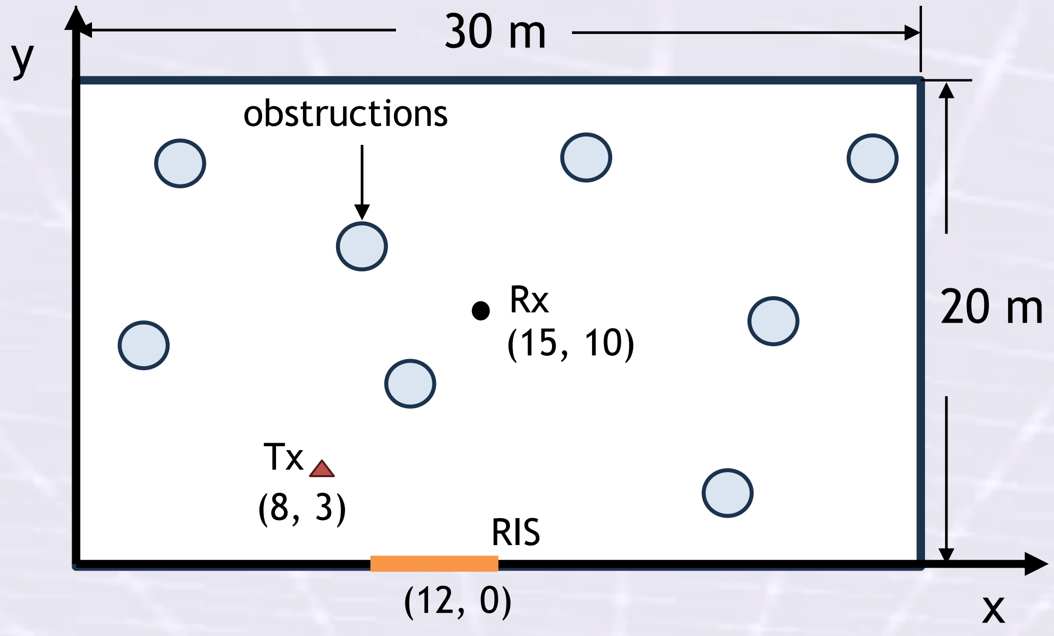
2D Indoor Case



- **Rectangular room:** realistic environments
- **Tx, Rx, and RIS are located in fixed positions**
- **Evaluate the performance of the RIS-aided system using different number of RIS elements.**
- **Circular obstructions**



2D Indoor Case



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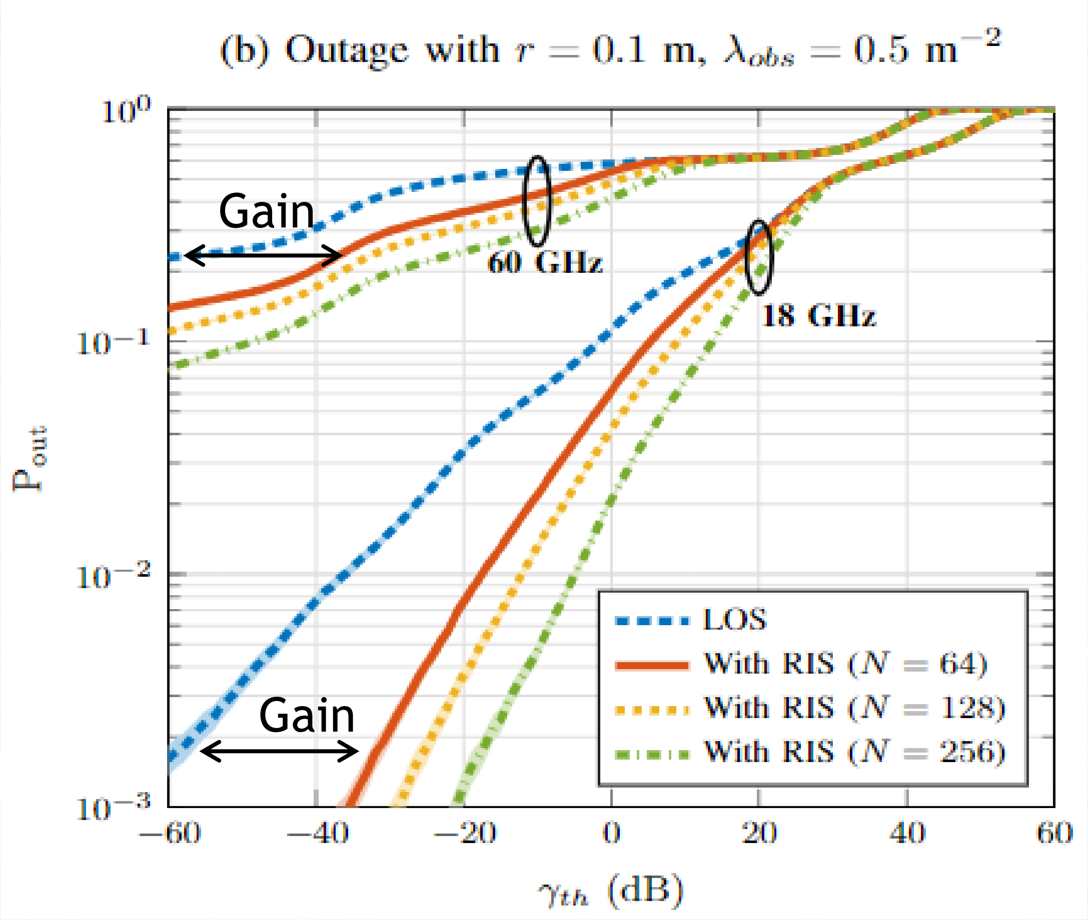
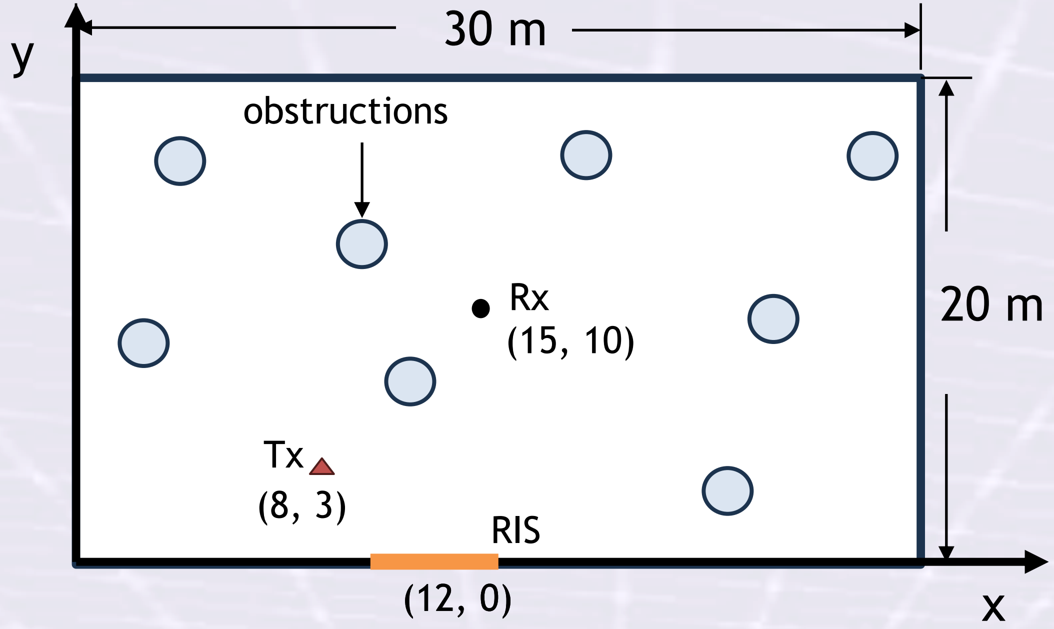
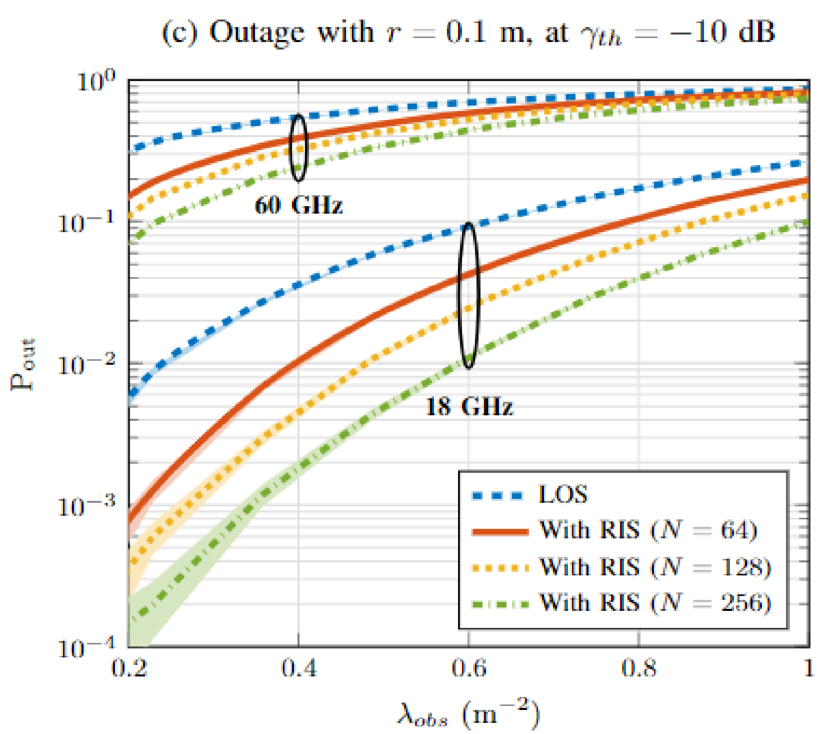
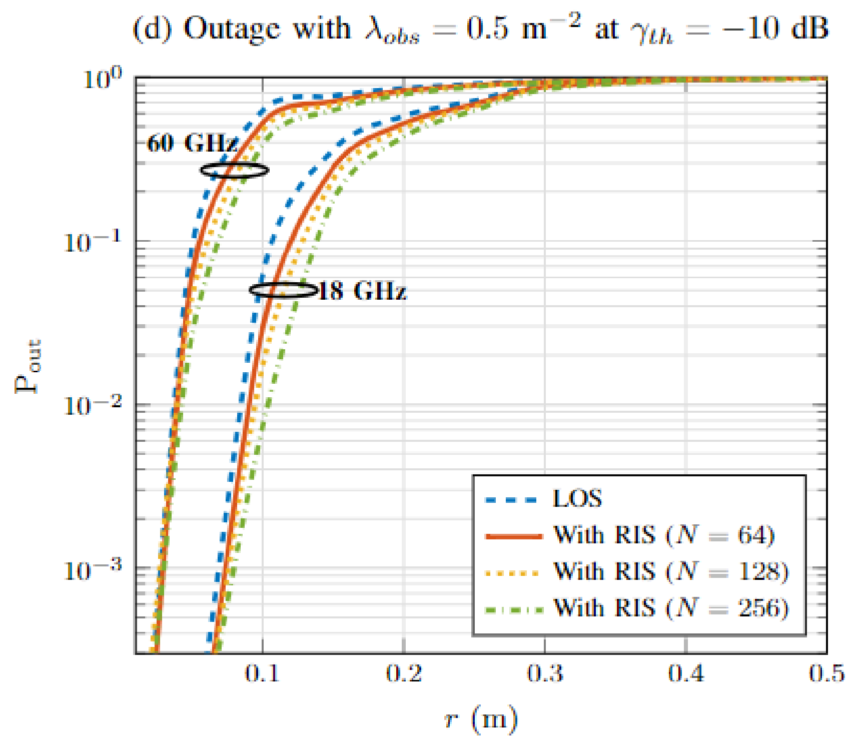


2D Indoor Case

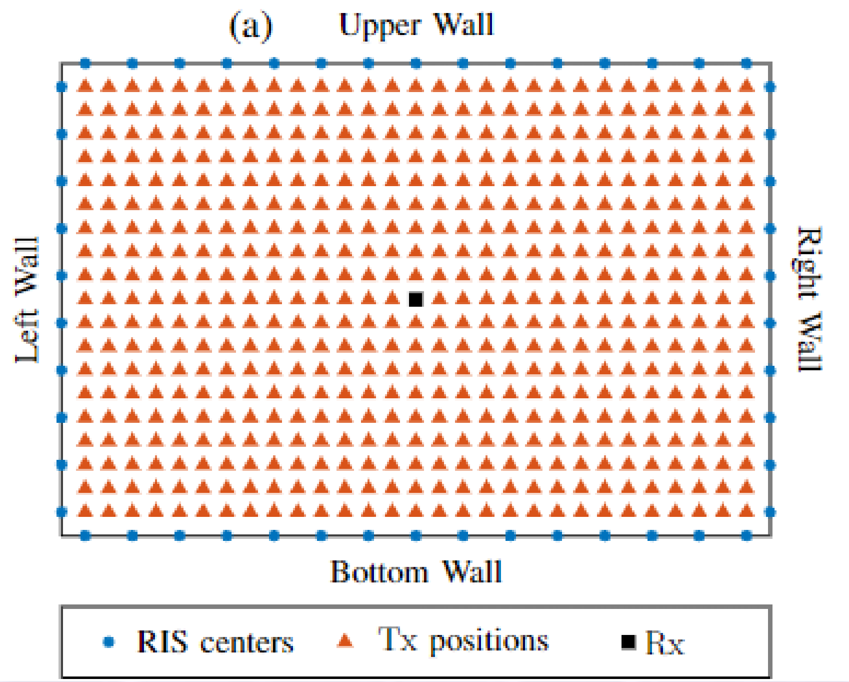






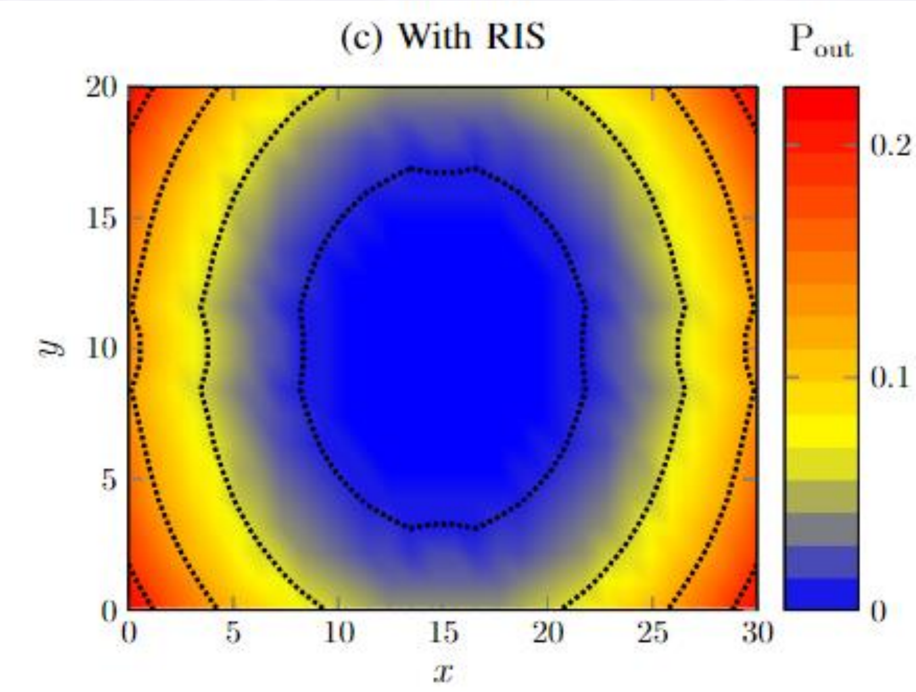
Multiple Tx positions

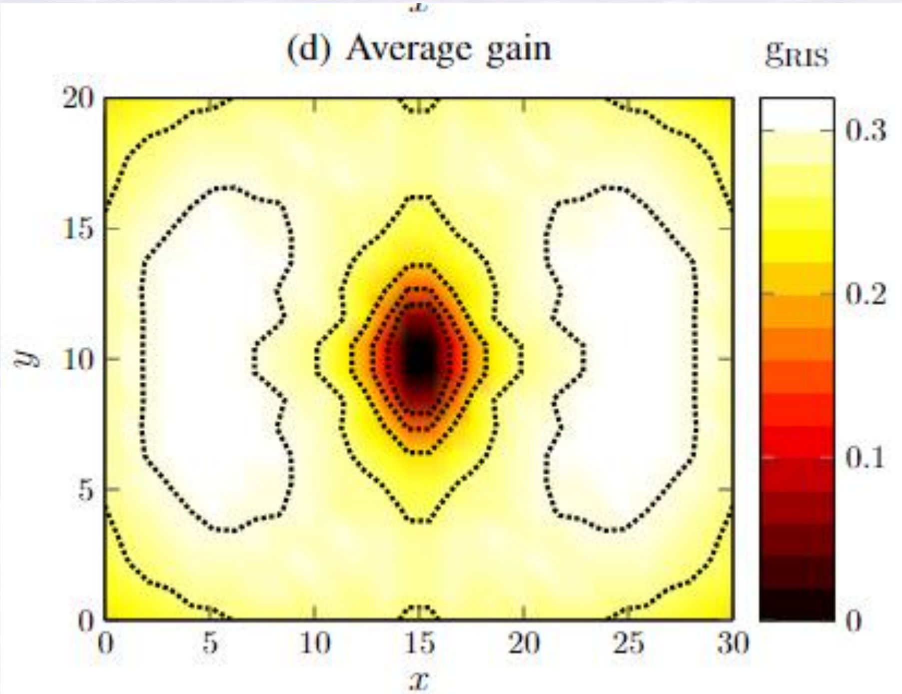
- Rx fixed position at (15, 10)
- Tx uniformly spaced horizotally and vertically



Relative Gain

$$g_{\mathrm{RIS}} = \frac{\mathrm{P}_{\mathrm{out}}^{[\mathrm{No\ RIS}]} - \mathrm{P}_{\mathrm{out}}^{[\mathrm{With\ RIS}]}}{\mathrm{P}_{\mathrm{out}}^{[\mathrm{No\ RIS}]}}.$$





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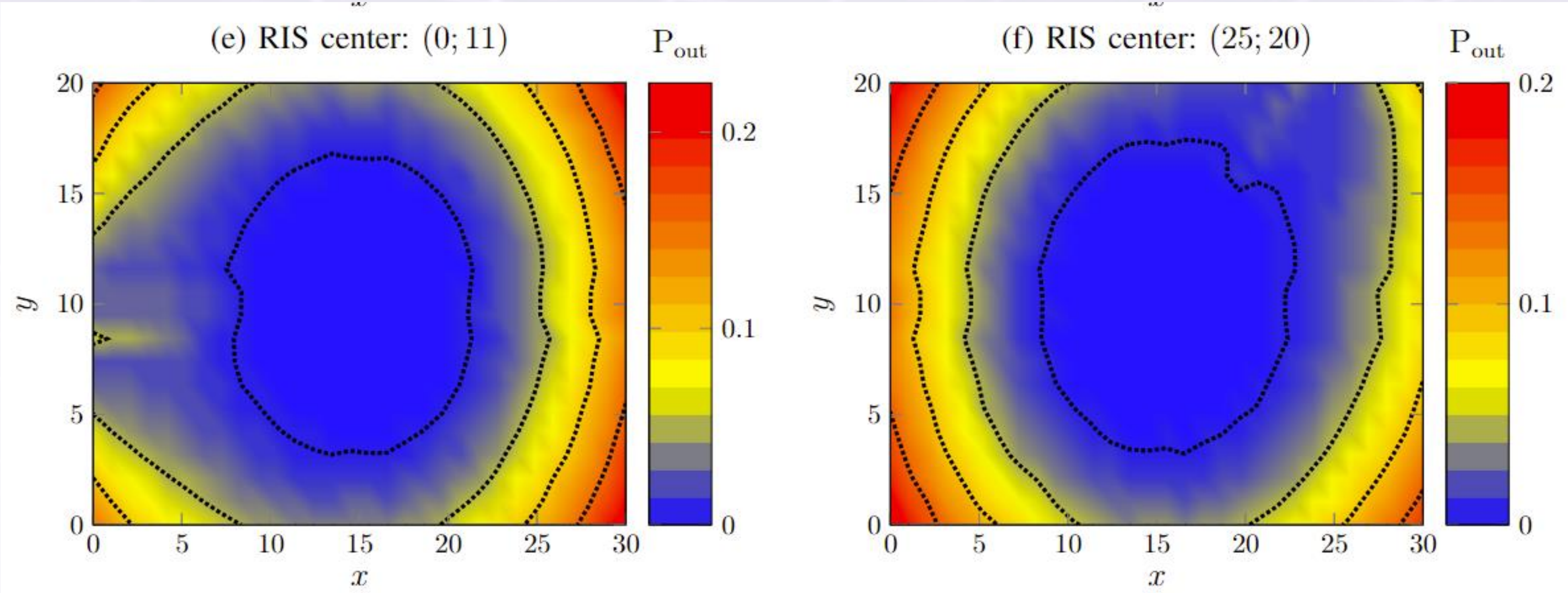
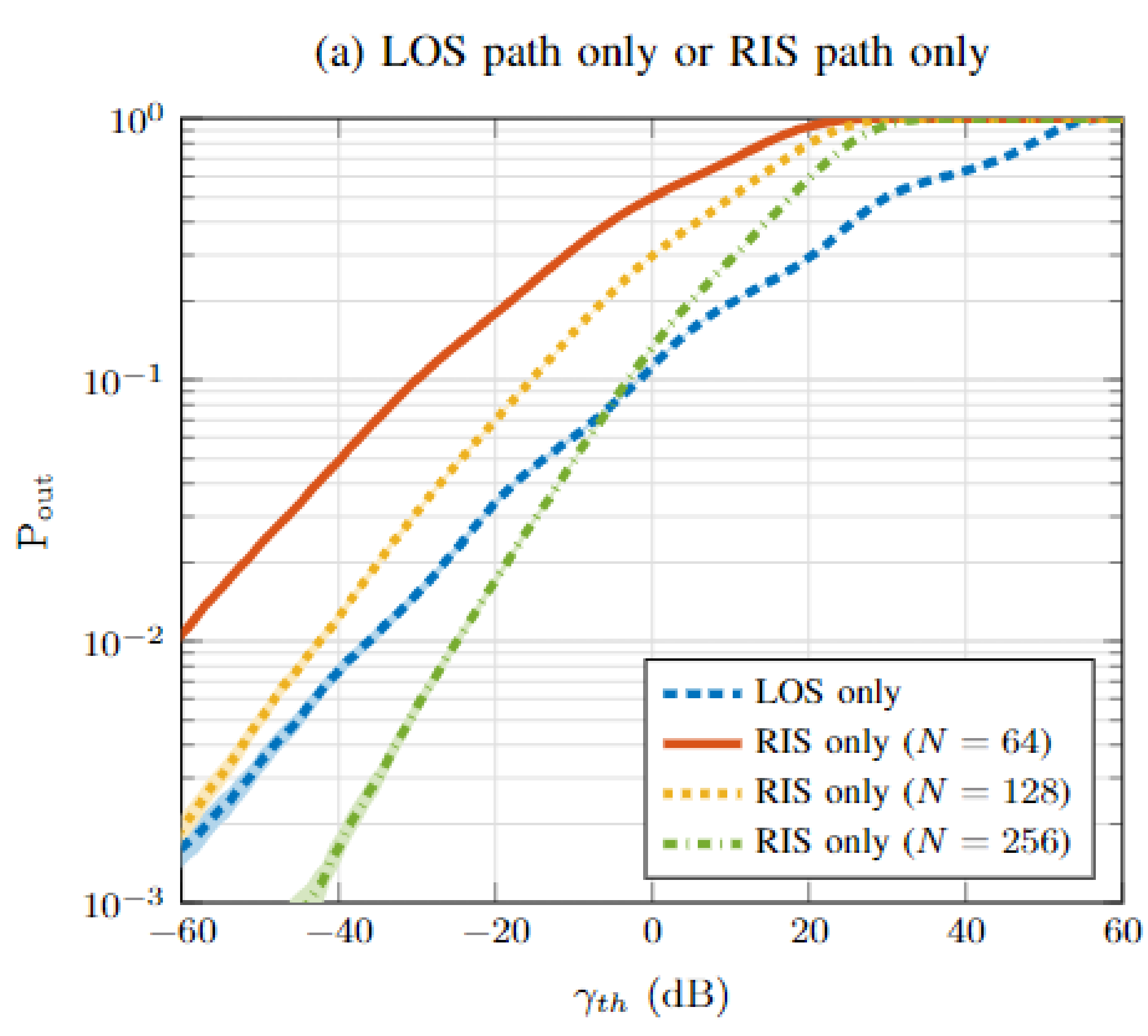


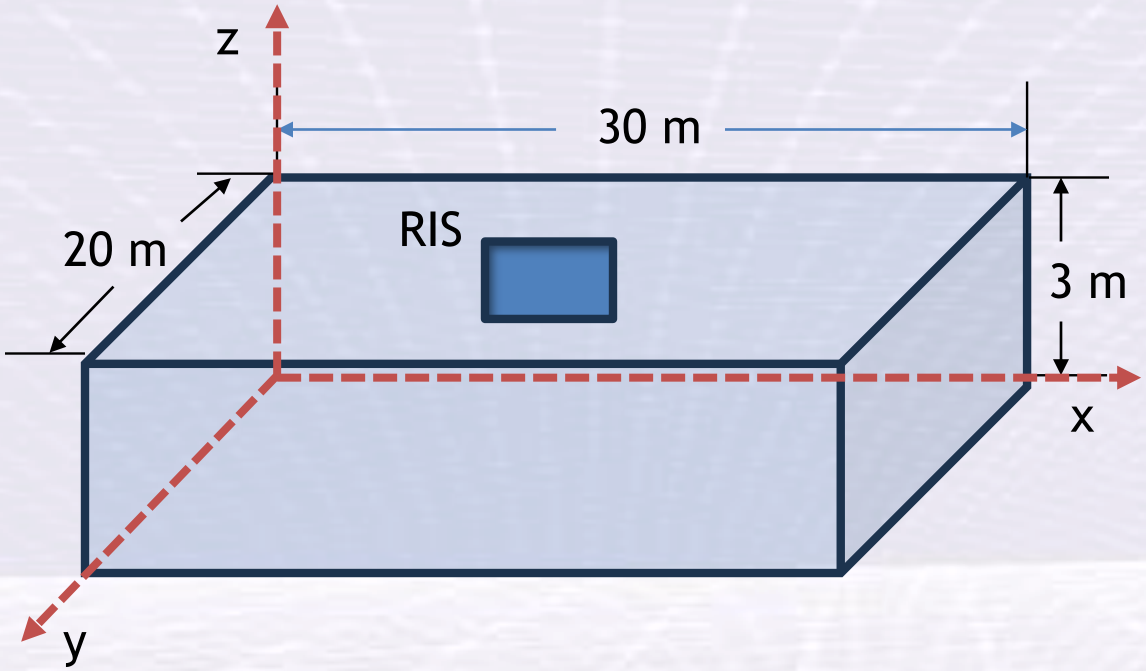
Abscence of Beamsteering

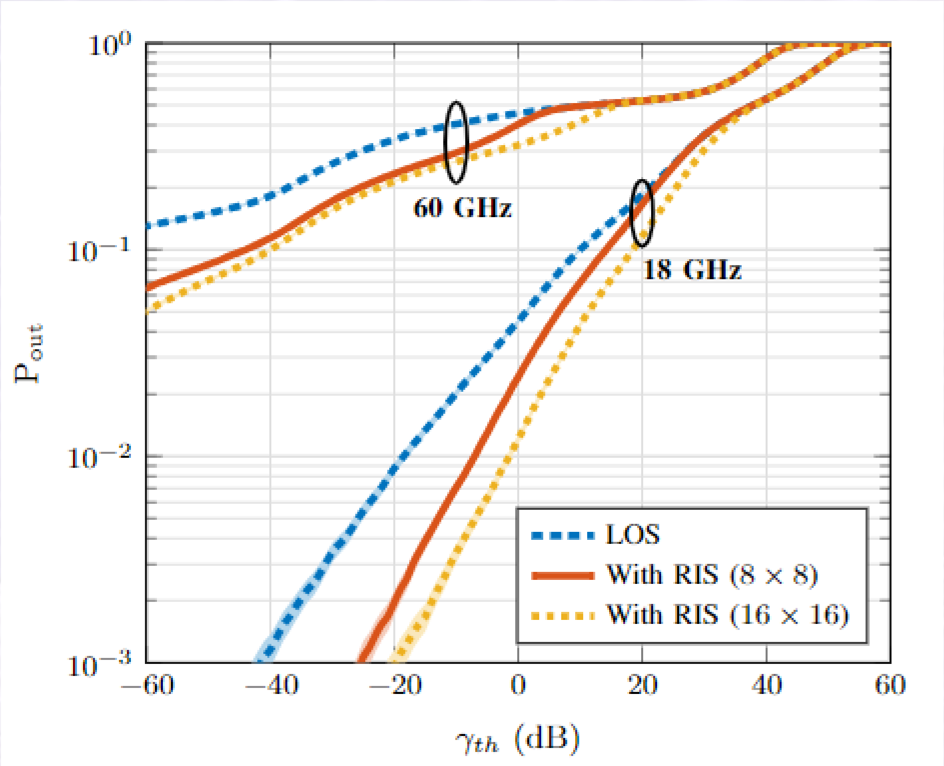
- **Objective:**
  - Evaluate the quality of the RIS path relative to LOS path.
  - Performance of the RIS path when the LOS path is blocked.



3D Indoor Case

- **Transmitter (Tx) position:** Coordinates (8, 3, 1)
- **Receiver (Rx) position:** Coordinates (15, 10, 2.5)
  - Located at the center of the room, just below the ceiling.
- **RIS center position:** Coordinates (12, 0, 1.5)





Conclusions and Future Work

- **A comprehensive path loss model of RIS-aided wireless comunication system:**
  - Include the effects of the transmission medium.
  - Consider the attenuation of obstructing objects.
- **Outage Probability Estimation:**
  - Focused on indoor scenarios with randomly located obstructions.
  - RIS positioning and Transmitter locations.
  - Beamsteering scenarios.
  - A 3D indoor case.
- **Future work**
  - Develop and propose simplified models for RIS-aided systems.

Acknowledgments

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SECRETARÍA DE ESTADO DE TELECOMUNICACIONES E INFRAESTRUCTURAS DIGITALES

Financiado por la Unión Europea NextGenerationEU

Plan de Recuperación, Transformación y Resiliencia

UNICO 5G I+D

Questions?

References

- **Path loss model of RIS-assisted system:**

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