Unlock Self-Sustainability of Reconfigurable Intelligent Surface in Wireless Powered IoT Networks

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***Abstract*—This article discusses the self-sustainability of reconfigurable intelligent surface (RIS) in wireless powered Internet of Things (IoT) networks. Our vision is that RIS helps improve energy harvesting and data transmission capabilities simultaneously, without the extra utilization of radio frequency (RF) spectrum and energy consumption. The inherent properties of RIS are first discussed to unveil its distinctive features, followed by a broader range of use cases motivated by the RIS as their enabling technology. The focus is on the application of RIS in the wireless powered IoT networks, and its potential to interconnect and support these practical use cases. Such an application is then thoroughly evaluated in a case study of a RIS-assisted wireless powered sensor network (WPSN), with system throughput, energy transmission time consumption, and energy harvesting as the key performance metrics. The comprehensive performance evaluation showcases the self-sustainable property of the RIS being unlocked in the considered scenario, identifying a clear pathway towards the future wireless powered IoT networks. We further pave that pathway by exploring research challenges and open issues related to emerging technological development.**

I. INTRODUCTION

The global information and communications technology (ICT) sector anticipates the success of an automated Internet of Things (IoT) network over the next decade, i.e., a wireless network with little human intervention that guarantees various types of connectivities for myriads of IoT devices in a high spectral/energy-efficient fashion. In principle, the automated IoT network analyzes and processes the data collected from vast numbers and types of sensor nodes (SNs), all by the network itself, which forms a wireless sensor network (WSN). The WSNs have already been applied to current vertical industries, e.g., structural health monitoring, healthcare diagnosis, event detection for emergency services, smart home appliances, intelligent transportation, smart manufacturing [1]. However, towards the future wireless networks that require massive or explosive connectivity such as trillions of IoT devices, it is far from sufficient for the existing multiple access techniques to facilitate the future WSNs with such a large amount of devices. The energy issue is another showstopper. Most low-power SNs in an IoT network are powered by the finite-capacity battery and require periodic maintenance to prolong their own lifetime, which can be considerably costly or sometimes infeasible for WSNs to be deployed in harsh environments, infrastructure, or human bodies. Although significant efforts have been devoted to the research and development of energy-efficient policies, the lifetime of the IoT sensors is still the bottleneck problem.

Leveraging radio frequency (RF) energy harvesting techniques by exploiting near-field and far-field radiative properties of electromagnetic (EM) waves, wireless powered communication (WPC) has been emerged as one of the potential solutions to address the energy-limited issue involved in the IoT networks [2]. In general, an energy source in WPC radiates RF energy to wireless devices (WDs) during a process called wireless energy transfer (WET), which utilizes the harvested energy to transmit/decode information to/from other devices during another process called wireless information transfer (WIT). With a controllable energy source, WPC can efficiently support the operation of WDs as a complement or viable alternative to the traditional battery-powered counterparts, and therefore potentially improve the energy efficiency of the wireless networks. Despite the anticipated efficiency, the magnitude and range issues remain unconquered for the future progress of WPC technology. Practical studies demonstrated some ultra low-power scenarios with dozens of microwatts (μW) RF energy effectively radiated over more than ten meters, whereas the WPC would be required to support a few of milliwatts (mW) operation power of the WDs to enable wireless powered sensor networks (WPSNs) [2].

Besides the connectivity and energy issues, answers are needed for meeting the following two open challenges so as to guarantee the required spectral efficiency and quality-of-service (QoS) of the future IoT networks: 1) "more data needs more power and emission of radio waves"; 2) "randomness of wireless propagations". For the former, most of the existing techniques, including, massive multiple-input multiple-output (massive MIMO), millimetre wave (MmWave), relaying, and ultra-dense networks (UDNs), considered a large number of RF chains at the base station (BS) or relay over high-frequency bands to help meet the ultra-high spectral efficiency. However,

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This work was supported in part by the Engineering and Physical Sciences Research Council (EPSRC) Project under Grant EP/P03456X/1 and Grant EP/P034284/1. The work of W. Hao was supported in part by the National Natural Science Foundation of China under Grant 62101499. The work of J. Shi was supported in part by the National Natural Science Foundation of China under Grant 61901327, Grant 61941105, and Grant 62101450. *Corresponding author: Jie Zhong and De Mi.*

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these techniques require multiple active RF chains, which incur higher energy consumption and hardware cost, and more importantly, lack of feasibility and self-sustainability for the deployment in the existing wireless networks. For the latter, the wireless propagation channel is traditionally treated as a random and uncontrollable medium. The main focus in the research society is on transceiver strategies, e.g., beamforming, power control, encoding and decoding. Those strategies aim to combat signal attenuation and fading in wireless channels, but not to make an effort to control the wireless propagations. To find a joint solution for these two questions, an inspiring and promising paradigm has been recently conceived, namely, *smart and reconfigurable radio environment*, for converting the conventional wireless environment to a programmable one [3]. One of the enabling techniques is the reconfigurable intelligent surface (RIS)[1], which can be a planar surface, and is composed of a large number of passive low-cost reflecting elements attached to a software-oriented smart controller. Each element can independently adjust its own reflecting coefficient, including amplitude and phase shift to the incident wave, to achieve a higher reflecting beamforming gain and hence, to strengthen the intended signal reception at receivers [4]. The RIS's nature makes it easy to be installed/uninstalled on the surfaces of environment objects, adding high flexibility to the deployment of RIS. In addition, RIS can be designed for its high compatibility and scalability, which makes it easy to operate in different wireless configurations without re-design of the existing network configurations. Current research works endeavour to spotlight the RIS by showing its capability to enhance the spectral efficiency of wireless networks at no expense of extra energy consumption. By contrast, our vision is that RIS is a better fit for wireless networks by exploiting its self-sustainability in wireless powered IoT networks.

The remainder of the paper is organized as follows. Section II elaborates on the self-sustainable property of the RIS and its application to wireless powered IoT networks. Section III provides a case study to demonstrate that performance gains introduced by the RIS can help improve spectrum and energy efficiencies of the WPSN. Several research challenges and open issues are discussed in Section IV be pursued in future investigations.

II. SELF-SUSTAINABILITY OF RIS EMPOWERED WIRELESS POWERED IOT NETWORKS

It is essential to build an understanding of the self-sustainability of RIS. The section provides an overview of this important property of the RIS, along with some practical use cases, leading to the application of RIS in wireless powered IoT networks as well as challenges and potential solutions of such an application.

A. Self-Sustainability of RIS

The RF signals can be significantly attenuated due to the blockage of direct links between transmitters and receivers by obstacles. Traditional solutions often require additional signal processing and active RF chains to cope with the destructive combination of the RF signals coming from different propagation paths, thus are vulnerable to substantial fading. In light of this, RIS provides an innovative approach to address this technical issue. Specifically, the RIS relies on its passive beamforming gain and wireless environment configuration to improve spectral efficiency without extra power consumption. Aside from WIT, the RIS can utilize the natural benefit to WET since its passive natures are highly desirable to enhance the energy harvesting level of the low-power devices via RF energy reflection, which effectively reduces their utilization of battery. As such, we conceive a novel concept of RIS, namely the self-sustainability of RIS. By controlling its reflection coefficients, RIS can reconfigure the intended signal in a desirable direction, such that the reflected link can be aligned with the direct link between transmitter and receiver, and both links carry the same useful information that can be coherently superposed at receivers [5]. This self-sustainable property is suitable for both WIT and WET in IoT contexts.

B. Use Cases of RIS

Unlocking its self-sustainability in wireless networks, RIS potentially enables a converged solution to long-standing infrastructural barriers to vertical industries, e.g., media and entertainment, IoT, automotive, safety and security, etc. Diverse use cases and bespoke requirements can be met by a common architectural design or even the same infrastructure built upon the RIS empowered wireless networks, which is illustrated in Fig. 1. The following examples present how RIS can support practical use cases with improved signal/energy coverage, spectral/energy efficiencies, computing/caching, and connectivity.

- *Edge users*: Users located at a network's edge may not be effectively covered due to the high blocking. This problem can be solved by deploying RIS to form virtual line-of-sight (LoS) links between BSs and edge users [6].
- *Edge computing and caching*: WDs (i.e., wearable devices) may not be able to locally perform computing tasks due to their limited power supply or restricted computational capability. In this case, the deployment of RIS in edge computing or edge caching systems can offer extra degrees of freedom (DoF) to handle computational resources and enhance computational bits [7].
- *Aerial communications*: RIS can be conveniently mounted on an unmanned aerial vehicle (UAV), e.g., at the bottom, as a separate horizontal surface. This creates an aerial RIS platform and offers the great flexibility and support for ground wireless network [8], [9].
- *Secure communications*: RIS can be deployed to establish secure links between BSs and legitimate users in the presence of eavesdroppers.[2] This can effectively mitigate intended signal leakage, thus enhancing wireless security and privacy [10].
- *Wireless information and power transfer*: RIS can provide the reflection link not only for information transmission but also for wireless charging, which facilitates simultaneous wireless information and power transfer (SWIPT) to energy harvesting devices [11]. The RIS configures wireless propagation by creating passive beam patterns to passively reflect information and energy signals in certain

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[1] Also known as intelligent reflecting surface (IRS)

[2] Especially when the eavesdroppers are located closer to the BS than the legitimate users.

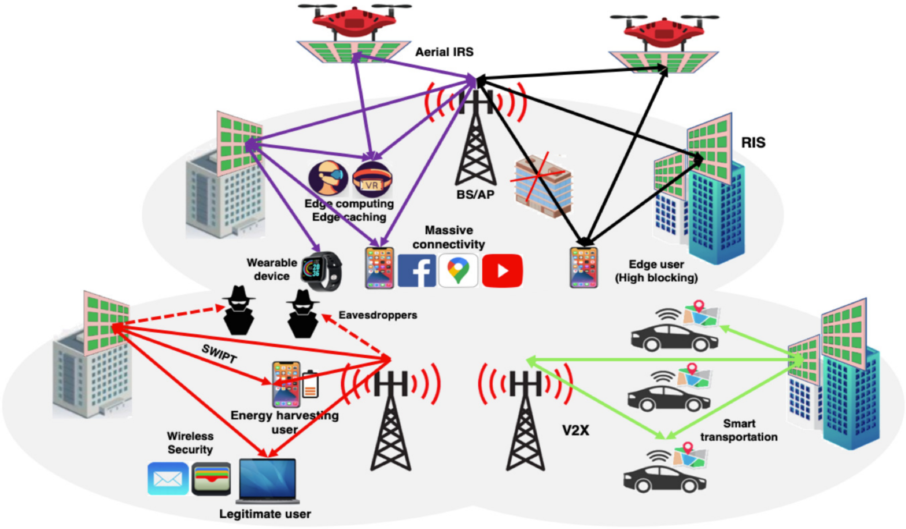

Fig. 1: Use cases of RIS.

directions for information and energy receivers (IRs and ERs), respectively. This simultaneously improves signal coverage for IRs and establishes improved wireless charging areas for ERs.

- *Vehicular communications*: Integrating RIS in vehicular communications helps coordinate the complicated propagation environment, e.g., vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) for smart transportation, to combat the weak direct links of BS-vehicle in urban areas [12].

C. RIS Empowered WPC

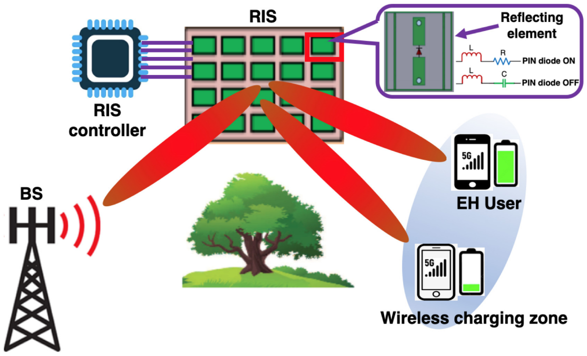

Fig. 2: RIS empowered wireless powered communications.

In this subsection, we highlight the application of RIS in a WPC system as illustrated in Fig. 2 that consists of a BS, a RIS, as well as multiple energy harvesting users, e.g., IoT devices or sensors. Each user equips with a rechargeable battery that can harvest and store the wireless energy radiated by BS. Direct link between BS and energy harvesting users are blocked by an obstacle. The RIS is thus deployed to shape passive energy beams for these users to handle the blockage of the direct links to establish an enhanced wireless charge zone, which practically extends the coverage of WET. Consequently, the energy harvesting users can extract sufficient wireless energy from the RF signal radiated by BS with the aid of RIS, to deliver their individual information to other central points. In practice, the low efficiency of WET is induced by the path loss and physical distance between BS and energy harvesting users. The utilization of RIS in the WPC is imperative via passive energy reflection, which saves the energy of BS and effectively improves the energy harvesting efficiency for the users. For those users with first energy harvesting and then information transmission, RIS helps coordinate downlink WET and uplink WIT. In addition, the RIS controller typically serves as a gateway to implement the low-rate information exchange for communication and coordination with the other network components via separate wireless links, which may lead to power consumption. The RIS can implement the energy harvesting during downlink WET for its controller's circuit operation, where the time-switching and power-splitting policies are proposed to coordinate the RIS working mode switching. Moreover, the optimal reflection coefficients are fed from the BS to RIS controller via a dedicated feedback link, which depends on the channel state information (CSI). The above application examples demonstrate how a self-sustainable system can efficiently address the energy issue experienced by low-power devices via improving their own energy harvesting efficiency, showing the importance of the RIS empowered wireless powered IoT network.[3]

D. Challenges and Solutions of RIS empowered Wireless Powered IoT Networks

Having all the enabling pieces in hand for the RIS empowered wireless powered IoT network, we shall close the gap on the network design by identifying the suitable performance metrics and finding feasible solutions.

1) Design of Multiple Coupled Reflection Coefficients: For a RIS empowered wireless powered IoT network, one of the design principles is the maximization of the system throughput, defined as the summation of the spectral efficiency of each IoT device in its particular time duration.

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[3] The existing RIS-assisted SWIPT system leads to a trade-off between harvested power and data rate, which affects the efficiency of WET or WIT.

This optimization problem consists of multiple coupled reflection coefficients for energy and information reflections, and the constraints of transmission time scheduling and unit-modulus of each reflection coefficient, which is, in general, a non-convex quadratically constrained quadratic programming. Such a problem can be indirectly solved by using semi-definite programming (SDP) relaxation, where each reflection coefficient can be optimally designed in an alternated manner. However, this numerical method induces a high computational complexity and is time-consuming, especially with a large number of reflecting elements. It is imperative to develop an efficient algorithm to optimize the reflecting coefficients with a low complexity, which also benefits the RIS implementation in practice [11]. Examples of the suitable low complexity algorithms are Majorization-Minimization (MM) algorithm, element-wise block coordinate descent (EBCD) method and Riemannian manifold optimization (RMO) method, which help to derive the locally optimal reflecting coefficients in closed-form alternately.

2) Hierarchical Interaction between Downlink WET and Uplink WIT: The RIS empowered wireless powered IoT networks can be classified into downlink WET and uplink WIT networks, and they may not necessarily belong to the same service provider. This introduces a hierarchical interaction between two networks, which leads to an interest conflict between them to gain their maximum revenue. For example, the WIT network would pay an energy incentive (i.e., monetary payment) to purchase energy service from the WET network for the wireless charging. In this case, game theory, e.g., Stackelberg game, can be invoked to effectively model the hierarchical interaction, and formulate leader-level and follower-level problems. Specifically, the WIT network acts as the leader who pays the price released by the WET network for purchasing wireless energy service, in order to maximize its total revenue, defined as the difference between benefits obtained by sum throughput and total payment for energy service. The WET network plays the follower role to maximize its own revenue, defined as the difference between total energy payment and energy cost [1]. A Stackelberg equilibrium can be involved in solving the leader-level and follower-level problems, where both parties come to an agreement and each results in an optimal strategy to maximize its own revenue.

III. CASE STUDY: RIS ASSISTED WIRELESS POWERED SENSOR NETWORKS

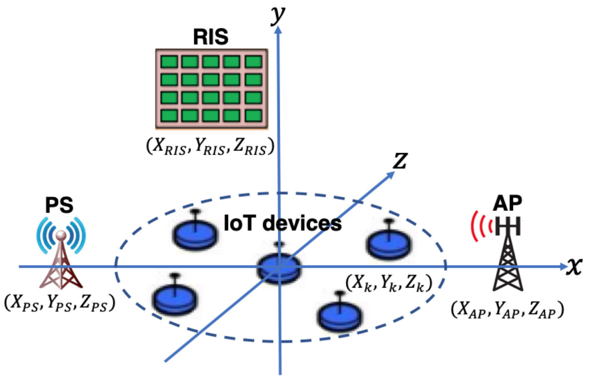

Fig. 3: A RIS-assisted WPSN.

This section provides a case study of a RIS-assisted WPSN. Here, K IoT devices first collect energy radiated from a power station (PS) and then deliver their individual information to an AP via either time or frequency-division multiple access (TDMA/FDMA). A RIS, equipped with N passive reflecting elements, is employed to participate in the energy/information reflection during the downlink/uplink WET/WIT to enhance energy harvesting and data transmission capabilities, respectively. As can be seen in Fig. 3, a three-dimensional (3D) coordinate is adopted to depict the network deployment, where the location of the PS, the RIS, and the AP are denoted as (X_i, Y_i, Z_i), $i \in \{\text{PS}, \text{RIS}, \text{AP}\}$. The IoT devices are randomly placed within a circular area of the horizontal $x-z$ coordinate, centered at $(0, 0, 0)$ with a radius of 5 meters. We set $X_{\text{PS}} = 10$, $X_{\text{AP}} = 10$, $X_{\text{RIS}} = 2$, $Y_{\text{RIS}} = 6$, $Y_{\text{PS}} = Z_{\text{PS}} = Y_{\text{AP}} = Z_{\text{PS}} = Y_k = Z_{\text{RIS}} = 0$. Assume that the direct channels of PS-device and device-AP links follow Rayleigh fading with a path loss exponent of 3.5, while other cascaded channels (i.e., PS-RIS, RIS-device, and RIS-AP) are modelled as Rician fading channels with the path loss exponents of 2, 2.5 and 2. The total bandwidth and time period of the WET and WIT are set to be 1 MHz and 1 second, the noise power density and energy conversion efficiency are -160 dBm/Hz and 0.8, respectively. Moreover, the following benchmark schemes and special cases are compared under the same configuration.

1) *Without RIS*: The system is degraded into the conventional WPSN without the aid of RIS, where the transmission time/bandwidth is optimally scheduled.
2) *Random phase shifts*: The phase shifts of the RIS are randomly generated to assist the WPSN.
3) *Fixed transmission time scheduling*: The WET and WIT equally share the total time period.
4) *Equal bandwidth allocation*: Each IoT device is assigned with the same bandwidth during the WIT.

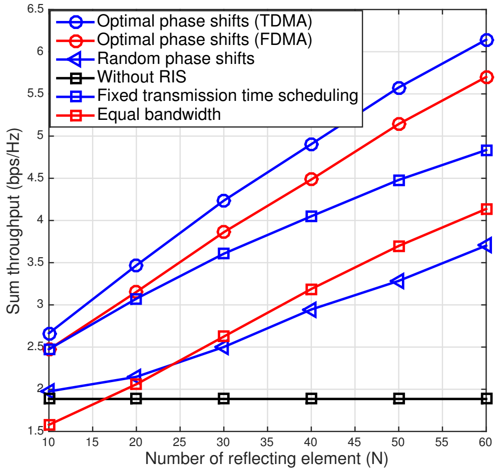

Fig. 4: Sum throughput versus number of reflecting elements N.

First, we evaluate the impact of the number of reflecting elements N on the sum throughput. As shown in Fig. 4, the sum throughput of TDMA and FDMA schemes has an increasing trend with respect to N, which is expected as an increased number of reflecting elements enhances the energy harvesting and information transmission capabilities. Also, the TDMA scheme slightly outperforms the FDMA scheme. The reason is that TDMA allows all IoT devices to sufficiently use the spectrum, such that these devices can perform the information transmission with the aid of the RIS over the same bandwidth during each WIT time slot. On the contrary, in the FDMA scheme, all devices share the total bandwidth dynamically over one time slot. It can be also observed from Fig. 4 that the optimal phases shifts have a significant performance gain over the random phases shifts, verifying the advantage of the optimization design. In addition, the TDMA and FDMA schemes perform much better than those with the fixed transmission scheduling and equal bandwidth, which highlights the benefits introduced by the optimal design of transmission time scheduling and bandwidth. Also, as expected, the RIS-assisted schemes clearly outperform that without the RIS (remains constant with N). For the RIS-assisted schemes, the reflected signal is strengthened with an increased number of reflecting elements to improve the energy reception at the IoT devices and the information reception at the AP.

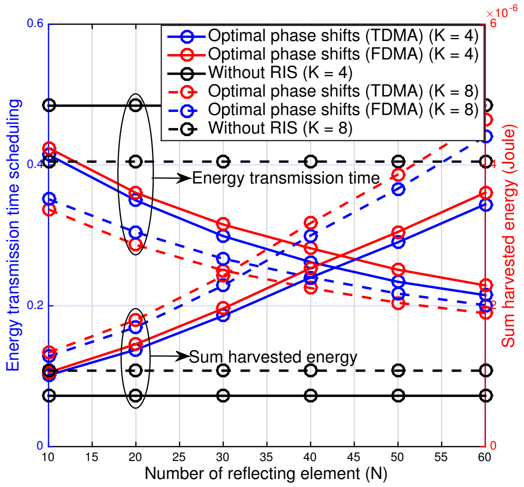

Fig. 5: Energy transmission time/Sum harvested energy versus number of reflecting elements N.

Next, we evaluate the optimized transmission time slot and sum harvested energy for the downlink WET versus N in Fig. 5. Specifically, the left y-axis of Fig. 5 shows the WET time duration of the TDMA and FDMA schemes yields a decreasing trend with respect to N, which is significantly lower than that without RIS (remains constant with N). This implies that less energy is consumed at the PS and more time is allocated for uplink WIT by increasing N, and a positive effect on the sum throughput that is monotonically increasing with respect to the time duration of WIT. Furthermore, a larger number K of IoT devices can effectively reduce the energy transmission time scheduling. This is due to the fact that increasing K results in allocating more time slots for each IoT to guarantee its own uplink WIT, which in turn consumes less energy for time allocation. Moreover, the TDMA scheme spends less time for the downlink WET than the FDMA scheme, suggesting that the TDMA scheme can allocate more time for the uplink WIT than the FDMA scheme, and thus achieve a higher sum throughput. Then, we depict the sum harvested energy collected by the IoT devices from the PS in the right y-axis of Fig. 5, which demonstrates that the sum harvested energy of the TDMA and FDMA schemes has a monotonically increasing relationship with N and is higher than that without RIS (constant with N). Also, as expected, a larger K can result in an increase of the sum harvested energy. This further confirms that the increase of the sum harvested energy is not affected by the decrease of the energy time scheduling. Again, this confirms the beneficial role of the RIS in the downlink WET due to the fact that the harvested energy depends upon the power gain of the cascaded link, which is proportionate to the phase shifts of the downlink WET. This result also shows that an increased N can strengthen energy reception at the IoT devices. More energy can be harvested in the FDMA scheme than that in the TDMA scheme, which is originated from that more energy transmission time duration scheduled in the FDMA scheme that in the TDMA scheme (see the left y-axis of Fig. 5), leading to more harvested energy during downlink WET.

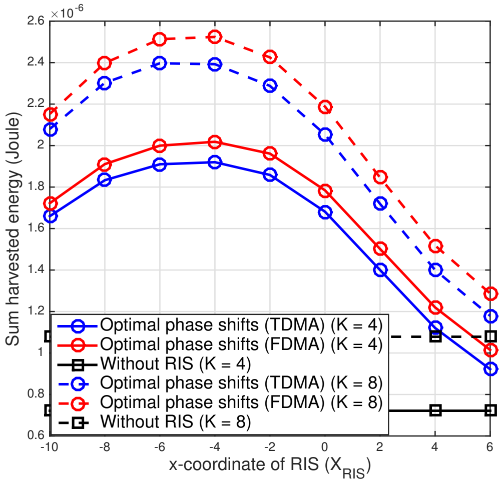

Fig. 6: Harvested energy versus x-coordinate of RIS X_{RIS}.

Finally, we demonstrate the impact of RIS's deployment on the sum harvested energy of the IoT devices in Fig. 6. From this figure, as the RIS starts moving from -10 to 6, the sum harvested energy first shows an increasing trend and then declines after approximately $X_{RIS} \geq -4$. This is because the sum harvested energy mainly depends upon the distance between PS and RIS as well as that between RIS and IoT devices. This ensures the increase of the harvested energy when the RIS is located in the region of x-coordinate between PS and IoT devices at the beginning of its movement approaching the maximum harvested energy. After that, the RIS moves far away from the PS such that it cannot perform energy reflection well, which results in the significantly declined harvested energy. This result suggests the optimal deployment of RIS to highlight its maximum energy harvesting capability. It can also be observed that more energy can be harvested by the FDMA scheme than the TDMA scheme. Moreover, a higher energy harvesting capability in both TDMA and FDMA schemes is demonstrated than that without RIS remaining constant with

X_{RIS}, which highlights the beneficial role of RIS in terms of the energy collection at IoT devices.

IV. RESEARCH CHALLENGES AND OPEN ISSUES

Inspired by the case study that showcased the self-sustainability of RIS in the wireless powered IoT network and the promising performance of the RIS empowered network, we propose several research challenges and open issues as the future work of this enabling paradigm.

A. Practical WET Design for RIS Empowered Wireless Powered IoT Networks

We anticipate that more practical WET designs for RIS empowered wireless powered IoT networks can be developed. One may be the RIS-assisted WET based on the non-linear energy harvesting model and the other may exploit the RIS transmitter architecture. One of the important future directions lies in the RIS-assisted non-linear energy harvesting model, which is considered as a fractional function. Such design may lead to a very complicated formulation for the optimization problem, due to the fractional property of the energy harvesting model. Moreover, RIS transmitter architecture can be exploited in the WET design. For example, the PS is equipped with multiple antennas constantly radiates WET signal to the transmissive RIS, which can correspondingly configure the incident digital beamforming in the analogue domain and transmit the reflected signal in the desired direction. The key highlight of the RIS transmitter lies in its energy-efficient and low-cost properties in comparison to the conventional counterpart since it does not require an active phase shifter, power amplifiers, and complicated RF chains. By applying the RIS transmitter in the WET network, a more difficult optimization problem may have to be formulated, which consists of the energy beamforming at the PS, the RIS phase shifts at the transmissive and reflective RISs. These coupled variables result in a different approach to dealing with the problem in an alternated fashion.

B. Distributed RISs Empowered Wireless Powered IoT Networks

With an increasing number of IoT devices deployed, only one RIS may not be sufficient to guarantee the required individual QoS, since all IoT devices are usually difficult to be covered by just one RIS. Instead, in practice, multiple RISs may be deployed in the hot-spot areas with a high density of IoT devices to improve the efficiencies of WET and WIT. However, this may result in a more challenging optimization problem to design the coupled passive beam pattern for WET and WIT. In the distributed RIS case, each RIS is equipped with a smart controller (i.e., RIS controller) to decide whether the corresponding RIS would participate in WET and WIT or not, and this decision-making depends on the proximity of the RIS to the IoT devices. Specifically, the RISs near the devices can be activated by their smart controllers to participate in the energy harvesting and data transmission, whereas those RISs deployed far away from the devices would be deactivated during the energy harvesting and data transmission. On the other hand, each IoT device may select the best RIS/RISs to improve its energy harvesting and data transmission, potentially triggering RISs' scheduling with their own binary working mode.

C. Practical Designs for RIS Empowered Wireless Powered IoT Networks

For ease of analysis, RIS is typically designed based on several strong assumptions, i.e., perfect CSI and transceiver hardware impairment, which can help examine the performance upper bounds of the system throughput. Unfortunately, these perfections cannot hold in practice, simply because the RIS is equipped with passive elements that lack the baseband signal processing capability. Although the existing work in [13] has introduced the channel estimation algorithm for acquiring CSI of the cascaded channels, there still exists a research gap to investigate the efficient channel acquisition schemes for the RIS-assisted WET phase. To achieve this, an additional energy overhead will be introduced at the IoT devices for the cascaded CSI. Also, the extra time may be another overhead to CSI acquisition of the WET, which results in more energy consumption at the PS. Ultimately, these issues result in the further network throughput degradation. In addition, transceiver hardware impairments, such as phase shift quantization error and amplifier non-linearity, may degrade the throughput performance of the low-power devices during the WET, which cannot be neglected in RIS-assisted wireless powered IoT networks. Hence, this future direction lies in the design of the efficient channel estimation algorithms with low energy and latency overheads, and characterizing the impact of the CSI acquisition and transceiver hardware impairments on the efficiencies of WET and WIT.

D. RIS Empowered Wireless Powered Communications, Computing, and Caching (3C) Networks

In the core network, the redundant latency and traffic congestion may be suffered as a larger volume of data need to be processed and analyzed on demand due to IoT devices' explosive proliferation [14]. As such, a future direction would focus on the investigation of the RIS-assisted wireless powered communications, computing, and caching (3C) networks. By utilizing mobile edge computing (MEC) and wireless edge caching (WEC), the computational tasks for edge nodes and for content delivery and offloading can potentially offset the functional degradation of the conventional cloud computing in the edge of the network in low-latency, energy-efficient and computational-efficient fashions. This wireless powered 3C network will create a new form of edge IoT networks, which can address: wireless charging for the low-power edge nodes to prolong the network lifetime for computational offloading, local computing and caching delivery; low offloading and delivery efficiencies of edge computing and caching due to high blockage of direct links.

E. Artificial Intelligence (AI) driven RIS empowered Wireless Powered IoT Networks

Recently, artificial intelligence (AI) is introduced as an efficient tool in the RIS-assisted wireless networks, demonstrating the flexibility and robustness against uncertain conditions, imprecise modelling, and dynamic environments for practical implementations. This future direction motivates to use AI for improving the learning efficiency, and for the design of novel learning frameworks for the RIS empowered wireless powered IoT networks. For example, AI may be employed to jointly design the passive energy and information beam patterns in the dynamic and complicated environment. Specifically, federated learning (FL) can be employed to enable each IoT device to keep its data locally [15]. To this end, each IoT device needs to allocate a portion of its harvested energy to update its local model by connecting with the edge aggregation sever for model training. Therefore, a joint energy engagement and IoT device scheduling framework will be established to characterize the multiple coupled passive energy beam patterns of WET, transmission time and bandwidth scheduling of WIT, as well as FL model parameters.

V. CONCLUSION

This article has unveiled the self-sustainability of RIS empowered wireless powered IoT networks. The inherent properties of RIS have been discussed, along with some practical use cases, the application of RIS in WPC system, challenges and solutions of the RIS empowered wireless powered IoT networks. The key finding is that exploiting synergies among RIS, WPC and wireless powered IoT networks can boost the spectrum and energy efficiencies. The beneficial role of RIS in WPSN has been numerically verified in a specific case study, with the improved system throughput, reduced energy time scheduling and enhanced harvested energy of IoT devices. Finally, various research challenges and open issues have been raised, such as resource allocations, practical designs, integrated 3C and AI techniques, which pave the pathway for the future development and deployment of the RIS empowered wireless powered IoT networks.

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