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Study of Reconfigurable Intelligent Surface and Its Application in Wireless Networking

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ABSTRACT

RIS is a technology with a physical layer that is crucial to 5G technology and also helps with 6G technology. Intelligent surfaces (RISs) that can be reconfigured in wireless contexts improve spectrum and energy efficiency. Given that the RIS idea as the leading technology in 6G wireless communications has been very new, we are presenting a survey of RISs in this study. In particular, we classify recent RIS studies in the following categories. The overview covers capability/data rate analysis, power/spectral optimisation, channel prediction, profound learning and reliability analysis in RIS-aided communication. We also study the introduction of RISs and the use of RISs in safe connectivity, terminal placement, etc. We also define potential research directions for RISs with a view to RIS technology in 6G communication networks that plays a vital role close to that of large 5G networks MIMOs. As an opportune overview of RISs, both researchers and clinicians who work on RISs for 6G networks will benefit from our work. The RISs mounted in the building or somewhere else can absorb wireless signals from a transmitter and can turn them passively into the receiver. In this paper, we will study: first, the evolution of the RIS technology, and second, its application

Keywords : Wireless communication, passive, RIP, 6G Radio Transmitters, Receivers, MIMO, Wireless networks

I. INTRODUCTION

Existing cell networks face huge difficulties with the increased expectations for high quality and omniprésent wireless services. Targets for the development of fifth generation(5G) communication systems are applications such as rate-centered enhanced mobile broadband (eMBB), ultra-reliable, low-latency (URLLC) and massive machine-type (mMTC) communications services. However, the aim is to achieve disruptive and revolutionary wireless communications systems for the sixth generation (6G) such as data-driven, instantaneous, ultra-massive and ubiquitous wireless connection and linked intelligence[1],[2]. To enable these new applications and services, new transmission technologies are thus needed. Reconfigurable smart surfaces (SRSs) [3], [4], or large smart surfaces (LISs)[5], [6] include a series of devices that reconfigure incident signals to reflect them. Due to its potential to change the wireless communication system proactively, RISs have become a central area in the field of wireless communication research to mitigate a broad variety of issues in various wireless communications networks[7],[8].

A smart reconfigurable surface (RIS) is an engineered material's two-dimensional surface whose attributes can be reconfigured rather than static. For example, with the time and software it may be adjusted, the qualities of dispersion, absorption, reflection and diffraction. In principle, when it comes to how electromagnetic waves interact with it, the surface is employed in synthesis of an arbitrary object of the same size. The long-standing objective of RIS technology is the creation of intelligent radio environments, where wireless propagation circumstances and physical layer signals are co-engineered, and how this new capacity should be utilised. The common protocol stack consists of 7 levels and the concentrate on the first three levels is wireless (physical, link, and network). An RIP works at Layer 0 where antennas of the transmitter/receiver are the typical design issues; RIS may be understood as extending the antenna design to the environment, generally viewed as uncontrollable and chosen by "nature." This way the wireless architecture can alter even beyond 5G.

Why Use RIP

The advantages of RISs are as follows:

Easy to deploy:

An RIS is an electromagnetic material (EM) passive device. There are several RISs for building façades, internal walls [9], air platforms, billboards on the roadside, highway polls, car windows and clothing for footballers because of its inexpensive cost.

Spectrum efficiency enhancement

An RIS can reconfigure the wireless propagation environment through compensation of long-distance power loss. The connection from the Base Stations (BSs) to the mobile users of Virtual Sight Line (LoS) can be created through their received signals. By targeting high-rise buildings with a high likelihood, the performance improvements become much more considerable. The LoS connection between BSs and users. Thanks to smart RISs, a software-defined wireless environment can be developed, and the receivable signal-to-interference-plus-noise ratio can be improved in turn (SINR).

Environment friendly

Instead of using a power amplifier [11], [12], the RIS is capable of shaping the incoming signal, as compared with standard Relay Systems (i.e. Amplifying/Futures (AC/AF) and Decode-and-Futures (DF), [10]. The use of a RIS is thus more environmentally friendly and energy-efficient than traditional AF and DF systems.

Compatibility

Because RISs only reflect EM waves, full doplex (FD) and complete band transmission supports. RIS-enhanced wireless networks also comply with existing wireless network standards and hardware[13].

Different Categories of RISs

RISs can be produced with metamaterial or patch-array-based technologies in consideration of their structure. RISs built on metamaterials are known as metasurfaces. They can be used at various locations to reflect/refract RIS from the BS to the user or to steer RIS at a BS.. RISs can be modified electrically, mechanically or thermally, taking into account tuning mechanisms. RISs can be classified as passive-loss, passive-loss, or active, depending on their power consumption. RISs decide the active and passive character of their final performance.

Three main operating conditions of RIS are discussed here: waveguide [14], refraction [15] and reflection [16]. The reflected and refracted EM field may be examined by injecting electric and magnetic surface equivalent current [15] using the LOVE principle of equivalence in field[17]. In the three operating circumstances, the RIS turns the wave into a desired wave of spatial propagation.

Waveguide RIS:

A theoretical analysis of waveguide-fed metasurfaces was provided by R. Smith et al.[24]. The metasurface elements are modelled on a non-connected magnetic dipole. The extent of each dipole element depends on the product of the reference wave and the polarisation of each element. The metasurface antenna may be transformed by adjusting the polarizability. Each metasurface piece acts as a micro-antenna. The compact metasurface waveguide takes less area and transmits broader angles of radiation patterns compared to traditional antenna arrays.

Refracting RIS:

The theoretical design of a refractory and reflective metasurface was proposed by Viktar S etal.[18]. The authors employed an analogous impedance matrix model to adequately optimise the tangent field components on both sides of the metasurface. Three alternative realisations are also discussed: telecommunication metasurfaces that self-oscillate, non-local metasurfaces and solely loose-free-component metasurfaces. The important importance of omega bianisotropy in the construction of precisely refractive surfaces for lossless-component realisations is highlighted.

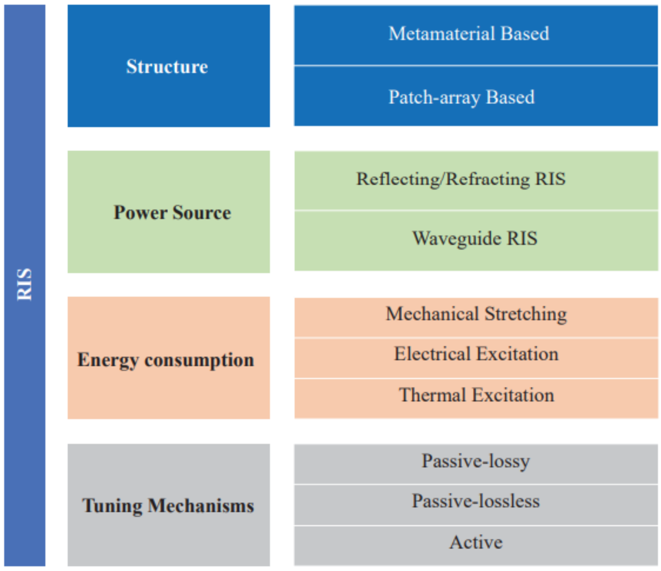

Figure 1: Different types of metasurfaces.

Reflecting RIS:

A digital reflective metasurface coding was developed by Dai et al. [29]. The metasurface components are composed of varactor diodes with a configurable biassing tension. Each element may carry out discrete phase shifts and produce a beam shaping for the reflected wave by constructing various digitised biassing voltage levels. The remainder of this section is concentrated on the operational concepts for reflecting RISs.

About the Metasurfaces of RIS

An EM wave travelling in a three-dimensional (3D) area is essentially a wireless signal. The interaction between a RIS and impinging EM waves may be characterised by the use of ray-optics or wave-optics as approximations and devices. Physicists have traditionally employed these two views. Although these two analytical methods are based on certain approaches, they are helpful to gain crucial knowledge about the interaction between light or radiocommunication waves and materials. Both analytical methodologies are extensively used in the RIS literature. However, its assumptions and physical hypotheses are inherently distinct. In this paragraph we compare the two to illustrate their differences and similarities. The EM wave is modelled as a collection of geometric rays with various phases from a ray-optic view as illustrated in Fig 6(a). Each ray phase rises linearly with the length of the optical path through vacuum or other media.

This enables for the determination of a phase (identified by μi) for each i-th ray point. The phenomena are examined by discovering the link between the change of phase and the refractive index of the material when the beam interacts with optical material. Finally, if the ray collection meets the correct co-phase requirement, the required reflected wave can be achieved. Figure 6(b) shows the wave-optics view, with the electrical field and magnetic field being the respective EM wave. These two vector fields at each place may be defined by a complex vector having a time-vary with a direction, an amplitude and a stage. The interaction of the wave and the reflected substance may be explored utilising the many equivalent concepts from a wave-optic perspective.

Comparing Ray-optics and Wave-optics Perspectives:

Table I shows some distinctions in the two points of view. The ray-optical view is a greater simplification of the real system compared to wave-optics. It is therefore easy to take and can quickly forecast the design of the RIS. However, when you include RIS power flow, ray optics fail. On the other, wave optics foretell the power flow from the Poynting vector that allows us to examine the energy consumption of the local and overall RIS. In the genuine design and production of the RIS this is a key subject to address.

For example, [18] and [19] indicate that the local passive RIS cannot be used to drive the lossless plane-wave beam. [19] claims that RIS constructed using wave optics compared to those based on ray-optics approximation, can be expecting a progressively better performance based on their simulation findings. Finally, both positions have significant advantages. In most circumstances, though, taking the wave optic point of view is the best decision. The analysis between radiation optics and wave-optics analytical methods is provided in [7] on the differences in terms of power flow and reflection coefficient.

	Ray-optics	Wave-optics
Wave representation	Geometrical rays	Vector fields
Theoretical foundation	Snell's law	Maxwell's equations
Surface profile	Phase discontinuity	Surface impedance
Requirement of the reflected wave	Co-phase condition	Proper wavefront
Power flow	Not accurate	Accurate

Table I: Highlights some of the differences between the two perspectives.

PERFORMANCE ANALYSIS OF MULTI-ANTENNA ASSISTED RIS SYSTEMS

The impact of RIS on the performance of communication remains an outstanding problem. We explore the following aspects in order to comprehensively examine existing RIS-aided network designs. (1) model route losses, (2) study of performance and (3) model benchmarks. A. Models for Path Loss An RIS path-loss survey is presented in [7], [20] and [21]. The results are provided. These works have demonstrated that RIS power is normally expressed as an integral component that accounts for the influence of the entire surface by utilising the Huygens principle. In contrast, the closed-form integral formulations, save for particular asymptotic regimes that are consistent with the RI, are difficult to produce.

Furthermore, the path-loss model depends on the phase-specific gradient used by the RIS. In particular, when the RIS acts as an anomaly reflector and a focusing lens, the scaling rules might be different. In the following, we address briefly two scaling legislation recently observed for anomalous RISs (described in the previous text). Additional facts and information are provided in [7] and [21].

- *Electrically Small RISs:* The RIS, compared to the transmission distances, in that asymptotic regime is believed to be quite modest. The RIS can be represented as a tiny scatterer under this environment. In general, path-loss scales with the reciprocal distance of the product from the transmitter to the RIS centre and the distance from the RIS centre to the receiver. Furthermore, with the RIS size, the power received generally rises. The received power is frequently maximised to reflect anomalies..

- *Electrically Large RISs:* Within this asymptotic scheme, it is assumed, compared to transmission lengths and wavelength, that the RIS is big (preferably infinitely big). The RIS may be considered a huge flat mirror under this regime. Let's define by x0 the RIS point (if it exists), at which the first-order derivative of the combined incoming signal's total phase response, reflected signal, and coefficient surface reflection of the RIS equals to zero. Generally a weighting sum of the distance between the transmitter and x0 and the distance between x0 and the receiver is generated asymptotically. Furthermore, the power received does not rely on the size of the asymptotically unlimited RIS. This conclusion confirms the fact that the RIS power scaling rule is valid physically since the size of the RIS does not go to infinity. This is because the RIS' scaling rule and behaviour diverge from the small electric regime.
- *Spatial Analysis:* Stochastic geometry (SG) tools are able to record the random position of user such that the essential performance measurements are derived from calculable or closed-form formulas. In particular a number of well-accepted processes are selected for modelling location-based user randomization on different wireless networks, e.g. the HPPP [22], [23], the PCP [24], [50], the Binomial-Point process (BPP) and the Hard Core-Point process (HCPP), [25]. Below are a few promising SG augmented RIS networks techniques in Table II. The RIS components are used on the barriers in [26] and it is considered to be positioned in the RIS servicing region. The network performance may be assessed by placing the RIS components in the cell centre, which might be a possible solution for the RIS-assisted networks[5].

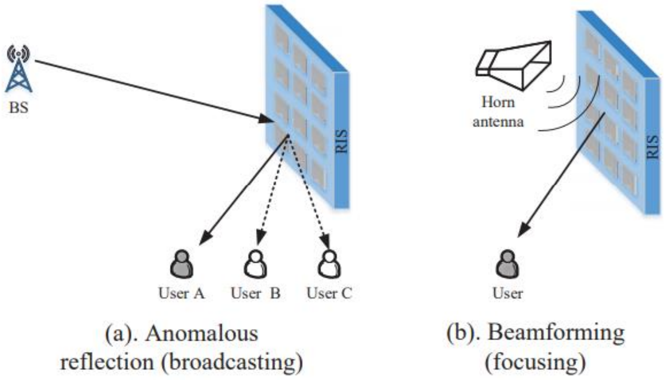

Figure 2: Typical function of reflcting metasurface

The items in[27] are modelled on a modified, random, fixed length procedure and a random positioning. Which explored the chance for a pair of transmitters and recipients that a randomly dispersed object covered with a RIS is to be used as a reflector. Since however, the user sites are altered at random, the duration assessment of BS-users or RIS-users remains an unresolved issue. Overall, widespread fading involves road loss and shadowing. There is yet no study on the shadowing of the RIS-assisted networks, which is potential for study.

Table II: Functions of reflecting metasurface

Approaches	Advantages	Disadvantages	Ref.
RIS-aided HPPP	Fairness-oriented design	Restricted user distribution	[5]
RIS-aided two layer HPPP	Coverage-hole enhancement	RISs are deployed at obstacles	[52]
HPPP conditioned on angle	Practical design	Not tractable	[54]
RIS-aided HPPP conditioned on angle	Practical design for the RIS-aided networks	Complicated	–

Currently, two main approaches have been used for performance analysis:

(1) Central-limit theorem-based (CLT-based) distribution,

(2) Approximated distribution.

CLT-based Distribution

Approximation tool for performance assessment in low-medium SNR schemas is the methodology based on CLT. This is because the CLT based methodology, which shows a system performance in the high-SNR range is not exact, does not distribute the Probability Density funktion (PDF) in range 0 to 0+[28]. It is further demonstrated that, using the fading channels of Rayleigh, a modified Bessel function follows the distribution of the RIS-aided networks[28]. Since the transmitter and RIS are both part of the infrastructure and since the RISs normally use the LoS path with regard to the transmitter's location, this increases the signal power received. The findings show that the signal power follow the non-centralized chi-squared distribution and two degrees of freedom [29], which focuses on Ricans fading channels. Zhang et al. Ding and Poor[30] suggested to establish a RIS-aided network, which uses RISs to efficiently align user's channel gain directions and can thereby serve the cell-end users.

Approximated Distribution

The Simple Input and Single output network (SISO) was suggested by Lyu and Zhang [34] with many RIS arrays being randomly installed, which proved that the precise 23 signal output distribution may be approximation by Gamma. The RIS-assisted network, on which Fisher-Snedecor F was modelled, has been proposed by Makarfi et al. (26). [26]. The exact allocations are based on the contributions referred to above [26], [29]–[31], [33], [34]. The Simple Input and Single output network (SISO) was suggested by Lyu and Zhang [34] with many RIS arrays being randomly installed, which proved that the precise 23 signal output distribution may be approximation by Gamma. The RIS-assisted network, on which Fisher-Snedecor F was modelled, has been proposed by Makarfi et al. (26). [26]. The actual distribution of RIS networks remains an unresolved subject on the basis of the contributions stated above[26],[29]–[31],[33],[34]. The diversity gain in the high-specific SNR regimes is 1 2 for the CLT distribution in [29], whereas for the approximate Gamma distribution the diversity gain is n 3, while n is the number of RISs indicated.

RIS-aided Designs

Multiple antenna approaches are important because they give greater variety in the space field. Substantive attention is being drawn by academia[5],[33],[34] and industry[12],[35],[36] in the implementation of multiple antenna-assisted RIS networks. Given the growing contribution to RIS research, its advantages, in particular for its high spectral efficiency (SE) and energy efficiency are evident (EE). The performance analysis in RIS assisted networks presents many important issues. The evaluation of the actual distributions of cascade canals between the BS and users through RISs is one of the major issues. The effective channel gain following passive RIS beamforming is also a difficulty. Table III aggregates and shows comparisons of existing RIS contributions by several antennas. The multi-user instances are then turned our focus..

RIS-aided Signal Enhancement Designs

A number of antenna approaches are used at both the BS and users in order to increase further the SE of RIS-assisted networks. Ntontin et al.[37] evaluated a pair of extreme situations, which examined the diffuse dispersions and anomalous situations. Yuan et al. [38] suggested a Multi Input and Single Output (MISO) cognitive-based RIS support network, with both the perfect and imperfect CSI situations being examined. Continuous amplitude and phase changes were nonetheless expected on the RIS in most literature, 24 Table IV: Significant RIS-aided MIMO contributions. Downlink and uplink signify "DL" and "UL.". The "sum benefit" means that, while in practical application, phase shifts of RISs cannot be continuous, the gain from invoking the RIS approach. Thus, for a MISO aided RIS network, You et al. [39] presented a discrete phase shift model. Zhang et al. [64] then tested in the UL SISO network, which revealed that 1-bit would enough, the needed number of bits for limited RIS resolutions. Hou et al.[5] examined a RIS-supported Network of MIMOs where the use of SG tools to simulate the impact of user sites was taken into account in a fair design-based design.

RIS-aided Signal Cancellation Designs

The fact that two wave sources have just a consistent phase difference but with the same frequency and the same waveform is a totally consistent one. In contrast to typical RIS designs to increase the signal intensity received, the alignment of the reflected signal signals for signal cancellation is another reason for RISs being implemented. This may be used to implement certain intriguing applications, i.e. physical safety layer and cancellation of interference. On the one hand, the intercell and inter-cluster interferences can be removed by assuming that flawless CSI is provided on the RIS controller. RISs also represent a viable solution for cooperative jamming techniques, i.e. RISs function as artificial noise sources, given the physical layer safety standards. Several contributions were made to RIS-assisted networks with this methodology. Hou et al[36] developed a cancellation methodology for RIS-assisted interference within a MIMO network that could eliminate the interference without active weights and detection vectors. inter-cluster interference may be removed. This work may also be adapted easily by 25 to apply for the cancellation of intercell interference in the mobile network for the coordinated multipoint (CoMP) networks.

Benchmark Schemes

In order to assess the advantages and limitations of RISs, two benchmark transmission technologies are usually considered:

1) surfaces with random phase shifts; and

2) relay networks.

Random Phase Shifts:

RISs may change the incident signal phase and can thus amplify or delete various signals on the BS side or the user side. Thus, a well-accepted benchmark to assess RIS elements for performance improvement is offered by a not customizable surface, perfectly designed for a surface with random phase changes. [29].

Relay Networks:

Two classical protocols (1) FD and Halfduplex (HD) relaying networks; and (2) AF and DF relayed networks) may generally be categorised as a relayscaping network. In particular, the datacent of the RIS-assisted and DF relief assisted SISO networks, which prohibit the direct connections between the BS and the consumers, was compared by Bjornson et al.[12]. When there is sufficient amount of tunable components for the RISs, a RIS-supported network can operate a relay-supported network. It was pointed out that. Ntontin et al. [63] examined the system efficiency of conventional MRT and max ratio combination technologies in an effort to give a thorough study for both RIS and relays. Fig. 3 shows the possible network output improvements of RIS-assisted networks compared to both HD-relay and FD-relay networks[33].

In this case, the HD-relay performance is achieved with a time-split ratio. It can be seen that as the number of RIS is raised, the network output gap between the RIS-supported network and the other relay-supported networks is less. Note that for N = 18, both FD and HD Relay Assisted Networks may perform more competitively, indicating that the NOMA RIS-assisted Network is more competitive when the number of RISs is sufficiently great. Observation should be given. It has also been demonstrated that a RIS-supported network is possible to increase both the capacity and the EE considerably. The comparison between the RISaid and multiple relay-helped networks and random phase shifter networks is shown in Table IV.

Ref.	Scenarios	Direction	Users	Main Objectives	Techniques
[5]	MIMO	DL	Multiple users	OP and Throughput	Fairness SEB
[12]	SISO	DL	Single user	sum-rate gain	Compare with Relay
[26]	SISO	UL	Single user	OP and Throughput	Effective Channel gain
[55]	SISO	DL	Single user	Effective channel gain	Compare with random phase shifting
[56]	SISO	DL	Single user	Effective channel gain	SEB
[57]	SISO	DL	Single user	OP	SEB
[59]	SISO	DL	Multiple users	OP and Throughput	Prioritized SEB
[60]	SISO	DL	Single user	Effective channel gain	SEB
[58]	MIMO	DL	Single users	Effective channel gain	Random matrix theory and CLT
[63]	MIMO	DL	Multiple users	sum-rate gain	SEB
[62]	MIMO	DL	Multiple users	Interference Cancellation	SCB and less constraint at RAs
[64]	SISO	UL	Multiple users	Sum-rate	Minimum required finite resolution
[65]	MISO	DL	Multiple users	Sum-rate	Multi-RIS distribution
[66]	MISO	DL	Multiple users	Sum-rate	Discrete phase shifts

Table III: Important contributions on RIS-aided MIMO. “DL” and “UL” represent downlink and uplink, respectively. The "sum-rate gain" implies that the gain brought by invoking RIS technique

Mode	Pros	Cons	Delay	Power	Interference	CT
RIS-aided	High EE, simple device	CSI must be perfect known	✗	✗	✗	✓
HD relaying under AF protocol	No decoding at relay	Noise is amplified	✓	✓	✗	✗
HD relaying under DF protocol	No self-interference	Latency is high	✓	✓	✗	✗
FD relaying under AF protocol	No decoding at relay	Noise and interference are amplified	✗	✓	Self-interference	✓
FD relaying under DF protocol	No latency	Rate ceiling occurs	✗	✓	Self-interference	✓
MIMO relay	High SE	High cost, difficult to realize at mmWave	✗	✓	✓	✓

Table IV: Comparison of the RIS-aided and Benchmarks. The "Power" Implies That the Additional Power Supply at the RISs or at the Relay. The "CT" Denotes Concurrent Transmission

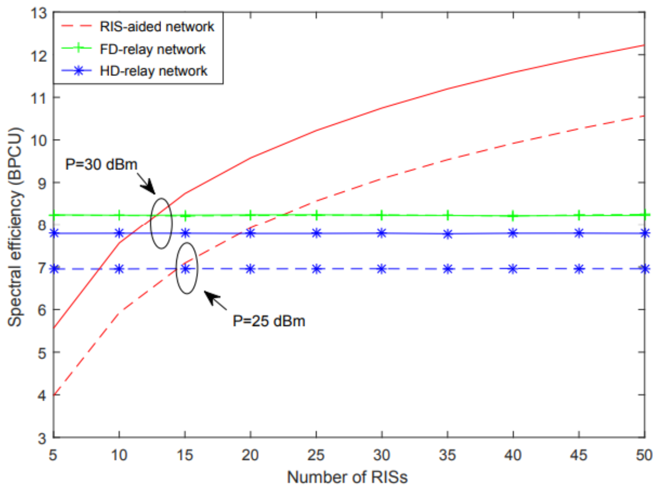

Figure 3: Spectral efficiency of the RIS-aided, FD-relay as well as HD-relay networks versus the number of RISs. Please refer to [59] for simulation parameters.

Discussions and Conclusion

While the estimated Network performance of RIS assisted networks has been analysed in earlier research contributions, some key unresolved research questions still persist. Two newly reported scaling rules for route loss modelling of RISs which function as anomalous reflector and focal lens. Is there anyway a situation between little electrically and huge RISs in electricity? A interesting research guidance for modelling route loss of RIS networks is the realistic propagation pattern of signs reflected in RISSs. Furthermore, most of the earlier contributions chose the estimated distribution for modelling the fading channels, the precise distribution of RIS networks is still in their imaginations. Further research initiatives are planned to simulate the precise fading channel of the reflected connections in both the near-field and far-field regimes.

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