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Reconfigurable Intelligent Surface-Empowered 6G

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Preface

Launching from fifth-generation communications, which provide a single platform enabling a variety of data services, evolution towards sixth-generation (6G) has been kicked off, envisioning future wireless networks to become distributed intelligent communications, sensing, and localization systems. Though such a demand has gained support from existing techniques such as massive MIMO and small cells, they heavily depend on the quality of the uncontrollable wireless environments. Differently, reconfigurable intelligent surface (RIS) as a new type of ultra-thin meta material inlaid with multiple sub-wavelength scatters can create favorable propagation conditions by controlling the phase shifts of the reflected waves at the surface such that the received signals are directly reflected towards the receivers without any extra cost of power sources or hardware. It provides a revolutionarily new approach to actively improve the link quality and coverage, which sheds light into the future 6G. Due to the coupling between radio propagation and discrete phase shifts of RIS, existing protocols and design methodologies cannot be directly applied any more. Therefore, it is essential to develop new communication and signal processing techniques and to explore various RIS-based applications such as intelligent sensing and localization.

In this book, novel RIS-based smart radio techniques are discussed, targeting at achieving high-quality channel links in cellular communications via design and optimization of RIS construction. Unlike traditional antenna arrays, three unique characteristics of RIS will be revealed. First, the built-in programmable configuration of RIS enables analog beamforming inherently without extra hardware or signal processing. Second, the incident signals can be controlled to partly reflect and partly transmit through the RIS simultaneously, adding more flexibility to signal transmission. Third, RIS has no digital processing capability to actively send signals nor any radio frequency (RF) components. As such, it is necessary to develop novel channel estimation and communication protocols, design joint digital and RIS-based analog beamforming schemes, and perform interference control via mixed reflection and transmission.

Benefited from its ability to actively shape the propagation environment, the RIS technique is further investigated to achieve two types of wireless applications, that is, RF sensing and localization.

- In RF sensing, the influence of the sensing objectives on the wireless signal propagation can be potentially recognized by the receivers, which is then utilized to identify the objectives. Unlike traditional sensing techniques, RIS-aided sensing can actively customize the wireless channels and generate a favorable massive number of independent paths interacting with the sensing objectives. It is desirable to design RIS-based image recovery algorithms, optimize RIS configurations, and study efficient tracking methods.
- For the second application, that is, RIS aided localization, RIS is deployed between the access point (AP) and users such that the AP can analyze the reflected signals from users via different RIS configurations to obtain the accurate locations of users. However, this is a challenging task due to the dynamic user topology as well as the mutual influence between multiple users and the RIS. Therefore, the operations of RIS, AP, and multiple users need to be carefully coordinated. A new RIS-based localization protocol for device cooperation and an RIS configuration optimization algorithm are also required. Implementations with respect to different real-world scenarios will be delivered to illustrate the proposed approaches separately in the above applications.

The aim of this book is to educate control and signal processing engineers, computer and information scientists, applied mathematicians and statisticians, as well as systems engineers to carve out the role that analytical and experimental engineering has to play in RIS research and development. This book will emphasize on RIS technologies and applications for future communications.

This book is organized as below. Chapter 1 provides an overview of RISs and introduces fundamentals of RIS aided wireless communications. In Chap. 2, we present some study cases on RIS-aided multi-input multi-output (MIMO) communications. In Chap. 3, we show how to integrate RISs into existing wireless technologies. Finally, in Chap. 4, we give study cases to show the possible applications in RF sensing and localization.

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Contents

Acronyms

2D	Two-Dimensional
3D	Three-Dimensional
5G	Fifth-Generation
6G	Sixth-Generation
ADC	Analog-Digital Converter
AF	Amplify-and-Forward
AoA	Angle-of-Arrival
AP	Access Point
BS	Base Station
CDF	Cumulative Distribution Function
CPU	Central Processing Unit
CSI	Channel State Information
DAS	Distributed Antenna System
DC	Difference of Concave/Convex Functions
DF	Decode-and-Forward
D2D	Device-to-Device
EM	Electromagnetic
eMBB	Enhanced Mobile Broadband
FGPA	Field-Programmable Gate Array
GPS	Global Positioning System
HBF	Hybrid Beamforming
IRS	Intelligent Reflecting Surface
ISI	Inter-symbol Interference
IOS	Intelligent Omni-surface
IoT	Internet-of-Things
LNA	Low-Noise Amplifiers
LoS	Line-of-Sight
MDP	Markov Decision Process
MIMO	Multiple-Input and Multiple-Output
MLP	Multi-Layer Perceptrons
mMTC	Massive Machine Type Communications

MU	Mobile User
NLoS	Non-Line-of-Sight
NN	Neural Network
PIN	Positive Intrinsic Negative
PPS	Pulses-per-Second
QoS	Quality of Services
RF	Radio Frequency
RFID	Radio Frequency Identification
RIS	Reconfigurable Intelligent Surface
RSS	Received Signal Strength
SA	Simulated Annealing
SBS	Small Base Station
SDP	Semi-definite Program
SINR	Signal-to-Interference-plus-Noise Ratio
SNR	Signal-to-Noise Ratio
SOI	Space of Interest
TOA	Time-of-Arrival
TDM	Time Division Multiplex
UAV	Unmanned Aerial Vehicle
UE	User Equipment
URLLC	Ultra-reliable and Low Latency Communications
USRP	Universal Software Radio Peripheral
WLAN	Wireless Local Area Network
ZF	Zero-Forcing