RIScatter: Unifying Backscatter Communication and Reconfigurable Intelligent Surface

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***Abstract*—We propose RIScatter as a novel protocol that unifies Backscatter Communication (BackCom) and Reconfigurable Intelligent Surface (RIS) from a probabilistic perspective. In particular, batteryless scatter nodes powered by ambient transmission partially modulate their information and partially engineer the wireless channel. The key is to render the probability distribution of reflection states as a joint function of the information source, Channel State Information (CSI), and relative priority of coexisting links.**

***Index Terms*—Active-passive coexisting network, input distribution design, Successive Interference Cancellation (SIC)-free receiver.**

I. Introduction

Ambient Backscatter Communication (AmBC) has been recognized as a promising technology that allows low-power devices to charge and communicate wirelessly by recycling ambient radio waves [1]. The idea was extended to Symbiotic Radio (SR) where the legacy transmitter and passive node are cooperatively decoded by a co-located receiver [2]. On the other hand, Reconfigurable Intelligent Surface (RIS) is a passive signal reflector that customizes the wireless environment for signal enhancement, interference suppression, etc [3]. Those concepts essentially exploit the same physical mechanism of RF wave scattering/reflecting, but for different aims (backscatter modulation and passive beamforming).

II. RIScatter

For passive RIScatter nodes, each reflection state is simultaneously an information codeword and a passive beamforming codeword. The nodes randomize the reflection pattern over time while still guaranteeing the probability of occurrence of each state. This probability distribution is carefully designed to incorporate the backscatter information, Channel State Information (CSI), and relative priority of both coexisting links.

We also propose a low-complexity sequential decoding scheme that is readily applicable to legacy receivers. It semi-coherently decodes the weak backscatter signal using an energy detector, re-encodes for the exact reflection pattern, then coherently decodes the primary link. Therefore, backscatter detection can be viewed as part of channel training, and the impact of backscatter modulation can be modelled as dynamic passive beamforming. It only requires one additional energy comparison and re-encoding per backscatter symbol (instead of primary symbol), and can be tailored for arbitrary input distribution and spreading factor.

In a single-user multi-node Multiple-Input Single-Output (MISO) RIScatter network, we characterize the achievable primary-(total-)backscatter rate region by optimizing the input distribution at RIScatter nodes, the active beamforming at the Access Point (AP), and the energy decision regions at the user under different Quality of Service (QoS). Uniquely, our optimization problem takes into account the CSI, QoS, and backscatter constellation. This is the first proposal to reveal the importance of backscatter input distribution and decision region designs in active-passive coexisting networks.

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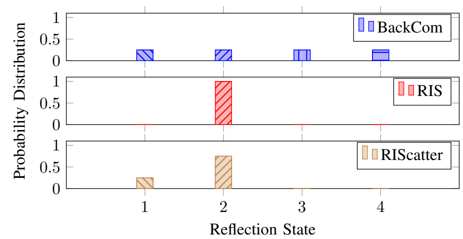
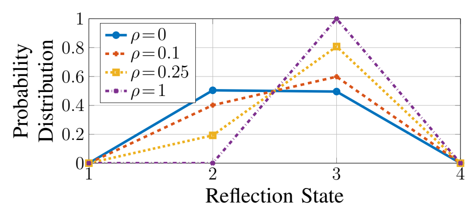
III. Results



(a) Input distribution: illustration



(b) Input distribution: simulation

Fig. 1. BackCom and RIS can be viewed as extreme cases of RIScatter, where the input distribution boils down to uniform and degenerate. ρ is the relative priority of the primary link.

At $\rho=0$ where the backscatter performance is prioritized, the optimal input distribution is 0 on two states and nearly uniform on the other two. This is inline with Shannon's observation that binary antipodal inputs is good enough for channel capacity at low Signal-to-Noise Ratio (SNR) [4]. At $\rho=1$ where the primary link is prioritized, the optimal input distribution is $[0,0,1,0]^{\mathsf{T}}$ since state 3 provides higher primary SNR than other states. That is, the reflection pattern becomes deterministic and the RIScatter node boils down to a static discrete RIS element. Increasing ρ from 0 to 1 creates a smooth transition from backscatter modulation to passive beamforming, suggesting RIScatter unifies BackCom and RIS from a probabilistic perspective.

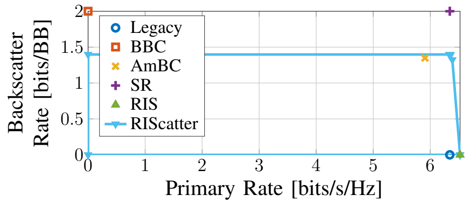


Fig. 2. Achievable rate of different scattering applications. “Legacy” means active transmission without scatter nodes. “BBC” means bistatic BackCom.

Fig. 2 suggests RIScatter enables a flexible primary-backscatter tradeoff. In terms of maximum primary rate, RIScatter coincides with RIS and outperforms the others. On the other hand, the maximum backscatter rate is higher than that of AmBC thanks to adaptive active beamforming and input distribution design. To decode each backscatter symbol, SR requires multiple re-encoding, precoding, subtraction and a time-domain Maximal Ratio Combining (MRC), while RIScatter only requires one energy comparison and re-encoding. This allows RIScatter to achieve a higher backscatter throughput at a lower cost.

IV. Appendix

Full text is available at https://arxiv.org/abs/2212.09121. Source code will be released at https://github.com/snowztail/riscatter.

References

[1] V. Liu, A. Parks, V. Talla, S. Gollakota, D. Wetherall, and J. R. Smith, “Ambient backscatter: Wireless communication out of thin air,” *ACM SIGCOMM Computer Communication Review*, vol. 43, pp. 39–50, Sep 2013.

[2] Y.-C. Liang, Q. Zhang, E. G. Larsson, and G. Y. Li, “Symbiotic radio: Cognitive backscattering communications for future wireless networks,” *IEEE Transactions on Cognitive Communications and Networking*, vol. 6, pp. 1242–1255, Dec 2020.

[3] Q. Wu, S. Zhang, B. Zheng, C. You, and R. Zhang, “Intelligent reflecting surface-aided wireless communications: A tutorial,” *IEEE Transactions on Communications*, vol. 69, pp. 3313–3351, May 2021.

[4] C. E. Shannon, “A mathematical theory of communication,” *Bell System Technical Journal*, vol. 27, pp. 379–423, Jul 1948.