ARIADNE

Newsletter 1/2022

Reconfigurable Intelligent Surfaces in ARIADNE's beyond Shannon Communications Framework

The ARIADNE Project

Artificial Intelligence Aided D-band Network for 5G Long Term Evolution

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Editorial

Reconfigurable Intelligent Surfaces in ARIADNE's beyond Shannon Communications Framework

In April 2022, the ARIADNE project completed its theoretical work on analysis of application of Reconfigurable Intelligent Surfaces (RIS) in future telecommunications networks within the ARIADNE's beyond Shannon Communications Framework. Currently, the achieved results are being explored within the project activities focusing on investigation of RIS aided networks supported by AI techniques and implementation of corresponding demonstrators.

Halid Hrasnica, Eurescom

The ARIADNE Concept and beyond Shannon Framework

The ARIADNE project exploits frequencies between 110-170GHz for access and backhaul links, taking advantage of breakthrough novel technology concepts, namely, the development of broadband and spectrally highly efficient RF-frontends in the D-band, the employment of Reconfigurable Intelligent meta-Surfaces (RIS) to cope with obstructed connectivity scenarios and the design of ML-based access protocols, resource and network management techniques for beyond 5G networking era. In this context, the ARIADNE project is working to transform the conventional networking system concept of a universal resources manager into a fully adaptive connectivity provider, in accordance with transmission channel and environmental characteristics, dynamic user and application requirements, and the users' mobility patterns.

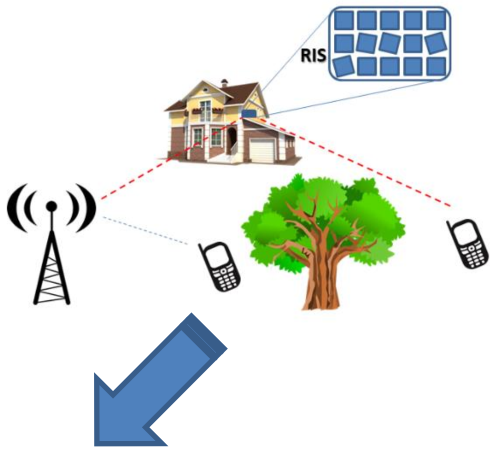
To ensure this transformation, the ARIADNE project considers using RIS-aided systems to ensure wireless communication in so-called NLOS (Non in Line Of Sight) scenarios. In these scenarios, two devices cannot communicate directly, because an obstacle, e.g., a tree or building, is preventing the connection. In such a case the connection can be ensured by redirecting the transmission signal via one or multiple RIS placed in a certain area.

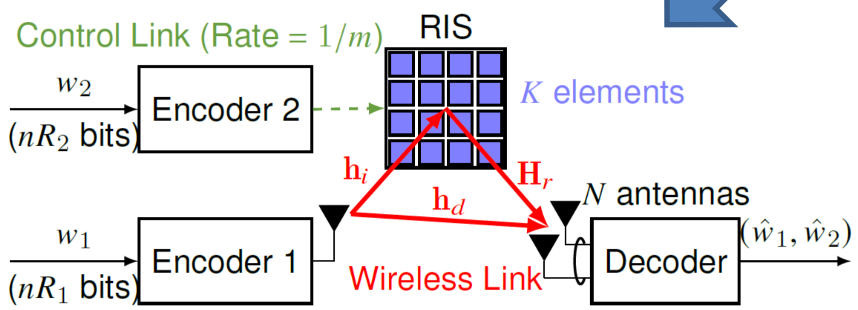
However, the RIS-aided communications require a joint optimization of the entire considered wireless communications environment, which includes not only modeling and optimization of input signals, as in the classical network characterization approach, but the entire changing and adaptive communications environment is considered as a variable. The main challenges for establishing the novel communications framework – beyond Shannon – are to ensure appropriate and accurate channel characterization and modelling, explore wave/beam-forming system capabilities, estimate blockage in the system, and more. This requires new approaches for system optimization and evaluation involving Artificial Intelligence and Machine Learning techniques to ensure programmable system design.

ARIADNE's approach and findings

The ARIADNE project considers passive RIS structures with possibly adjustable elements. The investigations have confirmed that with adequately sized RIS elements, it is possible to outperform relay-aided systems in terms of data rates and energy efficiency. The initial theoretical analysis showed that a significant capacity gain can be achieved by introducing a novel signaling approach. It is based on joint information encoding for transmitted and RIS-reflected signals, including their joint optimization. However, more accurate channel estimation is needed to ensure the capacity gain.

A first system coverage evaluation was carried out to extract an end-to-end path-gain formula, assuming a full knowledge of the system parameters at Access Points (AP) and RIS, to find out the optimal phase shift of each of the Reflection Units (RU) at RIS, estimate minimum AP transmission power ensuring full coverage, including elaboration on losses caused by molecular absorption in the system environment.





From basic RIS concept to detailed mathematical framework and analysis

Furthermore, the optimal RIS placement with respect to the position of the transmitter and receiver has been investigated. To answer this, we firstly computed the end-to-end received power and SNR under an RIS of arbitrary size. Subsequently, we provided closed-form approximate expressions for the cases of the RIS being either much smaller or larger than the transmit beam footprint at the RIS plane. Finally, based on the resulting SNR expressions, we analytically derived the optimal horizontal RIS placement that maximizes the end-to-end SNR. The analytical outcomes, which have been validated by Monte-Carlo simulations in various scenarios, reveal that: i) when the transmission beam footprint at the RIS plane is much larger than the RIS size, the optimal RIS placement is either close to the TX, RX, or the middle of the TX-RX horizontal distance, depending on the system parameters; ii) when the footprint is equal to or smaller than the RIS size, the optimal RIS placement is close to the RX. Such outcomes can be readily used by the system designer to properly deploy RISs in a way that the system performance is maximized.

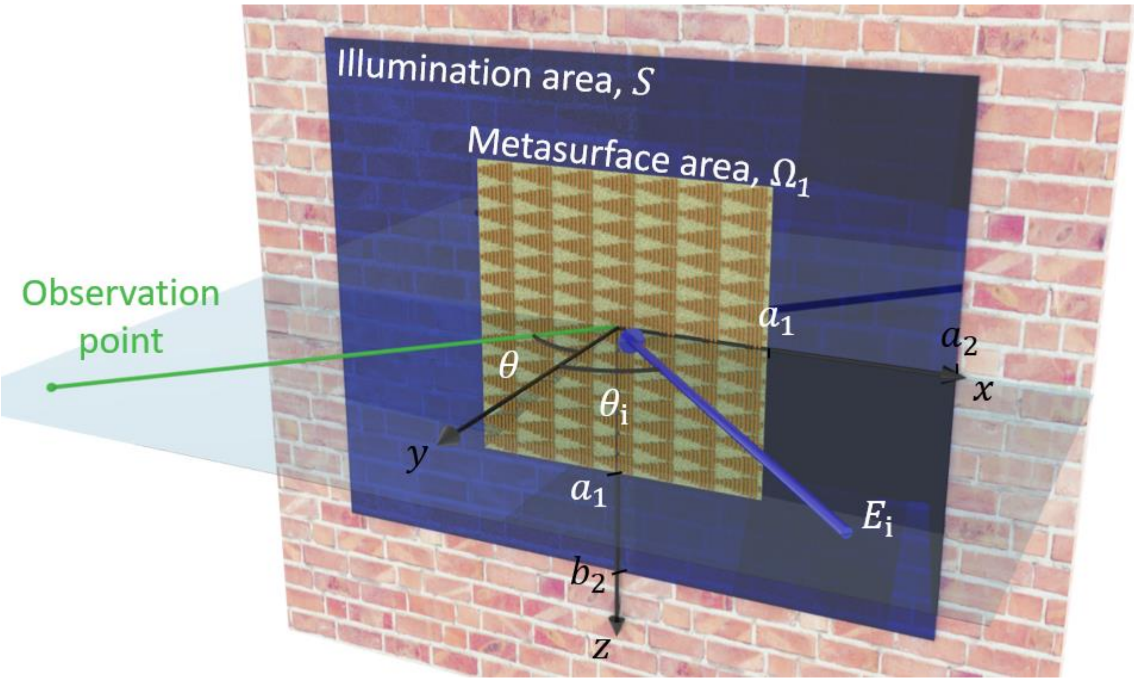
In addition, a line of works has started targeting the possibility of supplying the energy consumption needs of the RIS through wireless energy harvesting from information signals. Towards this, we first identified the main RIS power-consuming components and then proposed an energy harvesting and power consumption model. Furthermore, we formulated and solved the problem of the optimal RIS placement together with the amplitude and phase response adjustment of its elements in order to maximize the signal-to-noise ratio (SNR) while harvesting sufficient energy for its operation. Finally, numerical results validated the autonomous operation potential and reveal the range of power consumption values that enables it. The results from this study can help the system designer identify the design requirements of future ultra-low power components in order to materialize the vision of autonomous RIS operation.

Metasurfaces - Implementation and demonstration

Novel reflecting surfaces – metasurfaces - can be implied for dramatic enhancement of new generations network coverage. Known methods for theoretical characterization and design of such reflectors are based on a so-called conventional phase-gradient reflectors (reflect-arrays) approach. However, this approach has a number of limitations, leading to reduced reflection efficiency and overestimations of the channel characteristics. In ARIADNE, we apply a novel method of nonlocal optimization for metasurface reflectors, that allows us to obtain theoretically perfect reflection for the desired functionality. Using this method we develop and investigate reflection from finite-sized reflectors mounted on walls with realistic scenarios of prospective indoor communications.

As a particular example, we have developed an analytical model of far-field scattering from anomalously reflecting metasurfaces of a finite size and discussed the features of reflected fields that cannot be found using existing models. Another analysis was focused on clear physical understanding of scattering from these metasurfaces illuminated from different directions. Our analytical results are supported by full-wave simulations.

As a final goal within this project, our work is targeted on an indoor demonstration of the developed and experimentally realized metasurfaces for the next generations of wireless communications systems, as presented below.



Schematic representation of a finite-size reflective metasurface mounted over an impenetrable wall. The incident signal, created by a directive antenna, is reflected towards the desired direction

Related ARIADNE scientific contributions

ARIADNE Guest Editorial

Special issue of the IEEE Journal on Selected Areas in Communications (IEEE J-SAC) on the topic "Beyond Shannon Communications: A Paradigm Shift to Catalyze 6G.

The members of the ARIADNE team are guest editors of a special issue of the IEEE Journal on Selected Areas in Communications (IEEE J-SAC) on the topic "Beyond Shannon Communications: A Paradigm Shift to Catalyze 6G", which will be published in the second quarter of 2023. Topics of interest of the journal include but are not limited to the following:

- Reconfigurable Intelligent Surfaces in wireless systems: channel models, fundamental performance, algorithm and protocol design
- Holographic MIMO communication systems: physics-based modeling, signal processing, network optimization and emerging applications
- 3D connectivity and intelligence support wireless systems
- Semantics-native and goal-oriented communication systems: critical components modeling and validation, mathematical frameworks, fundamental trade-offs and limits
- Artificial Intelligence/Machine Learning for wireless systems modeling, analysis, design and optimization
- System architecture and HW design implications for Beyond Shannon 6G paradigms

Deadline for contributions is on 1 August 2022 – more information is available at ARIADNE project website.

Workshops organized so far

Until now, the members of the ARIADNE project consortium published a number of papers in recognized journals and magazines as well as at relevant conferences. Furthermore, the project also organized several workshops on RIS related research, as listed in annex of the newsletter.

- Network Management workshop at EUCNC 2021 – with other B5G projects of 5G PPP
- IEEE MeditCom, 7-10 September 2021, Athens, Greece – ARIADNE Workshop on Reconfigurable Intelligent Surfaces: A Technology Enabler to catalyze 6G
- IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), 13-16 September 2021, Helsinki – workshop with RISE-6G and AIMM projects - Workshop on Reconfigurable Intelligent Surfaces for B5G/6G
- IEEE Global Communications Conference (GLOBECOM 2021), 7-11 December 2021, Madrid - WS-19: Workshop on Reconfigurable Intelligent Surfaces for Future Wireless Communications

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Project Consortium

This project has received funding from the European Horizon 2020 Programme under grant agreement number 871464 – ARIADNE

Imprint:

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