Reconfigurable Intelligent Surface-Assisted Backscatter Communication: A New Frontier for Enabling 6G IoT Networks

Sarah Basharat, Syed Ali Hassan, Aamir Mahmood, Zhiguo Ding, and Mikael Gidlund

Abstract

Backscatter Communication (BackCom), which is based on passive reflection and modulation of an incident radio-frequency (RF) wave, has emerged as a cutting-edge technological paradigm for self-sustainable Internet-of-things (IoT). Nevertheless, contemporary BackCom systems are limited to short-range and low data rate applications only, rendering them insufficient on their own to support pervasive connectivity among the massive number of IoT devices. Meanwhile, wireless networks are rapidly evolving toward the smart radio paradigm. In this regard, reconfigurable intelligent surfaces (RISs) have come to the forefront to transform the wireless propagation environment into a fully controllable and customizable space in a cost-effective and energy-efficient manner. Targeting the sixth-generation (6G) horizon, we anticipate the integration of RISs into BackCom systems as a new frontier for enabling 6G IoT networks. In this article, for the first time in the open literature, we provide a tutorial overview of RIS-assisted BackCom (RIS-BackCom) systems. Specifically, we introduce the three different variants of RIS-BackCom and identify the potential improvements that can be achieved by incorporating RISs into BackCom systems. In addition, owing to the unrivaled effectiveness of non-orthogonal multiple access (NOMA), we present a case study on a RIS-assisted NOMA-enhanced BackCom system. Finally, we outline the way forward for translating this disruptive concept into real-world applications.

Introduction

The Internet-of-Things (IoT) is envisaged as one of the key technology trends toward developing intelligent Internet solutions for future sixth-generation (6G) systems [1]. The IoT paradigm targets seamlessly connecting massive power-limited, sensor-like devices, with data sensing and transmission capabilities, for realizing diverse applications, such as environmental sensing, industrial automation, pervasive monitoring, intelligent transportation, smart farming, and smart cities. IoT aims to bring the power of the Internet and data processing to the real world of physical objects. According to the Cisco report, "500 billion devices are expected to be connected to the Internet by 2030" [2]. Compared with the IoT services included in the fifth generation (5G) deployment, 6G IoT is expected to exploit high density heterogeneous devices involving extremely high throughput, supporting ultra-low-latency communications and artificial intelligence (AI)-based smart consensus algorithms [3].

Despite rapid research and evolution over recent years, IoT is still at the germination stage, awaiting a large-scale deployment and a wide-range commercialization. In many IoT applications, powering IoT devices is a major challenge, especially when battery maintenance is not feasible, due to cost, inconvenience, and the size of the networks. In this context, energy harvesting is a promising solution for self-sufficient and self-sustainable IoT network operations.

Backscatter communication (BackCom), one of the energy harvesting techniques, has emerged as an energy-efficient solution for pervasive connectivity of power-limited wireless devices in an IoT network [4]. BackCom enables the passive backscatter devices (BDs) to not only transmit information, by reflecting and modulating incident radio-frequency (RF) signals via intentional load impedance mismatch at the antenna, but also to harvest energy from the incident signals to sustain its operations. With this energy saving feature, BackCom achieves a green communication paradigm for IoT networks.

The architecture of BackCom systems has evolved over time with three different configurations, namely monostatic, bistatic, and ambient [5], as outlined below.

Monostatic BackCom Systems: In a monostatic BackCom system, such as RF identification (RFID), the carrier emitter (CE) and backscatter receiver (BR), are integrated as a single equipment, for example, a reader. The reader transmits the RF signal to the BD, which then loads its own information onto the incident signal and backscatters the modulated signal to the reader. Since the CE and BR are co-located, the modulated signal suffers from round-trip path loss. Consequently, a monostatic BackCom system is limited only to short-range applications.

Bistatic BackCom Systems: Unlike monostatic BackCom systems, the CE and BR are spatially

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separated in the bistatic configuration, thus improving system flexibility by allowing the optimal CE placement. In addition, the bistatic BackCom system improves the performance in a cost-effective manner due to a less complex design than the monostatic counterpart. However, for long-range applications, the bistatic configuration requires the dedicated RF source to be in close vicinity of BDs in an interference-limited region.

Ambient BackCom Systems: Similar to bistatic configurations, the CE is also separated from the BR in an ambient BackCom system. However, instead of a dedicated RF source, it exploits the ambient RF sources, such as TV/cellular towers, Bluetooth, or WiFi access points, which reduces the CE cost and power consumption of a dedicated CE. Moreover, ambient configuration improves spectrum resource utilization since it utilizes the existing RF signals. However, in an ambient configuration, the reader suffers from direct-link interference from the ambient signals, which adversely affects the detection performance and consequently limits the transmission range.

Despite the extensive research, a fundamental limitation exists in signal coverage and data rate of BackCom systems, hindering large-scale deployment. Therefore, alternative methods need to be developed, which can support the ubiquitous connectivity among a massive number of devices, while adapting to the dynamic nature of the wireless channels. This makes it necessary to control and manipulate the electromagnetic waves to steer the signals in the desired directions, paving a way toward the smart and reconfigurable propagation environments. In this regard, reconfigurable intelligent surfaces (RISs), also known as intelligent reflecting surfaces (IRSs), have come to the forefront to improve the propagation conditions by passive signal reflections [6–9].

Specifically, an RIS is a planar array of numerous low-cost passive reflecting elements, each capable of inducing a phase-shift in the incident signal. Through intelligent phase-shifts, the RIS reflected signal can be combined with direct link signals, either constructively, to boost the received signal strength, or destructively, to attenuate the co-channel interference, hence improving overall system performance. These properties make RIS an ideal candidate to assist BackCom systems to improve network coverage, lifetime and capacity.

As a change on the network infrastructure level, incorporating RISs into BackCom systems can pave the way for promising applications across many verticals. For instance, in a smart factory, heavy metallic objects may obstruct the communication of the BD deployed to enhance the manufacturing processes. To this end, RIS can be embedded on the wall or ceiling of the the factory hall, to bypass obstacles and establish reliable communications. Moreover, in smart agriculture, the performance of BackCom-based soil detector sensors can be significantly improved by exploiting RIS passive beamforming gains.

The rest of this article is organized as follows. The following section overviews RIS technology. We then introduce the variants of RIS-assisted BackCom (RIS-BackCom) systems. Following that, we unleash five potential improvements that can be achieved by integrating RISs into BackCom systems. A case study on an RIS-assisted, NOMA-enhanced BackCom system is then presented. Subsequently, we identify some challenges and research opportunities for realizing RIS- BackCom systems. Finally, we conclude the article.

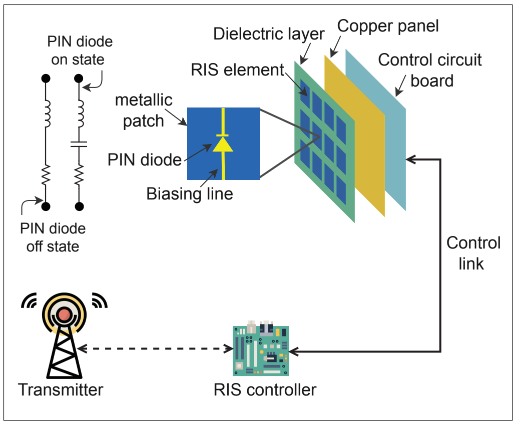

FIGURE 1. RIS hardware architecture.

RIS Technology: An Overview

In this section, to shed light on the basics of RIS technology, we provide an overview of RIS fundamentals.

Fundamental Principle

RIS implementation is based on the concept of synthetically produced two-dimensional form of electromagnetic metamaterials, known as the metasurface, which is composed of a massive number of reflecting elements, called meta-atoms [6]. The electromagnetic behavior of the metasurface is controlled by the geometrical properties, i.e, size, orientation, arrangement, etc., of the meta-atoms, thus their individual signal response, i.e., reflection amplitude and the phase-shift, can be modified accordingly. However, in wireless communication applications, the reflection coefficient of each RIS element is required to be reconfigured in real time to adapt to the dynamically fluctuating propagation environment. Fortunately, this can be realized through electronic devices, with fast response time and low reflection loss, such as positive-intrinsic-negative (PIN) diodes or field-effect transistors (FETs).

Hardware Architecture

RIS hardware architecture is composed of two parts: the multi-layer planner surface, and a smart controller [6]. In a typical three-layered architecture, as shown in Fig. 1, the outer layer consists of a large number of elements printed on a dielectric substrate to directly interact with the incident signals. The middle layer is a copper panel, which avoids any signal leakage. The inner layer is a control circuit board, responsible for adjusting the phase-shifts of each RIS element, which is managed by the smart controller, such as a field-programmable gate array (FPGA). The structure of an individual element, embedded with a positive-intrinsic-negative (PIN) diode, is also shown in Fig. 1. By controlling the voltage via biasing line, the PIN diode can be switched between on and off states to realize the phase-shift of π in radians. RIS is theoretically passive; however, in practice, it still requires a power source to sustain the operation of the controller and reconfiguring the elements.

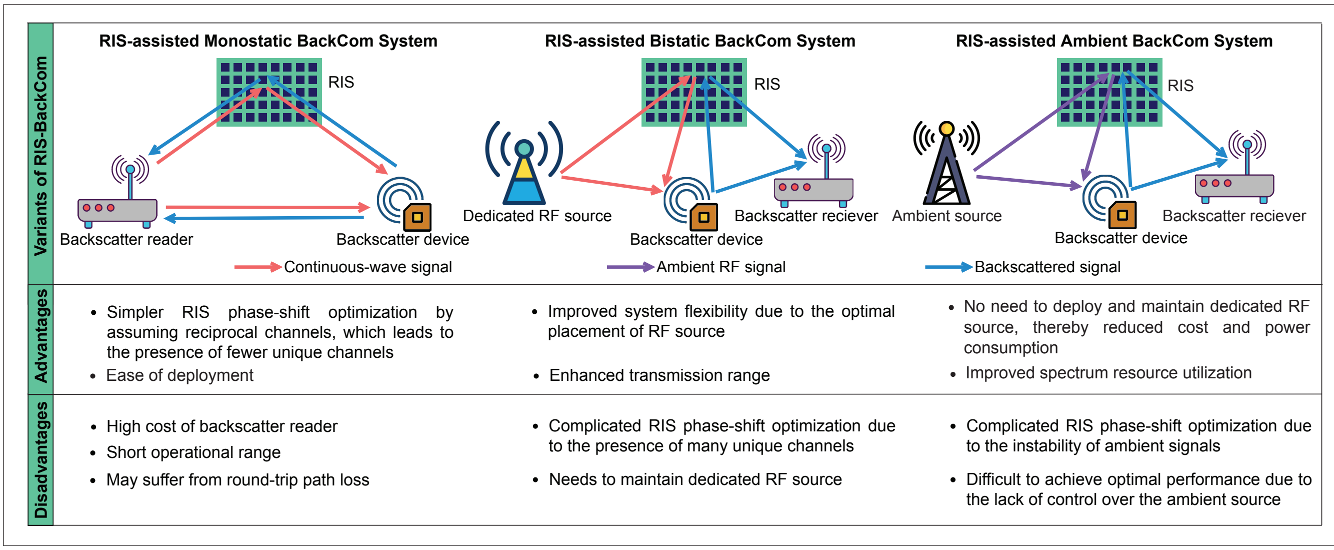

FIGURE 2. Variants of RIS-BackCom.

RIS Reconfiguration

For optimal configuration, the reflection coefficients of the RIS are calculated at the transmitter; then sent to the RIS's controller via a dedicated feedback link. The design of the reflection coefficients depends on the channel state information (CSI), which is only updated when the CSI changes on a comparatively longer time scale than the data symbol duration. Since RIS does not employ any RF chains, only the cascaded channel (i.e., the transmitter-RIS-user), can be estimated, which is, fortunately, sufficient in most cases. However, the RIS elements can be equipped with low-cost dedicated sensors to help CSI acquisition [7].

RIS and Related Technologies

The RIS technology is not only conceptually appealing, but also offers several advantages for practical implementation. Compared to conventional active relays, which require additional power for signal generation, transmission and amplification, RIS passively reflects the incident signal by introducing intelligent phase-shifts without the requirement of any active transmit module. Moreover, RIS operates in a full-duplex mode (FD), free from thermal noise and self-interference. Different from BackCom, RIS mainly assists the communication between the source and the destination, instead of sending any information of its own [9]. In addition, RIS differs from the active surface based massive multiple-input multiple-output (mMIMO), in-terms of the different operating mechanisms, that is, reflect versus transmit, and array architectures, that is, passive versus active [6].

Variants of RIS-BackCom

RIS can be incorporated into BackCom systems to realize the future green and ubiquitous communication for IoT applications. To this end, in this section, we discuss the three different variants of RIS-BackCom, as shown in Fig. 2.

RIS-Assisted Monostatic BackCom System

The communication in an RIS-assisted Monostatic BackCom system can be split into two phases, the excitation phase and the backscattering phase. In the excitation phase, the reader sends the continuous-wave (CW) signal to the BD directly, and via smart reflection from RIS. In the backscattering phase, the BD modulates the signal, and then backscatters it toward the reader via both the direct and RIS-reflected links. The intelligent phase-shifts induced at the RIS links result in the improvement of the received signal-to-noise ratio (SNR), which can be mapped to extend the transmission ranges of BDs.

RIS-Assisted Bistatic BackCom System

Similar to RIS-assisted monostatic BackCom system, in the bistatic configuration, the ability of RIS to reconfigure the wireless medium can be utilized to enhance the performance of both the forward (excitation) and the backward (backscattering) links. The direct and RIS reflected signals are added coherently, at both the BD and BR, resulting in favorable SNR scaling, which can be translated to reduce the transmit power requirement, extend the transmission ranges, and enhance the device lifetimes. Moreover, the application of RIS to a bistatic BackCom system allows the flexible placement and deployment of BDs, providing an additional degree of freedom.

RIS-Assisted Ambient BackCom System

In an RIS-assisted ambient BackCom system, the BD conveys information on the top of an already modulated ambient signal, received directly from the ambient source and via reflection from RIS. In the ambient configuration, the ability of RIS to focus the signals in the desired direction can be utilized to mitigate the direct-link interference from the ambient signals, which can improve the detection performance at low complexity. Moreover, similar to RIS-assisted monostatic and bistatic configurations, incorporating RIS in an ambient BackCom system can enhance the coverage range, data rate and energy harvesting capability at reduced transmit power requirements.

RIS-BackCom: Potential Improvements

In this section, we discuss the potential improvements that can be accomplished by incorporating RIS into BackCom systems.

Reconfigured Channel Conditions

In conventional BackCom systems, both the CW or ambient RF signal, and the backscattered signal, undergo various propagation phenomena such as reflection, diffraction and scattering, which result in multiple copies of the signals. These copies usually arrive out-of-phase at the BD, in the excitation phase; and the BR, in the backscattering phase, which produce significant distortions in the received signals, thus limiting the performance of BackCom systems. However, RIS can compensate the limitations of conventional BackCom systems. Through smart reflections, RIS can mitigate the negative effects of electromagnetic radiations, thereby improving the system performance.

RIS can establish virtual line-of-sight (LoS) links to improve the overall channel gains. For instance, in an indoor industrial IoT network deployed in a dense environment, RIS embedded on the wall or the ceiling of the industrial hall can bypass the obstacles to establish reliable communications. Moreover, optimizing RIS deployment can further improve performance by minimizing the product-distance path loss of both the forward and the backward channels. This is particularly useful for high-frequency bands, that is, millimeter waves (mmWaves), and Terahertz (THz), which are vulnerable to signal blockage and attenuation. In this regard, the authors in [10] analyzed the reliability performance of an RIS-assisted monostatic BackCom system in the absence of the LoS link between tag and the reader. The RIS-BackCom can achieve higher reliability than a relay-assisted BackCom with a massive number of RIS elements at a moderate SNR .

Enhanced Transmission Range

Despite the research achievements, conventional BackCom systems offer inherently limited range, on the order of a few meters, which is a major hurdle preventing their large-scale deployment. Specifically, monostatic systems suffer from roundtrip path loss; bistatic systems require the CE be placed very close to BDs; and ambient systems experience direct-link interference, restricting the BackCom to short-range, low-date rate applications only. However, to overcome this challenge, RIS' ability to introduce effective additional paths can be exploited to boost BDs' range and coverage.

RIS can be installed at the edge of the receiver's coverage zone to enhance the transmission range and cover the BDs located in the dead zones (regions with no signal reception). As a result, BDs' connectivity and coverage can be enhanced with the aid of RIS. For the coverage enhancement of ambient BackCom systems, the authors in [11] proposed a novel, RIS-assisted ambient BackCom technique over ambient orthogonal-frequency-division-multiplexing (OFDM) subcarriers. The proposed technique benefits from multipath gains reflected from the RIS elements, in terms of enhanced received signal power and consequently coverage.

Improved Energy Efficiency

The most attractive aspect of RIS technology, from an energy consumption standpoint, is the ability to amplify and forward the impinging signal without employing any power hungry source, but rather by appropriately designing the RIS phase-shifts to constructively combine the reflected signals. Hence, a BackCom system can benefit from the power gains realized through RIS passive reflections to achieve higher performance gains with less transmit power, which can significantly improve the energy efficiency of RIS-BackCom systems.

As an exploratory work toward an energy-efficient design for future BackCom systems, the authors in [12] proposed a novel setup for a bistatic BackCom system, where an RIS is deployed close to the CE to aid the communication between the BD and the reader. The joint optimization of a transmit beamforming vector at the CE and RIS phase-shifts can significantly reduce the transmit power consumption while guaranteeing a desired BackCom performance. The simulation results reveal the transmit power reduction of 3.5 dB by deploying an RIS with 49 reflecting elements. Hence, the application of RIS, even of moderate size, can significantly reduce the transmit power, which can be translated to improve the link budget and transmission ranges. However, currently, there is a paucity of research contributions to investigate the trade-offs between the transmit power consumption and throughput of RIS-BackCom systems for maximizing the energy efficiency, which is worth exploring in future.

Better Detection Performance

Among the three contemporary BackCom configurations, ambient BackCom is the most energy-efficient and cost-effective solution for the pervasive networking of massively deployed low-power IoT devices. Nonetheless, the robustness of ambient BackCom systems is a prominent challenge that needs to be addressed. Specifically, in ambient BackCom systems, the backscattered signal experiences direct-link interference from the ambient signals, thus rendering poor detection performance at the reader. Although the conventional methods, such as channel estimation and modification of BDs, can improve the detection performance, however, at the cost of high implementation complexity.

To tackle the aforementioned limitation, the ability of RIS to steer the signals in different directions can be exploited to suppress the direct-link interference, thus improving the detection performance at reduced complexity. In this regard, the authors in [13] proposed a deep reinforcement learning (DRL) based approach, namely the deep deterministic policy gradient (DDPG) algorithm, to optimize the performance of an RIS-assisted ambient BackCom system in CSI absence. The simulated results demonstrate the better detection performance of the proposed design over the conventional non-RIS based designs with full CSI knowledge.

High Energy Harvesting

Energy harvesting is an attractive technique toward the battery-free operation of IoT networks. However, currently, the typical energy conversion efficiency in BackCom is usually less than 20 percent. Such a poor energy harvesting performance can severely affect the self-sustainable operation of future IoT networks. To address this challenge, RIS can be exploited to improve the total received power by a coherent combination of reflected signals. Thus, enabling the BDs to har-

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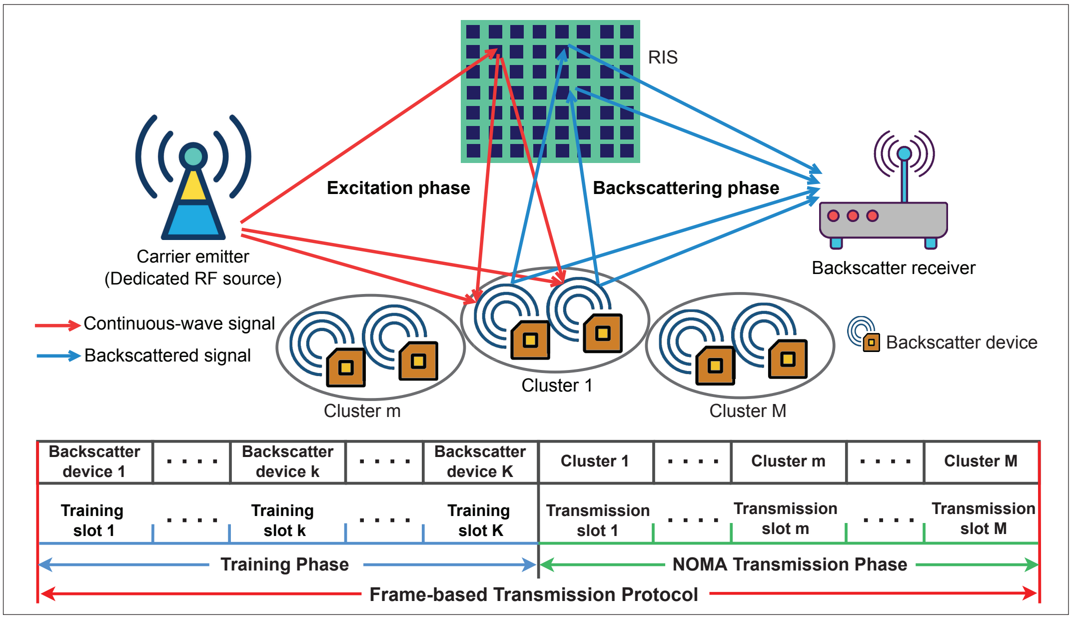

FIGURE 3. An illustration of RIS-assisted NOMA-enhanced bistatic BackCom system.

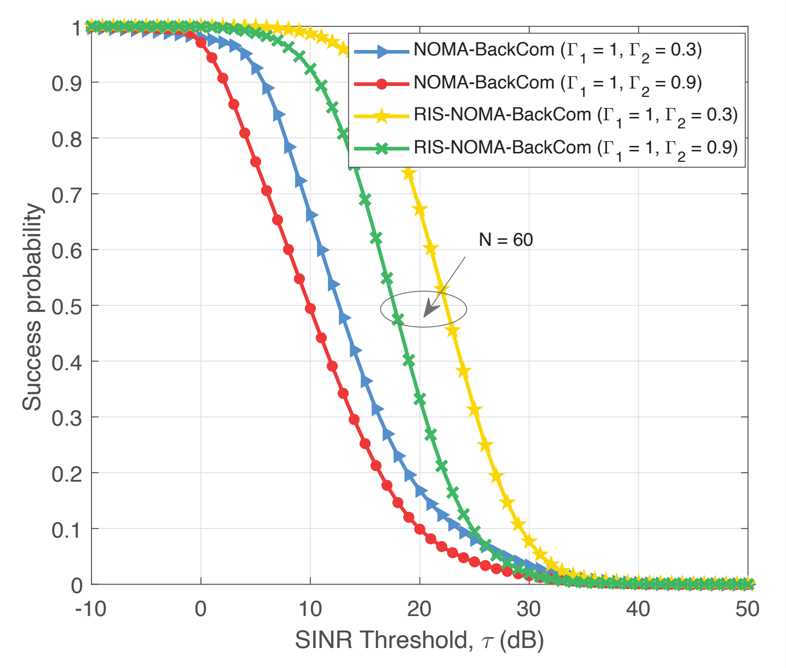

FIGURE 4. Success probability versus the SINR threshold for different values of reflection coefficients, and CE transmit power of 35 dBm.

vest energy from both the direct and RIS reflected signals, consequently, improving the total harvested energy to sustain the long-term operation of IoT networks.

Despite the exploratory works [10–13], the performance of RIS-BackCom systems in the context of energy harvesting has not been analyzed yet. Therefore, it is necessary to design efficient frame-based transmission protocols for RIS-BackCom systems to avoid destructive wireless interference among the energy harvesting and data transmission phases of the system. Moreover, to fully reap the RIS passive beamforming gain for energy harvesting, the transmit beamforming at the source needs to be jointly designed with the RIS phase-shifts.

RIS-Assisted NOMA-Enhanced BackCom System: A Case Study

To support massive connectivity of an increasing number of IoT devices, non-orthogonal multiple access (NOMA) is a promising multiple access candidate due to its capability of exploiting available resources efficiently. In NOMA-enhanced BackCom systems, multiple devices are multiplexed over the same orthogonal resource (time, frequency, code) block but with different backscattered power levels. In this way, NOMA promotes high-spectral efficiency, massive connectivity, lower latency, and better user fairness over orthogonal multiple access (OMA) techniques [14]. For the emerging 6G IoT networks, the performance of NOMA-enhanced BackCom systems can be improved by incorporating RIS. Therefore, in this section, we discuss the integration of RIS into a NOMA-enhanced bistatic BackCom system.

System Model

As illustrated in Fig. 3, we consider an RIS-assisted NOMA-enhanced bistatic BackCom system, consisting of a CE, K BDs, a receiver, and an RIS, where N reflecting elements only adjust the phases of the incident signals. The RIS is deployed to enhance the channel gains over both the excitation and backscattering phases of the bistatic BackCom system, where the CE transmits the CW signal to the BDs, while each BD modulates its information over the incident CW signal, and then backscatters it to the reader. We assume that each of the CE, BR, and BDs are equipped with a single antenna.

BackCom Model: We assume that the CE transmits the CW signal almost all the time, while each BD has two states:

- A sleep state, where the BDs harvest energy from the incident CW signals and store the harvested energy in the battery, to power the circuitry and perform sensing operations.
- An active state, where the BDs backscatter

the modulated signal to the BR by intelligently changing their load impedance.

To modulate the signal, we adopt the binary phase shift keying (BPSK) modulation. Accordingly, each impedance set can generate two reflection coefficients with the same magnitude, denoted as Γ_i, but different phase-shifts (i.e., 0° and 180°). We consider 2-BD NOMA multiplexing, therefore, each BD is equipped with two impedance sets, with the reflection coefficients Γ_1 and Γ_2, where $\Gamma_1 > \Gamma_2$ [15].

Frame-Based Transmission Protocol: As illustrated in Fig. 3, we propose a frame-based transmission protocol that integrates 2-BD NOMA multiplexing and time-division-multiple-access (TDMA) with K training slots, for the training phase; and M transmission slots, for the transmission phase. In each training slot, only one BD backscatters the CW signal with the same reflection coefficient, with all other BDs in the sleep state, and the BR estimates the BD's cascaded channel (the sum of the direct and the RIS reflected channel). Then, based on the BR's received power levels, the BDs are sorted decreasingly, and categorized sequentially into two power groups, namely the higher-power BDs and the lower-power BDs. Each higher-power BD is randomly grouped with a lower-power BD to form a cluster. In each transmission slot, only one cluster performs the NOMA transmission; with higher- and lower-power BDs switched to reflection coefficient Γ_1 and Γ_2 respectively, while the rest of the clusters remain in the sleep state.

Performance Evaluation

In this subsection, we demonstrate the performance gains achieved by integrating RIS in NOMA-enhanced bistatic BackCom systems. We assume that the RIS reflected channels, that is, channels between the RIS and the CE, BDs and BR, undergo Rician fading, with Rician factor 3 dB and path loss exponent 2.4; while all other channels experience Rayleigh fading with path loss exponent 3. All wireless channels are assumed to be mutually independent and perfectly estimated by the BR. As in [12], the CE, BR and RIS are located at [0, 0], [100, 0], and [20, 20] m, respectively, and the BDs are located between [5, 0] and [95, 0] m. The noise power at the BR is considered to be –90 dBm. The simulation results for a single cluster case are presented as follows.

Performance Improvement and the Effect of Reflection Coefficients: In Fig. 4, we evaluate the performance of the proposed RIS-assisted system (RIS-NOMA-BackCom) against the success probability, defined as the probability by which the received signal-to-interference plus noise ratio (SINR) is greater than the specified threshold, τ, required for successful decoding of each BD's signal. One can observe that for any combination of the reflection coefficients, the RIS-assisted system outperforms the no-RIS counterpart (NOMA-BackCom). Moreover, better performance can be achieved by reducing the value of Γ_2. The improved performance is because the smaller value of Γ_2 reduces the interference from the weaker signal, thus increasing the chances the stronger signal will be decoded successfully.

Effect of the RIS Location and Elements: The performance of RIS-assisted systems highly depend upon the RIS location, and the number of RIS elements. In this regard, Fig. 5 compares the cluster throughput for the RIS located at [20, 20] and [50, 20] m. First, for a given number of RIS elements and CE transmit power, the throughput decreases with the increase in the horizontal distance between the CE and RIS, owing to the increase in the pathloss of the composite channel, which is the product of the forward and backward channels. Second, the throughput scales up with the increase in the number of RIS elements. For instance, for 30 dBm CE power and RIS located at [20, 20] m, throughput is 11 bps/Hz for 40 RIS elements. While this value increases to about 15 bps/Hz for 60 RIS elements. From here, we can conclude that RIS provides passive beamforming gain, which can be either utilized to improve the BackCom system throughput, or reduce the CE power consumption.

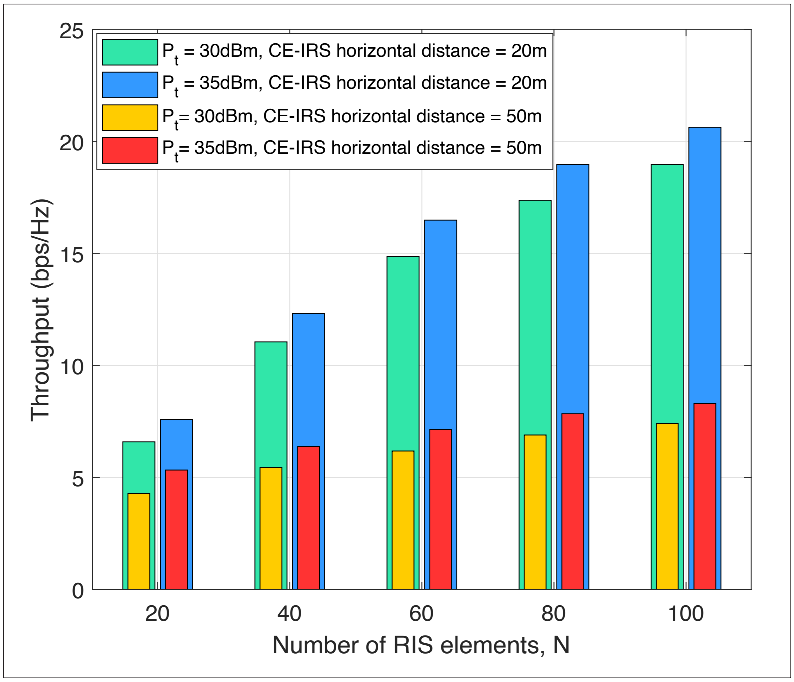

FIGURE 5. Throughput for varying number of RIS elements, CE transmit power (P_t), and RIS location with SINR threshold of 15 dB.

Energy Harvesting Performance: To evaluate the energy harvesting performance, Fig. 6 highlights the impact of the increasing number of reflecting elements at the RIS on the harvested energy in the sleep state. It can be observed that for given energy conversion efficiency, the harvested energy scales with the number of reflecting elements. For example, for 20 percent energy conversion efficiency, the harvested energy increases by 0.15 mJ when RIS elements increase from 50 to 100. Therefore, in practical BackCom systems with low energy conversion efficiency, greater energy can be harvested by deploying RIS with massive number of elements.

Challenges and Research Opportunities

Despite so many promising aspects, as a newborn concept, RIS-BackCom also raises up some challenges and research opportunities, discussed as follows.

Channel Estimation for RIS-BackCom Systems

The enormous passive beamforming gains brought by RIS highly depend on the availability

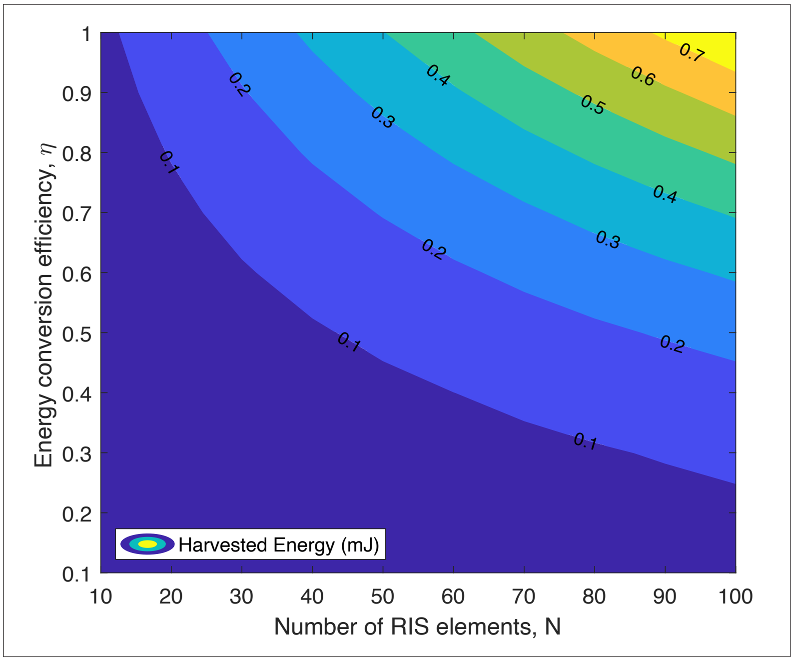

FIGURE 6. Harvested energy for varying number of RIS elements and energy conversion efficiency with CE transmit power of 30 dBm.

of CSI, which is quite challenging to acquire since passive RIS elements and backscatter devices lack signal processing capabilities. Consequently, only the composite channel can be estimated at the backscatter receiver. This limitation makes the channel estimation schemes available for conventional RIS-assisted systems inapplicable. Therefore, novel schemes must be developed for channel estimation of RIS-BackCom systems, while accounting for the practical constraints.

Mobility Scenarios

The mobility of IoT devices introduce an additional design challenge for the application of RISs to BackCom systems. In such scenarios, the transmission channels may vary according to some stochastic models, which need to be developed. Moreover, in the case of rapidly varying channels, the required capacity of the feedback link from the transmitter to the RIS also increases, thus imposing higher system overhead and cost. To guarantee the desired BackCom performance in mobility scenarios, it is imperative to develop robust optimization schemes for RIS phase-shift design and resource management.

Joint Radio Resource Management and Phase-shift Optimization

Radio resource management and RIS configuration highly impact the overall performance of RIS-BackCom systems. The joint optimization of the power reflection coefficients of the BDs, transmission time, and the RIS phase-shifts, while guaranteeing a required BackCom performance, leads to a non-convex optimization problem, which is challenging to solve in dynamic radio conditions. Therefore, efficient and low-complexity algorithms need to be developed for RIS-BackCom systems. Especially, it is imperative to develop and evaluate the AI-based resource allocation and phase-optimization schemes for RIS-BackCom systems.

RIS-BackCom versus the Relay-Aided and Multi-Antenna Backscattering

The conventional solutions to overcome the limitations of BackCom systems include relay-aided and multi-antenna backscattering. However, due to the presence of active components, such techniques may incur high power consumption, which may not be suitable for low-power applications. In this context, RIS stands as a potential solution for the future BackCom systems. However, to fully validate the potentials of RISs for BackCom systems, it is important to evaluate the performance of RIS-BackCom against the relay-aided and multi-antenna backscattering, both theoretically and experimentally, taking into account the power consumption, hardware cost and complexity.

Conclusion

In this article, we explored the integration of RISs into BackCom systems for enabling 6G IoT networks. Specifically, we first outlined the fundamentals of RIS technology to develop an understanding of RIS in BackCom. We introduced three different variants of RIS-BackCom and identified the potential improvement that can be achieved by incorporating RISs into BackCom systems. In addition, a case study for a RIS-assisted NOMA-enhanced BackCom system is presented. Our numerical results clearly demonstrated the RIS performance gains, in terms of success probability, throughput, transmit power consumption, and harvested energy. Finally, to provide useful guidance for further research, we indicated the crucial challenges and promising research directions for realizing RIS-BackCom systems.

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