Abstract

With the evolution of wireless technologies beyond 5G and toward 6G, there is an increasing emphasis on achieving high spectral efficiency, massive connectivity, low latency, and ultra-reliable communication for emerging applications such as the Internet of Things (IoT), autonomous systems, and smart radio environments. To meet these demands, next-generation wireless networks are expected to integrate intelligent propagation control, advanced multiple access techniques, and energy-efficient communication paradigms.

In this context, this dissertation presents a comprehensive performance analysis of reconfigurable intelligent surface (RIS)-assisted wireless communication systems, progressively extending the system model and transmission strategies to address distinct challenges related to reliability, spectral efficiency, interference management, and energy sustainability. The contributions of the thesis are structured to evolve from single-user reliability enhancement to multi-user access optimization and, finally, to ultra-low-power communication scenarios.

In the first part of the dissertation, an RIS-assisted wireless system is studied where communication between a single-antenna source and destination is facilitated through an RIS. Since acquiring channel state information (CSI) at a passive RIS is challenging, an RIS-assisted Alamouti space–time block coding (STBC) scheme is employed to virtually transmit M-ary PSK symbols without requiring multiple RF chains at the source. This approach significantly reduces hardware complexity while improving link reliability. Closed-form analytical expressions for symbol error rate (SER) and outage probability are derived and validated through simulations, highlighting the diversity benefits achievable through RIS-assisted STBC transmission.

Building upon this framework, the second part of the dissertation shifts focus to multi-user communication and spectral efficiency enhancement. A downlink STAR-RIS-assisted NOMA system with index modulation (IM) is investigated, where the STAR-RIS enables simultaneous transmission and reflection to serve users located on both sides of the metasurface. By integrating IM into the STAR-RIS–NOMA framework, additional information is conveyed through receive antenna indices, improving spectral efficiency without increasing transmit power. The bit error rate (BER) performance is analyzed under Rician fading, and the effects of RIS size, power allocation, receive antenna diversity, and channel conditions are examined via Monte Carlo simulations.

Although non-orthogonal multiple access (NOMA) enhances spectral efficiency, its performance strongly depends on perfect successive interference cancellation (SIC) and favorable channel conditions. In practical scenarios with moderate channel disparities and residual interference, the achievable gains of NOMA can be limited. To address these limitations, the third part of the dissertation introduces rate-splitting multiple access (RSMA) within a coordinated direct and relay transmission (CDRT) framework. In this system, a base station serves one user cluster directly and another via a decode-and-forward relay, with an RIS incorporated alongside the relay to form a hybrid relay network. RSMA enables flexible interference management by partially decoding and partially treating interference as noise, thereby outperforming conventional NOMA-based CDRT schemes. Analytical expressions for outage probability and ergodic capacity are derived for both half- and full-duplex relay modes and validated through simulations.

Finally, the dissertation shifts focus from spectral efficiency to energy efficiency and low-latency communication by investigating an RIS-assisted ambient backscatter communication (AmBC) system operating under both infinite and finite blocklength regimes. A segmented-RIS architecture is adopted to simultaneously enhance the source–RIS–tag and source–RIS–destination links. To capture practical circuit behavior, a non-linear energy harvesting model is incorporated. Analytical expressions for outage probability and average achievable rate are derived for infinite blocklength transmission, while block error rate (BLER), achievable rate, and system goodput are analyzed for finite blocklength transmission. The results reveal fundamental tradeoffs between reliability, latency, and energy availability, highlighting the suitability of RIS-assisted AmBC for ultra-low-power IoT applications.

Overall, this dissertation demonstrates how RIS-assisted systems can be systematically tailored to address diverse communication objectives, ranging from reliability enhancement and interference management to energy-constrained short-packet transmission, providing useful insights for the design of next-generation wireless networks.