MATLAB Toolbox Development For The Research Community: SimRIS Channel Simulator

İbrahim Yıldırım
Visiting Research Fellow, Broadband Comm Research Lab, McGill Uni, Canada
PhD Student, CoreLab, Koç University, Turkey
Research Assistant, Istanbul Technical University, Turkey
ibrahimyildirim19@ku.edu.tr

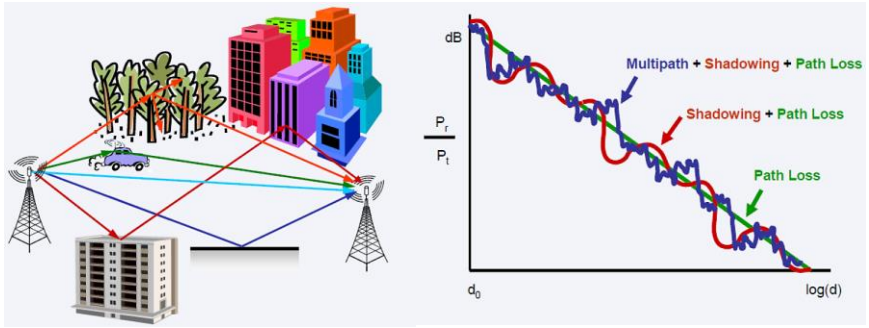
1. Introducton and Motivation:

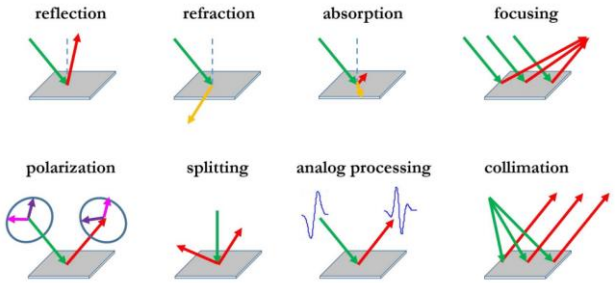
Wireless 2.0: Intelligent Radio Environments

- The propagation medium
  - a randomly behaving entity between the Tx and the Rx
  - degrading the quality of the received signal
  - uncontrollable interactions of the transmitted radio waves with the surrounding objects.
- **Reconfigurable intelligent surfaces (RISs)**
  - man-made surfaces of electromagnetic (EM) material
  - electronically controlled with integrated electronics
  - have **unique** and **adaptive** wireless communication capabilities.

Motivation:

- Can we exploit the randomness of the channel by using an RIS that placed in environment?
- Can we manipulate reflection/scattering/refraction characteristics of incoming wave?



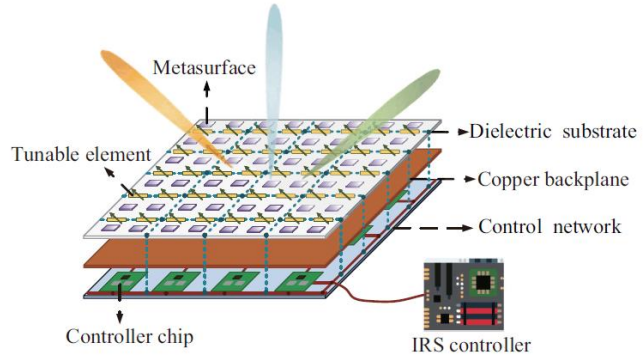


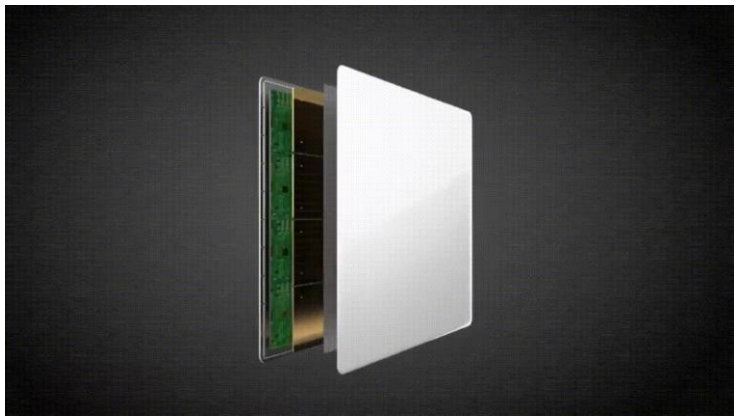
[3] M. Di Renzo *et al.*, "Smart Radio Environments Empowered by Reconfigurable Intelligent Surfaces: How It Works, State of Research, and The Road Ahead," in IEEE Journal on Selected Areas in Commun., vol. 38, no. 11, pp. 2450-2525, Nov. 2020

1. Introducton and Motivation:

Wireless 2.0: Intelligent Radio Environments

- Reconfigurable intelligent surfaces/walls/reflect-arrays/metasurfaces
  → smart devices that control the propagation environment with the aim of improving the coverage and signal quality.
- The large number of small, low-cost, and passive elements on a RIS only reflect the incident signal with an adjustable phase shift without requiring a dedicated energy source for RF processing, decoding, encoding, or retransmission.





re-engineering the electromagnetic waves…

W. Long, R. Chen, M. Marco, W. Zhang, J. Li. A Promising Technology for 6G Wireless Networks: Intelligent Reflecting Surface[J]. Journal of Communications and Information Networks, 2021, 6(1): 1-16.

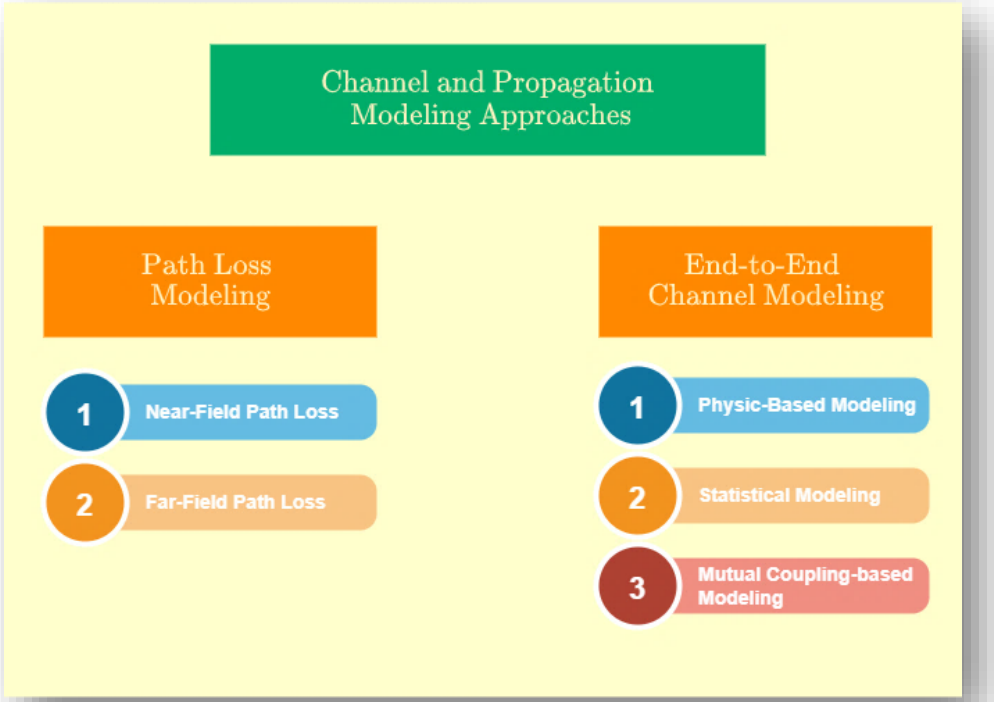
2. Channel Modeling in RIS-Empowered Wireless Communications

A General Perspective on RIS Channel Modeling

- RIS-empowered communication has received growing interest from the wireless research community due to its undeniable potential in
  - → extending the coverage,
  - → enhancing the link capacity,
  - → mitigating interference, deep fading, and Doppler effects,
  - → increasing the PHY security.

- !There is an urgent need for a physical and widely applicable mmWave channel model to be used in various RIS-assisted systems in indoor and outdoor environments!

! In our work, we aim to fill an important gap in the open literature by providing an accurate, open-source, and widely applicable RIS channel model for mmWave frequencies. !

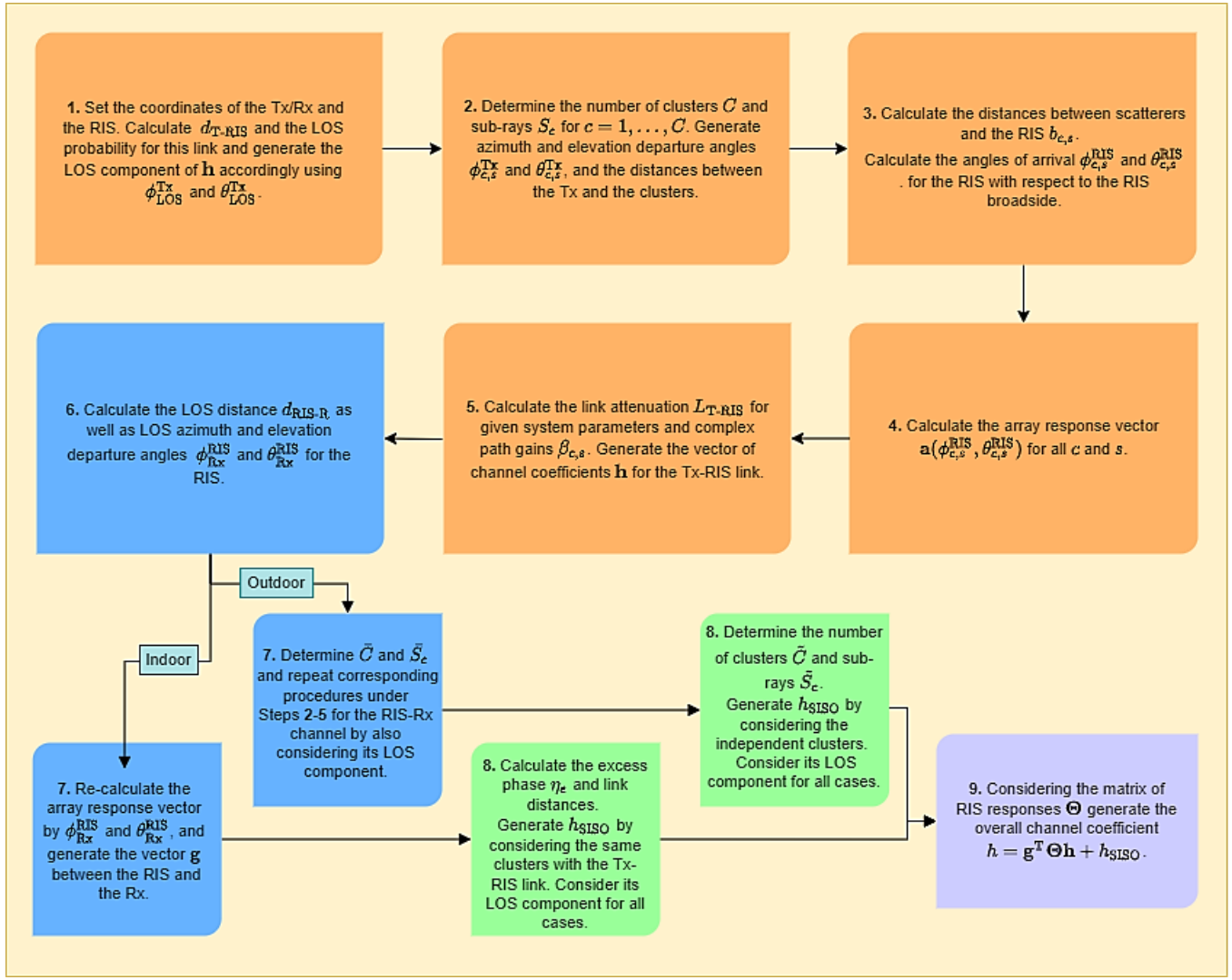


Classification of the channel and propagation modeling approaches based on the existing RIS literature.

I.Yildirim and E. Basar, "Channel Modeling in RIS-Empowered Wireless Communication," Jan. 2022. [Online]. Available: https://arxiv.org/abs/2201.06241 (Book Chapter of Wiley Book on *Intelligent Reconfigurable Surfaces (IRS) for Prospective 6G Wireless Networks*)

2. Channel Modeling in RIS-Empowered Wireless Communications

Indoor and Outdoor Physical Channel Modeling in mmWave Bands



$$\mathbf{h} = \gamma \sum_{c=1}^{C} \sum_{s=1}^{S_c} \beta_{c,s} \sqrt{G_e(\theta_{c,s}^{\text{RIS}}) L_{c,s}^{\text{RIS}}}\, \mathbf{a}(\phi_{c,s}^{\text{RIS}}, \theta_{c,s}^{\text{RIS}}) + \mathbf{h}_{\text{LOS}}$$

$$\mathbf{h}_{\text{LOS}} = I_{\text{h}}(d_{\text{T-RIS}}) \sqrt{G_e(\theta_{\text{LOS}}^{\text{RIS}}) L_{\text{LOS}}^{\text{T-RIS}}}\, e^{j\eta} \mathbf{a}(\phi_{\text{LOS}}^{\text{RIS}}, \theta_{\text{LOS}}^{\text{RIS}})$$

$$\mathbf{g} = \sqrt{G_e(\theta_{\text{Rx}}^{\text{RIS}}) L_{\text{LOS}}^{\text{RIS-R}}}\, e^{j\eta} \mathbf{a}(\phi_{\text{Rx}}^{\text{RIS}}, \theta_{\text{Rx}}^{\text{RIS}}). \quad \text{(Ind.)}$$

$$\mathbf{g} = \bar{\gamma} \sum_{c=1}^{\bar{C}} \sum_{s=1}^{\bar{S}_c} \bar{\beta}_{c,s} \sqrt{G_e(\theta_{c,s}^{\text{Rx}}) L_{\text{RIS-R}}}\, \mathbf{a}(\phi_{c,s}^{\text{Rx}}, \theta_{c,s}^{\text{Rx}}) + \mathbf{g}_{\text{LOS}} \quad \text{(Out.)}$$

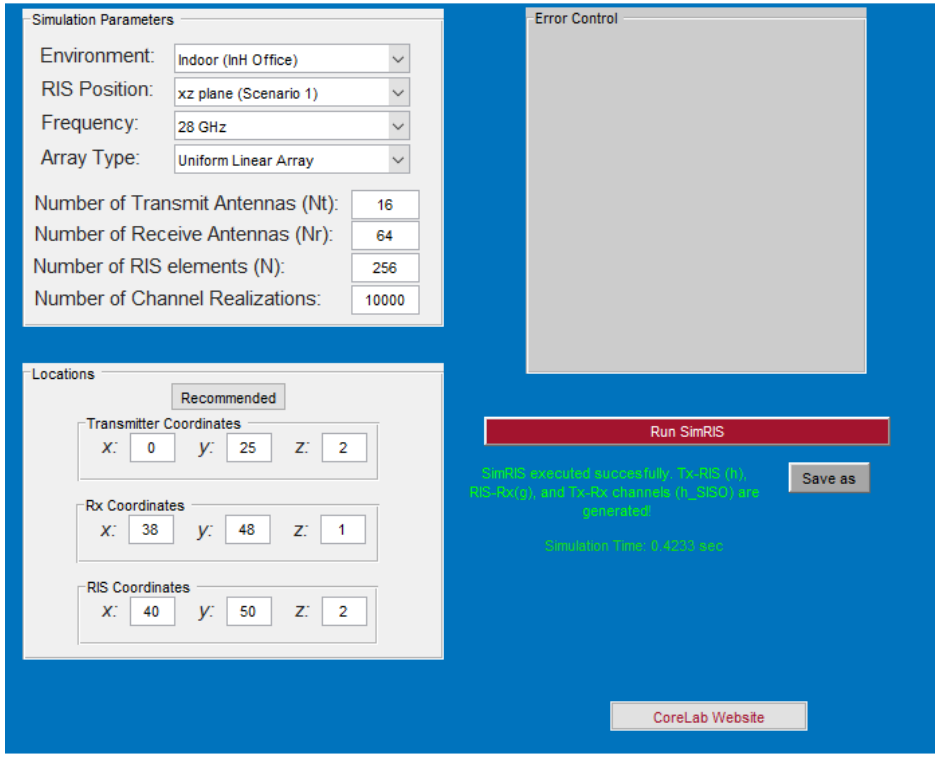
$$h_{\text{SISO}} = \gamma \sum_{c=1}^{C} \sum_{s=1}^{S_c} \beta_{c,s} e^{j\eta_e} \sqrt{L_{c,s}^{\text{SISO}}} + h_{\text{LOS}}$$

$$y = \left(\mathbf{g}^{\text{T}} \boldsymbol{\Theta} \mathbf{h} + h_{\text{SISO}}\right) x$$

E. Basar, I. Yildirim and F. Kilinc, "Indoor and Outdoor Physical Channel Modeling and Efficient Positioning for Reconfigurable Intelligent Surfaces in mmWave Bands," in IEEE Transactions on Communications, vol. 69, no. 12, pp. 8600-8611, Dec. 2021.

3. MATLAB-Based Open Source Simulator

SimRIS Channel Simulator



Graphical user interface (GUI) of the SimRIS Channel Simulator

- ***SimRIS Channel Simulator***: An accurate, open-source, and widely applicable RIS channel model for mmWave frequencies.
- User-selectable parameters
- Channel modeling of RIS-assisted systems with
  - tunable operating frequency,
  - terminal locations,
  - number of antennas and RIS elements, and
  - environments.

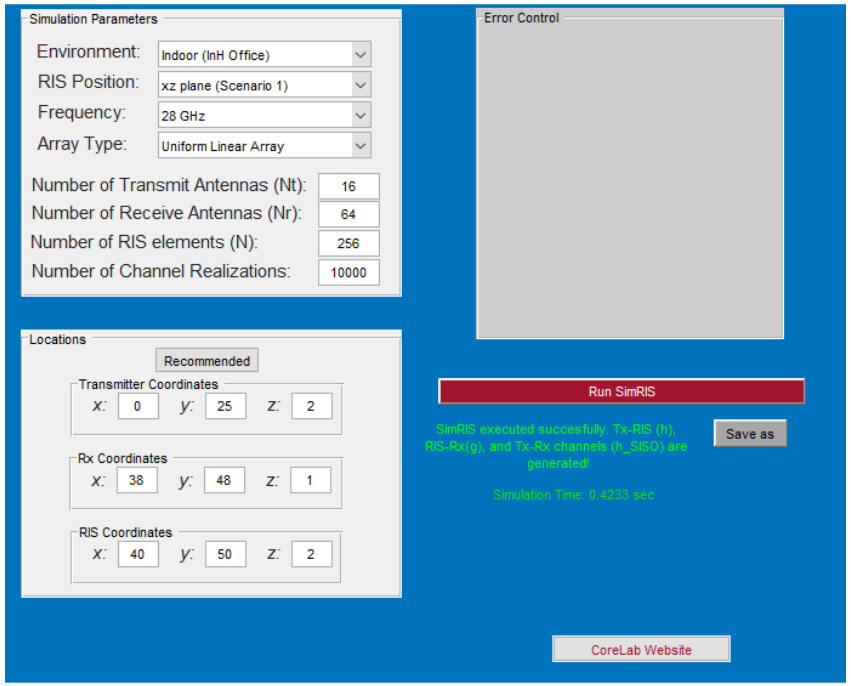
- **Environments:** InH Indoor Office and UMi Street Canyon
- **Frequencies:** 28 GHz and 73 GHz.

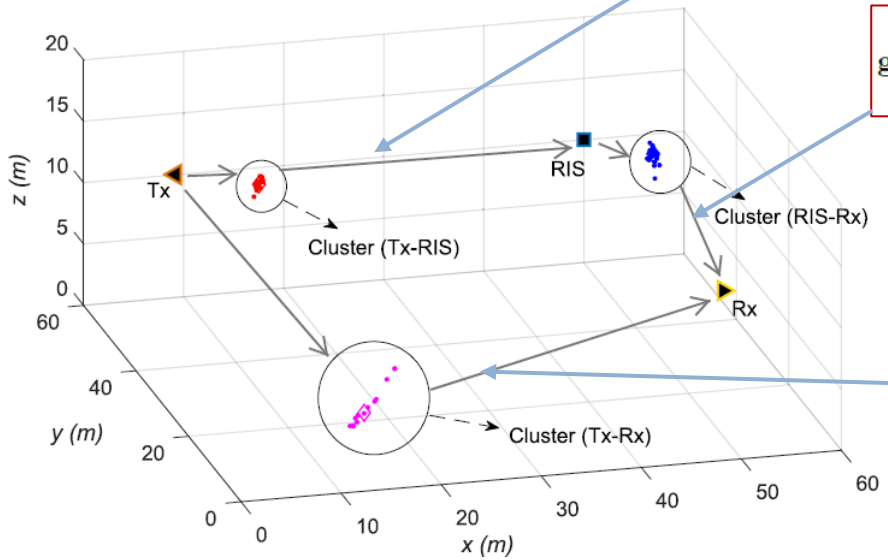
Codes available at
https://www.mathworks.com/matlabcentral/fileexchange/133422-simris-channel-simulator-for-ris-aided-communication-systems

E. Basar and I. Yildirim, "SimRIS Channel Simulator for Reconfigurable Intelligent Surface-Empowered Communication Systems," *2020 IEEE Latin-American Conference on Communications (LATINCOM)*, 2020, pp. 1-6

3. MATLAB-Based Open Source Simulator

SimRIS Channel Simulator





$$\mathbf{h} = \gamma \sum_{c=1}^{C} \sum_{s=1}^{S_c} \beta_{c,s} \sqrt{G_e(\theta_{c,s}^{\text{RIS}}) L_{c,s}^{\text{RIS}}}\ \mathbf{a}(\phi_{c,s}^{\text{RIS}}, \theta_{c,s}^{\text{RIS}}) + \mathbf{h}_{\text{LOS}}$$

$$\mathbf{g} = \bar{\gamma} \sum_{c=1}^{\bar{C}} \sum_{s=1}^{\bar{S}_c} \bar{\beta}_{c,s} \sqrt{G_e(\theta_{c,s}^{\text{Rx}}) L_{c,s}^{\text{Rx}}}\ \mathbf{a}(\phi_{c,s}^{\text{Rx}}, \theta_{c,s}^{\text{Rx}}) + \mathbf{g}_{\text{LOS}}$$

$$p = \min(20/d, 1)(1 - e^{-d/39}) + e^{-d/39}$$

$$h_{\text{SISO}} = \tilde{\gamma} \sum_{c=1}^{\tilde{C}} \sum_{s=1}^{\tilde{S}_c} \tilde{\beta}_{c,s} \sqrt{L_{c,s}^{\text{SISO}}} + h_{\text{LOS}}$$

$$y = \left(\mathbf{g}^{\mathrm{T}} \boldsymbol{\Theta} \mathbf{h} + h_{\text{SISO}}\right) x$$

KOÇ UNIVERSITY

CORELAB
Communications Research and Innovation Laboratory

Graphical user interface (GUI) of the SimRIS Channel Simulator

Codes available at
https://www.mathworks.com/matlabcentral/fileexchange/133422-simris-channel-simulator-for-ris-aided-communication-systems

E. Basar and I. Yildirim, "SimRIS Channel Simulator for Reconfigurable Intelligent Surface-Empowered Communication Systems," *2020 IEEE Latin-American Conference on Communications (LATINCOM)*, 2020, pp. 1-6

FiGES

4. Benefits / added value of using MATLAB

- **Versatile and Comprehensive Environment**
  - MATLAB provides a versatile and comprehensive environment for a wide range of applications. Whether you're working on data analysis, algorithm development, image processing, or simulation, MATLAB offers an array of tools and functions tailored to different domains.
- **High-Quality Visualization**
  - One of MATLAB's standout features is its exceptional data visualization capabilities. MATLAB enables you to create publication-quality plots and charts, making it an excellent choice for presenting your results to peers, stakeholders, and the wider community.
- **Easy Integration**
  - MATLAB seamlessly integrates with other programming languages, data sources, and software tools. This means you can work with a variety of data formats and connect to external databases, making it suitable for interdisciplinary research and industry applications.
- **Access to a Rich Ecosystem**
  - The MATLAB ecosystem includes a vast library of toolboxes, add-ons, and community-contributed functions. This wealth of resources extends the capabilities of MATLAB, allowing you to solve complex problems without starting from scratch.
- **Reproducibility and Collaboration**
  - MATLAB promotes reproducibility by enabling you to capture your work in scripts and functions. Sharing your code and data with colleagues and collaborators is straightforward, fostering a collaborative research environment.

5. Results obtained and personal considerations

- **Citations**:
- Our research using the SimRIS Channel Simulator has garnered nearly **300 citations on Google Scholar**, highlighting its significant impact in the wireless communication field.
- **Global Collaboration**: Researchers worldwide have provided valuable feedback and actively collaborated with us, extending and adapting our channel modeling methods for their studies.
- **Open-Source Contribution**: The success of our work reaffirms the power of open-source tools in fostering knowledge sharing and advancing scientific research. Our commitment to open-source principles continues to drive innovation.
- **Interdisciplinary Impact**: By bridging gaps between different disciplines, we've created a dynamic research environment where ideas and expertise from various fields come together to produce insightful results.
- **Innovative Approaches**: The collaborative nature of our research has led to innovative approaches and novel solutions in the realm of wireless communication.
- **The Power of Knowledge Sharing**: Our journey emphasizes that knowledge sharing, accessibility, and collaborative efforts are essential for making meaningful contributions to the scientific community.

Indoor and outdoor physical channel modeling and efficient positioning for reconfigurable intelligent surfaces in mmWave bands E Basar, I Yildirim, F Kilinc IEEE Transactions on Communications 64 0 33 0	110	2021
Reconfigurable intelligent surfaces for future wireless networks: A channel modeling perspective E Basar, I Yildirim IEEE Wireless Communications 28 (3), 108-114 54 0 31 0	81 *	2021
SimRIS Channel Simulator for Reconfigurable Intelligent Surface-Empowered Communication Systems E Basar, I Yildirim 2020 IEEE Latin-American Conference on Communications (LATINCOM) 57 0 59 0	64	2020
Physical channel modeling for RIS-empowered wireless networks in sub-6 GHz bands F Kilinc, I Yildirim, E Basar 2021 55th Asilomar Conference on Signals, Systems, and Computers, 704-708 14 0 19 0	16	2021

6. Future plans

- **Enhancing Antenna Radiation Patterns**: Our primary goal is to enrich the transmitter and receiver antenna radiation patterns, allowing for more versatile and tailored simulations.
- **Adding Beamforming Capabilities**: We aim to integrate beamforming capabilities into the SimRIS Channel Simulator, enabling precise control and optimization of signal direction.
- **Simulating Different RIS Physical Characteristics**: To reflect real-world scenarios, we plan to expand the simulator to allow the modification of RIS physical characteristics, accommodating various RIS configurations.
- **Integration of Deep Learning-Based Phase Adjustment Algorithms**: The next step involves seamlessly integrating deep learning-based phase adjustment algorithms into the simulator, enhancing its adaptability and performance in complex wireless environments.
- **User-Friendly Features**: We will continue to focus on user-friendly features, such as an intuitive graphical user interface and streamlined setup, ensuring that the SimRIS Channel Simulator remains accessible to researchers and enthusiasts.
- **Wideband and Time-Varying Channels**: Our roadmap includes the development of wideband and time-varying channel models to address a broader range of wireless communication scenarios.
- **Web-Based Application**: To reach a wider audience, we are actively working on a web-based application for the SimRIS Channel Simulator, making it even more accessible

Thank you

Q&A – 5min

İbrahim Yıldırım
Visiting Research Fellow, Broadband Comm Research Lab, McGill Uni, Canada
PhD Student, CoreLab, Koç University, Turkey
Research Assistant, Istanbul Technical University, Turkey
ibrahimyildirim19@ku.edu.tr