LiFi Through Reconfigurable Intelligent Surfaces: A New Frontier for 6G?

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Abstract—**Light fidelity (LiFi), which is based on visible light communications (VLC), is celebrated as a cutting-edge technological paradigm that is envisioned to be an indispensable part of 6G systems. Nonetheless, LiFi performance is subject to efficiently overcoming the line-of-sight blockage, whose adverse effect on wireless reception reliability becomes even more pronounced in highly dynamic environments, such as vehicular application scenarios. Meanwhile, reconfigurable intelligent surfaces (RIS) emerged recently as a revolutionary concept that transfers the physical propagation environment into a fully controllable and customisable space in a low-cost low-power fashion. We anticipate that the integration of RIS in LiFi-enabled networks will not only support blockage mitigation but will also provision complex interactions among network entities, and is hence manifested as a promising platform that enables a plethora of technological trends and new applications. In this article, for the first time in the open literature, we set the scene for a holistic overview of RIS-assisted LiFi systems. Specifically, we explore the underlying RIS architecture from the perspective of physics and present a forward-looking vision that outlines potential operational elements supported by RIS-enabled transceivers and RIS-enabled environments. Finally, we highlight major associated challenges and offer a look ahead toward promising future directions.**

I. TOWARDS INTELLIGENT LIFI

Harnessing the power of billions of connected devices, future Internet-of-Everything (IoE) is envisioned to enable innovative and progressive services such as telemedicine, extended reality and automatic high-precision manufacturing. Such applications require unprecedented wireless connectivity with specific key performance indicators (KPIs) including terabit-per-second speed, exceedingly high-reliability, extremely low-latency and high energy-efficiency, which cannot be efficiently supported by 5G networks. To cater for these demands, 6G is envisioned to be built on a new physical layer architecture that incorporates subterahertz and visible light bands to support and complement radio frequency (RF) communications.

Light fidelity (LiFi), which offers a fully networked bidirectional wireless solution based on visible light communications (VLC), has been identified as an important component in the 6G blueprint, with predictions of the LiFi market reaching $8

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billion by 2030 [1]. The directionality and short-range travel distances of light signals allow for extreme cell densification in indoor, vehicular and underwater communications, providing secure high-speed connectivity. It is also considered an energy and cost effective technology as it utilises the lighting infrastructure to provide connectivity on top of the illumination functionality. Nonetheless, the achievable capacity in LiFi systems is limited by: 1) the modulation bandwidth of the transmitting light-emitting diodes (LEDs), and 2) the high dependency on the line-of-sight (LoS) which means that signal quality is influenced by link blockage and random receiver orientation. The use of multiple-input multiple-output (MIMO) configurations is a promising solution to overcome these limitations and boost the capacity and diversity gains of LiFi, albeit with a possibly hindered performance due to the high correlation between the spatial subchannels.

Until recently, the design of LiFi systems was mainly focused on enhancing the transmission and reception capabilities in the face of undesirable uncontrollable channel conditions. In order to achieve the KPIs of 6G, there is a need to go beyond the current communication architecture, which is limited by the transceiver front-ends capabilities, and to exploit the available degrees of freedom in the environment. Based on this, intelligent LiFi can autonomously and dynamically adapt its operation in order to achieve ubiquitous connectivity that is resilient to adverse probabilistic effects such as blockage and random receiver orientation. This article aims to give a forward-looking vision of the role that reconfigurable intelligent surfaces (RISs) can play in enabling intelligent LiFi as a new frontier for 6G wireless networks. To the best of our knowledge, this is the first article that attempts to give an overview of the opportunities, applications, and challenges related to the integration of RISs in the context of LiFi.

A. RIS: A Disruptive Concept

A RIS comprises a metasurface that can be proactively reconfigured to alter the wireless wave propagation. The electromagnetic (EM) response of each RIS element can be adjusted by tuning the surface impedance through electrical voltage stimulation. Based on this newly emerging concept, future wireless networks may utilise the different surfaces and physical objects in the environment as wireless boosters to enhance their operations. RIS research has recently become a focal point of interest in wireless communications communities as it offers a spectrum, energy, and cost efficient approach for sustainable evolution in wireless systems. The integration

of RIS in RF communications is shown to offer performance enhancement in terms of coverage, quality-of-service (QoS), and security [2]. The application of this emerging technology in optical communications is still in its infancy. The use of RIS in free space optical systems was investigated as a means to maintain the LoS in the existence of link obstructions in [3], while [4] and [5] considered the use of wall-mounted RISs to focus the incident light beams towards optical receivers in indoor VLC systems.

To better understand the potentials and limitations of the interplay between RISs and LiFi, we next shed light on some of the reported capabilities of metasurfaces to control visible light propagation.

B. Metasurfaces From the View of Physics

Metasurfaces are two-dimensional artificial structures that consist of programmable sub-wavelength metallic or dielectric elements whose EM characteristics can be reconfigured to introduce an engineered response to the incident wave-front by manipulating the outgoing photons. Although the use of metasurfaces in optical communications have only recently became an active area of research, their capabilities in light manipulation have already been developed in the field of flat optics. Fig. 1 illustrates four of the most important light manipulation capabilities that can be realised by metasurfaces and are detailed as follows:

1) Refractive index tuning: with a negative refractive index it is possible to reverse the phase velocity of the light-wave and bend it in a direction that is impossible with a positive index [6].
2) Anomalous reflection: metasurfaces make it possible to break the law of reflection and steer the light into desired directions with near-unity efficiency [7].
3) Signal amplification and attenuation: metasurfaces can be tuned to provide light amplification, attenuation, or even complete absorbance [8].
4) Wavelength decoupling: it is possible to engineer wavelength-specific EM response to control different wavelengths independently [9].

Based on these capabilities, we next draw a vision on the use of metasurfaces within LiFi transceiver structures.

II. RIS FOR ADAPTIVE TRANSCEIVERS

LiFi transmitters emit directional beams of light characterised by their field-of-views (FOVs). A large FOV results in a wider beam angle, which is beneficial in terms of providing higher coverage and more uniform illumination. This comes at the cost of producing lower light intensity at the receiver, i.e. lower Watt/unit area. As a result, transmitters with small FOVs can better preserve the received optical power, albeit requiring perfect link alignment.

Light rays falling within the receiver's FOV generate an electrical current that is directly proportional to the received optical power. The more data-carrying photons are observed at the photo-detector (PD) surface, the higher the detection accuracy is. This suggests that using PDs with large physical areas leads to better performance. However, large PDs
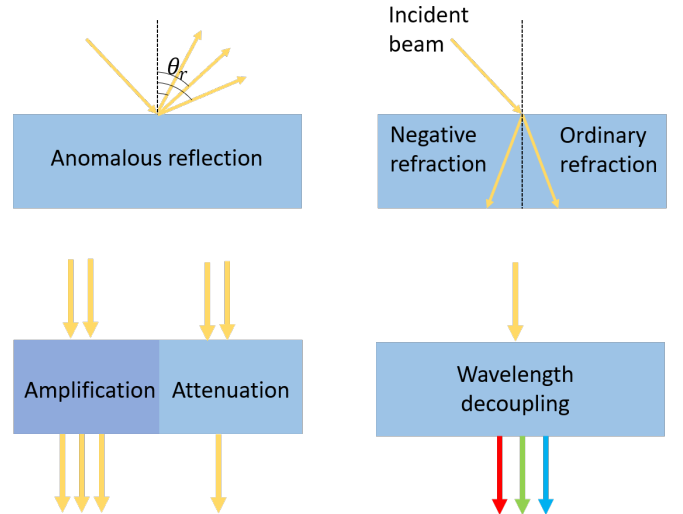

Fig. 1: Metasurfaces light manipulation capabilities.

typically have lower 3 dB bandwidth due to the increased capacitance, and hence, are not suitable for high data-rate applications. To tackle this problem, receivers employ PDs with small physical areas combined with convex, spherical, or compound parabolic concentrating lenses, to help focus the light rays that fall in the receiver's FOV onto the PD surface.

The optical components used in state-of-the-art LiFi transceivers are non-configurable structures, meaning that their characteristics, such as FOVs, amplification factors and operating wavelengths, are predetermined and cannot be dynamically adjusted. Due to the tunability of their physico-chemical characteristics, RISs can unleash the possibility to achieve dynamically tunable transceivers as discussed in the following.

A. Beam Steering and Amplification

A concept design of a RIS-based receiver was demonstrated in [8], where the traditional convex lens is replaced with a liquid crystal array to provide a two-fold impact on the incident beam, namely: steering and amplification, which was shown to extend the coverage range by few meters. The amplification in this case is achieved locally using the surface waves, but the RIS is globally passive, i.e. it does not require power supply. In such configurations, it is critical that the RIS handles amplification without driving the PD to work in the saturation region to avoid signal distortion. Besides enabling beam steering at the receiver, it is also possible to exploit this functionality at the transmitter to enhance the beams' directivity, as illustrated in Fig. 2 (a).

B. Configurable Wavelength Division Multiplexing (WDM) Transceivers

In WDM, data streams are multiplexed on distinct wavelengths by utilising a combination of different coloured LEDs. Dichroic mirrors are typically used in WDM transceivers to combine the different wavelengths at the transmitter and to decorrelate the received signals at the receiver. Such transceiver structures are fixed configurations that can only

(a) beam steering

A RIS placed at the transmitter front-end can be tuned to control the beam width and the FOV of the LED allowing extended coverage, beam concentration or directivity.

| AP controller |
| Driver |
| LED |
| RIS |

| AP controller |
| Driver |
| LED |
| RIS |

| AP controller |
| Driver |
| LED |
| RIS |

Larger FOV allows larger coverage area but results in lower light intensity.

Smaller FOV helps to concentrate the beam power when the user is close to the LED.

Beam steering to reach far users with better light intensity.

(b) configurable WDM

Adaptive WDM transmitter

Adaptive WDM receiver

Red LED

Green LED

Blue LED

PD

PD

PD

Programable RISs can be used to realise dynamic wavelength-specific amplification at the transmitter and selective interference rejection at the receiver.

(c) dynamic angular diversity

Fixed ADT

Dynamic ADT

Equipping ADTs with RISs allows dynamic beam steering, resulting in less interference compared to fixed structures.

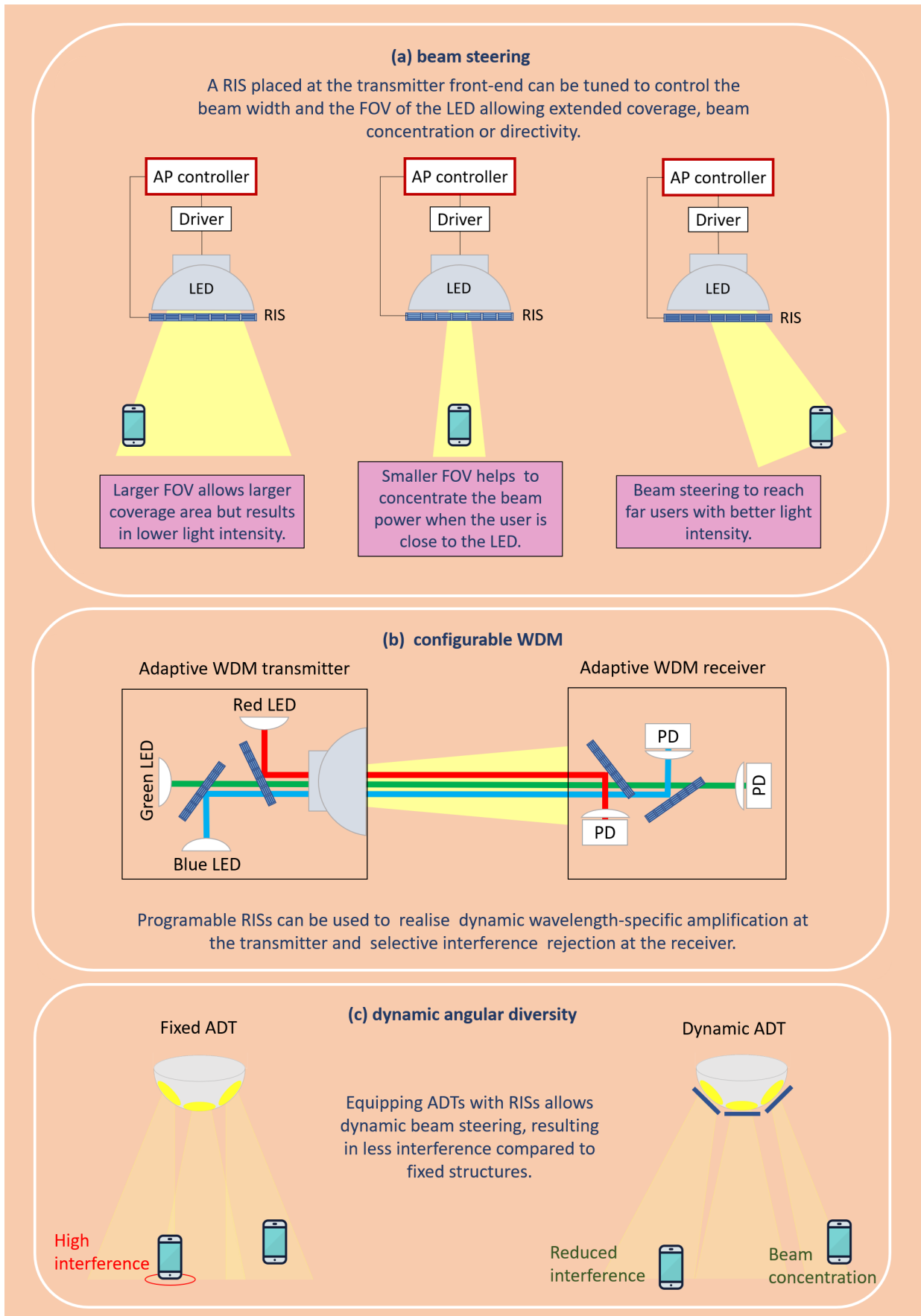High interference

Reduced interference

Beam concentration

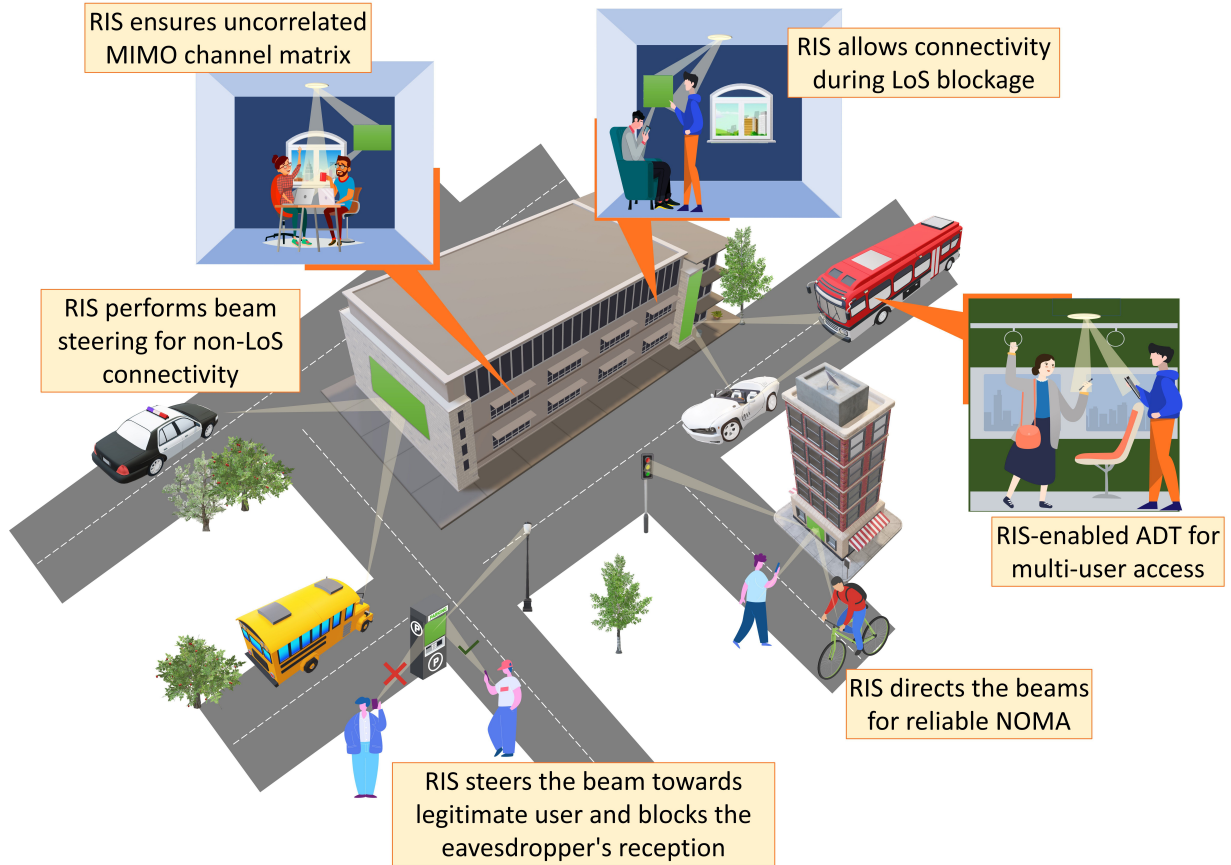Fig. 2: Envisioned functionalities for RIS-enabled transceiver front-ends.

Fig. 3: Envisioned RIS-enabled smart LiFi applications in indoor and outdoor scenarios.

work for a specific WDM scheme, i.e. a receiver comprising red, green, and blue (RGB) filters can only decorrelate an RGB-based WDM signal. Since the EM response of RISs can be tuned at different wavelengths, they could be possibly integrated in WDM transceivers as illustrated in Fig. 2 (b). The spectral width of RIS elements can then be tuned to realise dynamic interference filtering according to the used transmission scheme. RIS tuning allows for allocating different weights to each received wavelength, and hence, the effective signal-to-interference ratio can be optimised. The realisation of WDM tunable transceivers requires the fabrication and characterisation of metasurfaces whose response can be finely tuned for different wavelengths.

C. Dynamic Angular Diversity

Fig. 2 (c) illustrates an angular diversity transmitter (ADT) consisting of multiple LEDs, each pointed towards a particular direction to create multiple sub-cells for multi-user access. Since the optical components in ADTs are closely located, the degree of decorrelation between the subchannels is not always high enough to provide meaningful diversity gain. Interference levels can be high for users existing in the overlapping area of two sub-cells, which diminishes the performance gain. There is a need to adapt the spatial separation and width of the optical beams according to the number and locations of users, since fixed transceiver structures are not always guaranteed to

provide the required performance gain. To tackle this issue, RIS may be utilised to dynamically change the width and divergence of the optical beams, allowing higher numbers of users to be simultaneously served with less interference and higher area spectral efficiency.

III. RIS-ENABLED ENVIRONMENTS

In this section, we discuss some potential applications for the integration of RIS within LiFi environments, as illustrated in Fig. 3.

A. Non-LoS Links for Resilient Connectivity

The optical link quality primarily relies on the existence of LoS paths and is likely to be significantly deteriorated or completely interrupted in the event of LoS obstruction, which necessitates perfect alignment between the transmitter and the receiver. While this is a viable solution in VLC links between static terminals, the case is more complicated in LiFi networks supporting high user mobility. LiFi receivers perceive multi-path components that are coherently added at the PD to maximise the total received power. In typical indoor environments, however, non-LoS signals are totally uncontrolled and nearly isotropic in their spatial distribution and are very weak in their average intensity. It was shown in [4] that using a 25 cm × 15 cm reflector can enhance the received power five fold compared to the direct LoS link,

which makes RIS a very appealing solution to compensate for LoS blockage in LiFi systems. Leveraging RIS could indeed enable ubiquitous connectivity under mobility conditions and link blockages as well as random device orientations, as shown in Fig. 4, making LiFi resilient to these probabilistic factors.
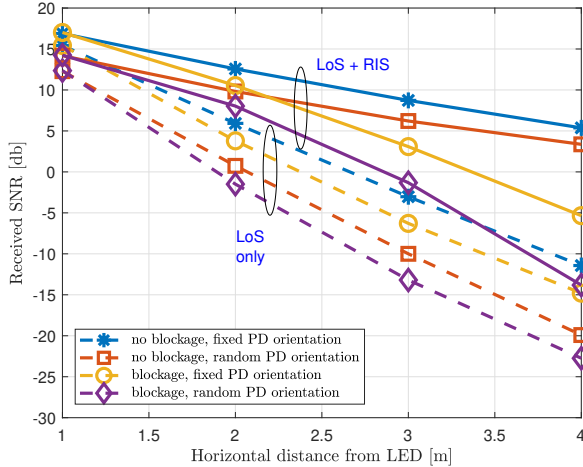

Fig. 4: Simulation results for received signal-to-noise ratio (SNR) vs. the horizontal separation between the user and the LED in a $8 \times 8 \times 3$ m^3 room setup with 1 m^2 RIS mounted on one wall.

B. Uniform Coverage for Seamless User Experience

LiFi coverage is typically confined within the width beam of the transmitted light which spans 2 m - 3 m in diameter. While this property makes LiFi particularly secure against eavesdropping, it results in short communication range and non-uniform distribution across the area, as shown in Fig. 5 (a). The reduced link reliability at the cell-edge means that users moving in the proximity of the LiFi access points (APs) will need to perform frequent horizontal handovers, between neighbouring LiFi APs, or vertical handovers, between the LiFi and the RF networks. RIS-enabled environments can enhance the LiFi coverage by mitigating dead-zone problem for cell-edge users as shown in Fig. 5 (b). For a user located at the room edge, the direct received power from an AP mounted in the room centre could range from low to none. However, since the user is close to the wall-mounted RIS, the reflected signal strength can allow for meaningful link quality.

C. Spatial Decorrelation for Enhanced MIMO

The application of MIMO systems in LiFi is particularly appealing, due to the existence of large numbers of LEDs in a single luminary and the existence of many luminaries in various indoor and outdoor settings. Unlike RF, optical links do not exhibit fading characteristics and thus, do not always represent unique signatures. In fact, the optical channel is subject to a strong deterministic component, since it is mainly influenced by the transceivers' geometry, meaning that the MIMO channel can be rank-deficient or ill-conditioned. This constitutes a performance bottleneck for different MIMO configurations such as spatial multiplexing and spatial modulation, particularly in massive MIMO due to the high proximity of the front-ends.

One possible solution to tackle this problem is to carefully align the LEDs and PDs in a way that ensures uncorrelated subchannels. However, optimising the locations of the transceiver front-ends in LiFi systems that support high user mobility proves to be a challenging requirement. RIS-enabled environments could offer an excellent solution to improve the MIMO channel matrix rank, yielding better spatial decorrelation. In scenarios where MIMO receivers observe equivalent subchannels from the direct LoS link, the intensity of the reflected paths from RIS to receivers can be controlled so that the total observed subchannels are sufficiently distinguishable. Better spatial uniqueness will enable higher spectral efficiency and boost the achievable data rates of LiFi MIMO systems.

D. RIS-Based Modulation

A RIS can be used to provide an additional dimension for data modulation by controlling the EM response of each of its reflecting elements [10]. RIS-based modulation is a generalisation of spatial modulation (SM) that exploits the radiation patterns of reconfigurable elements instead of the activation states of LEDs. Compared to conventional SM, which utilises multiple LEDs, RIS-based modulation offers a smaller size, lower cost, and more flexible solution to increase the system spectral efficiency. The operating principle of RIS-based modulation is illustrated in Fig. 6. A RIS equipped with multiple reflecting elements receives the data modulated signal from the LED and reflects it to the intended receiver. Assuming that each reflecting element has two distinct reflecting states (on/off), different on/off combinations correspond to different observed channel realisations at the receiver. Hence, by controlling the EM response of N_r reflecting elements, a spectral efficiency enhancement of N_r bits per symbol is realised. Assuming that the LED transmitted signal is M-ary modulated, the total spectral efficiency of the system is $N_r + \log_2(M)$.

In principle, the spectral efficiency of RIS-based modulation increases linearly with the number of reflecting elements. However, the error performance is practically limited by the Euclidean distance between the constellation points, which is governed by the degree of decorrelation among the reflections. In other words, although a high number of distinct channel combinations can be generated, a superior performance enhancement can be only realised if these combinations are clearly distinguishable. At the receiver terminal, the detector task is not only to decode the M-ary modulated symbol, but also to estimate the channel state of each reflecting element. This implies that the receiver needs to be trained with pilot signals from all possible RIS combinations. While this task might be complex in fading RF channels, the complexity of obtaining the channel state information (CSI) is considerably lower in LiFi due to the somewhat deterministic nature of the optical channel. An important question that arises here is: how will the RIS receive the intended data bits in order to alter the reflecting elements' states? A possible way to do this is to
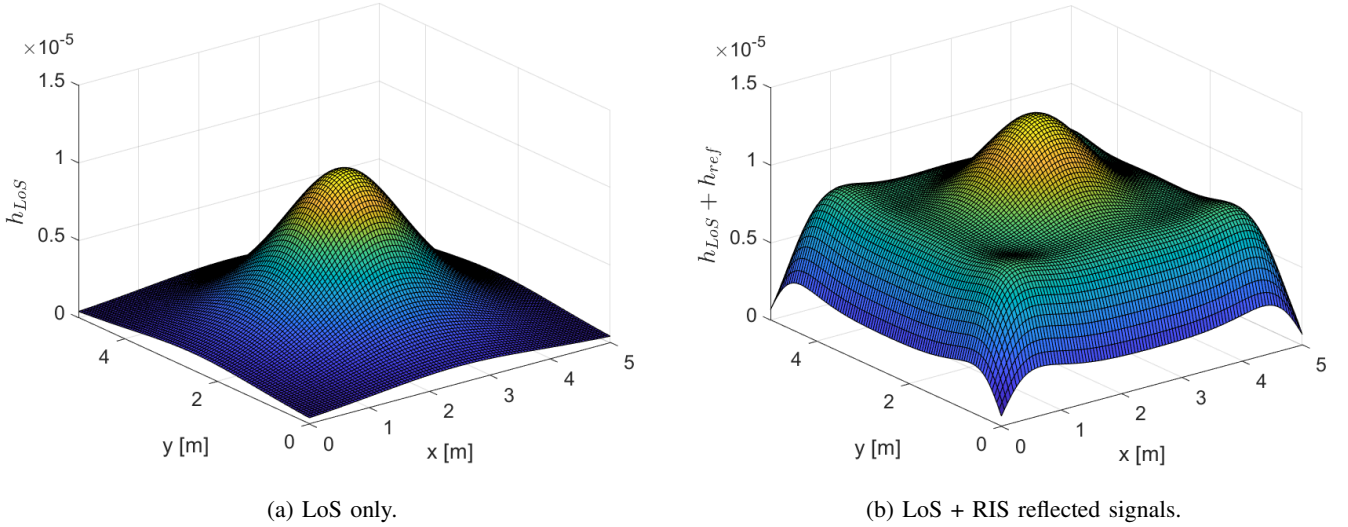
(a) LoS only.

(b) LoS + RIS reflected signals.

Fig. 5: Simulated channel gain distribution across a $5 \times 5 \times 3$ m^3 room with a) LED LoS only, and b) LED assisted with RIS covering an area of 1 m^2 on each of the four walls.

mount the RIS on a fixed object that is connected to the LiFi backhaul network. For example, an indoor wall-mounted RIS can be connected to the same power-line communication link feeding the LEDs in the ceiling. The same concept can be applied for an outdoor scenario in which RIS is mounted on a traffic light to modulate the light signals and reflect them to vehicular receivers.
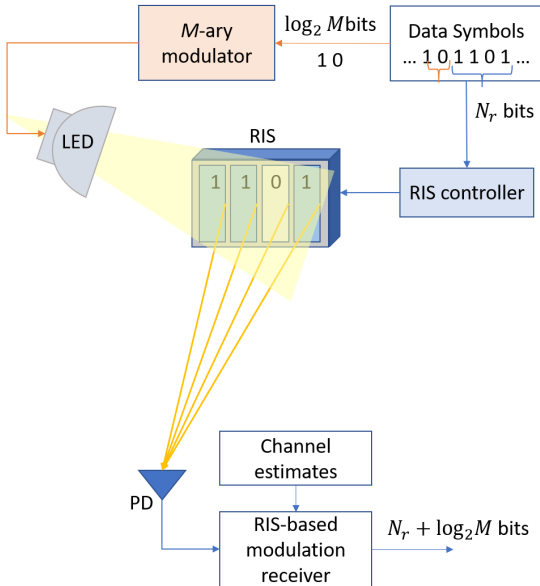

Fig. 6: RIS-based modulation in a LiFi transceiver equipped with RIS containing N_r reflecting elements.

E. Non-Orthogonal Multiple Access (NOMA)

Power-domain NOMA is a spectral efficient technique in which different users are simultaneously served using a single resource block, i.e., accessing the full time and frequency resources. The spectral efficiency gain offered by NOMA is dependant on having distinct channel conditions for different users, which is not always guaranteed in LiFi. In fact, since the optical channel gain is determined almost exclusively by the relative location of the user with respect to the AP, it is highly likely that multiple users will have similar channel conditions, hindering the feasibility of NOMA.

The case might completely change in RIS-assisted LiFi systems. By controlling the multi-path channel propagation, it would be possible to dynamically alter the perceived channel gains at different users to achieve performance enhancements in two ways:

1) Higher reliability: by introducing and controlling the channel gains, it is possible to create perfect conditions for effective power allocation, and thus, successful successive interference cancellation.
2) Enhanced fairness: NOMA users with lower decoding order, i.e., lower channel gain, have to always decode their signals with the existence of interference which means that their achievable data rates might not be enough to satisfy their QoS requirements. Dynamic RIS tuning makes it possible to change the users decoding order despite their locations, leading to enhanced fairness.

F. Physical Layer Security (PLS)

Although LiFi is inherently secure in confined places because light signals do not penetrate walls, LiFi links are susceptible to eavesdropping by malicious users existing under the coverage area of the same AP. This makes it particularity crucial to secure LiFi transmissions in public spaces, such as shopping malls, libraries, and airports, as well as in outdoor and vehicular applications [11]. The integration of RIS in LiFi

systems can lead to enhanced PLS in one of the following ways:

1) Enhanced secrecy capacity: dynamic multi-path tuning to maximise the channel gain for legitimate users while minimising it for the eavesdroppers.
2) Jamming: randomised multi-path reflections directed towards the eavesdropper to produce artificial noise.
3) Secure beamforming: multiple RIS elements can be configured to produce precoding vectors so that the data signal can only be decoded at the legitimate user.

In order to realise RIS-based PLS, there is a need to investigate the secrecy capacity performance in such systems in relation to the locations and capabilities of RISs, particularly with the existence of ambient noise in outdoor links, and to understand how RISs can be enabled to perform users authentication.

IV. RIS Beyond Communications

In the following, we discuss how RIS-enabled LiFi systems have the potential to provide enhanced monitoring and power transfer, on top of their communications functionalities.

A. RIS-Aided Light-based Monitoring

The dynamics of light propagation and reflection in LiFi systems carry huge amounts of information about the distance travelled by the light rays, the nature of obstacles encountered, and the movement patterns in the coverage areas. Light-based sensing solutions, such as LiSense, StarLight, and Li-Tect ([12] and the references therein), proved that light has the potential to provide high-accuracy 3D sensing. In these techniques, propagation paths of beacon signals between multiple optical transmitters and receivers were utilised to reconstruct point clouds for the purpose of localisation.

In RIS-assisted environments, each reflected path constitutes a unique spatial signature depending on the locations and EM response of the objects existing in the environment. The reflections from the RIS elements can be shaped by controlling the EM response of each element in order to enable better mapping from the position space to the measurement space. Based on this, accurate localisation can be achieved for indoor applications, including physical rehabilitation, gesture recognition, and automated manufacturing, as well as for outdoor applications, such as measuring the distances between vehicles, pedestrians, and buildings for safety and surveillance.

B. Simultaneous Light-Wave Information and Power Transfer (SLIPT)

The potential of LiFi systems to provide illumination while supporting information transfer concurrently with energy harvesting (EH) has led to the emergence of SLIPT as an innovative approach to extend the lifetime of energy-constrained terminals [13]. In this context, visible light-waves broadcasted through LEDs are captured at the receiver to perform information decoding (ID) and EH simultaneously according to a pre-defined time or power splitting factor (SF). SLIPT relieves the bottleneck of energy-sensitive networks, while avoiding the safety problems imposed by traditional wireless RF power transfer systems, and is, thus, appealing in many indoor IoE scenarios. One of the key challenges in SLIPT is that transceivers should be capable of identifying an optimal SF to satisfy the demands of both EH and ID. Furthermore, the EH efficiency is directly impacted by the light collection area at the receiver. The merits of integrating RIS within LiFi transceivers can be leveraged to dynamically tune the transceiver characteristics, through beam steering and amplification, as described in Sec. II-A, which together with smartly optimising the SF can lead to a balance between ID and EH. The synergy of MIMO and VLC creates a promising platform for highly efficient SLIPT-enabled systems, albeit at the cost of requiring complex signal processing at both source and receiver [13]. We envision that RIS-assisted smart environments can potentially offer an on-demand efficient resource allocation for such systems, especially in dense deployments. Capitalising on the design of efficient joint active and passive beamforming techniques, the amplitudes and phases of independently transmitted and reflected signals can be configured such that they are added constructively in desired directions and destructively in the undesired ones to create multiple data/light-wave energy streams conveyed to multiple receivers. This delivers an unprecedented flexibility of multiple access control in conjunction with transmission rate and light transmit power control that maintain individual QoS requirements on ID/EH and guarantee inter-user interference mitigation in a dynamic fashion.

V. Challenges

In this section, we discuss some critical challenges that need to be addressed for realising the full potentials of integrating RIS in LiFi.

A. Modelling and Characterisation

The development of realistic and accurate channel models is essential to capture the fundamental performance limits of RIS-assisted LiFi systems. Moreover, there is a need to quantify the efficiency and response time to achieve specific functionalities, such as amplification, absorption, anomalous reflection, etc. It is noted that the use of RIS-assisted LiFi is particularly desirable in outdoor transmissions, such as vehicle-to-vehicle and vehicular-to-infrastructure, due to the requirement of extremely small beam angles in such long-distance links. Underwater LiFi systems could also hugely benefit from dynamic tuning and beam steering because the underwater environment is characterised by severe signal attenuation, and thus, any possibility to precisely steer and focus the light beams will undeniably bring advantages. Accordingly, it is critical to understand how RISs perform in different media, such as underwater and outdoor environments with high ambient noise. Comprehensive practical implementations and measurements over practical setups are required to asses the performance in real-world scenarios.

B. Real-Time Estimation and Optimisation

RISs provide the fabric for dynamic LiFi configurability based on the knowledge of the varying system parameters,

which necessitates the availability of accurate CSI of direct and non-direct channel paths of all network users. The natural questions that arise are: how will the necessary amount of data be acquired in a practical and cost-effective manner, how to integrate the optimisation and resource management capabilities into the network topology, and what is the convergence, stability, and required frequency of this dynamic sensing and reconfiguration. Data acquisition and optimisation can be possibly performed in a distributed or centralised manner. In the distributed approach, RISs can locally estimate the channel gains and autonomously reconfigure their EM response accordingly, if they comprise sensing and processing capabilities. The use of RIS arrays with high numbers of elements and complex functionalities will require complex optimisation, resulting in increased computational, energy, and cost overhead. The centralised approach, on the other hand, employs a central control unit at the AP which executes the estimation and optimisation protocols and then communicates the optimal design coefficients to the RIS's control layer. The obvious advantage of the centralised approach is lower energy consumption and simpler hardware design, while the main challenge is the occurring signalling overhead between the AP and the RIS, which would be more pronounced in high mobility scenarios. The trade-off between distributed and centralised approaches needs to be quantified so as to develop practical strategies for different applications.

VI. THE WAY FORWARD

In the following, we present a forward-looking discussion on promising future directions.

A. Interplay of machine learning (ML) and RIS-Assisted LiFi

The promising prospects of RISs provide a foundation to support seamless real-time adaptivity of the LiFi-enabled wireless environment. However, their operation is intertwined with the need to implement a complex level of coordination to sustain a desired holistic behaviour while ensuring scalability and overhead reduction. This complexity stems from the fact that turning the environment into a programmable, and a partially deterministic space, relies on incorporating a colossal number of parameters in the performance optimisation, which in turn depends on a large amount of sensed data that is processed in a time-critical manner to interact with and incorporate responses from the dynamic environment surrounding RISs. This suggests that network resource management would be an extremely challenging task, since memory, computing power, traffic demands, space, and so forth are to be considered. To tackle this challenge, ML solutions may be exploited to support RIS functions, such as maintenance, management, and operational tasks, yielding LiFi networks to be autonomous, prescriptive, and predictive. Although it is envisioned that the fusion of ML and RIS will evolve the nature of LiFi applications emerging in all industries, such as healthcare, retail, transportation, etc., conventional ML algorithms are not well suited to guarantee real-time user and network needs in highly dynamic and ultra low-latency-driven applications [14]. Therefore, it is essential to explore innovative mechanisms

to resolve the shortcomings of existing ML approaches, such as prohibitive training and communication overhead and large processing delays, and hence, open up avenues for exciting applications across all verticals.

B. RIS-Assisted Hybrid LiFi-RF Networks

Hybrid LiFi-RF systems have recently emerged as a paradigm-shifting technology that is receiving significant attention, as they show outstanding capabilities in enhancing capacity, throughput, and coverage. This can be attributed to the mutual benefits gained by utilising both the optical and RF spectra, such as RF traffic offloading, increased LoS blockage mitigation, and improved security and privacy [15]. With RIS being widely recognised as a disruptive approach to augment RF communications, the coexistence of RIS-assisted LiFi and RIS-assisted RF networks seems to be a natural continuum to hybrid LiFi-RF. This close integration can offer significant synergies, yielding a combined solution that can potentially meet the stringent requirements of future wireless applications, which are defined by ultra-reliable, extremely low-latency, data-driven, and seamless wireless connectivity. Nonetheless, distinctive challenges arise in this case, such as the need to develop complex load balancing mechanisms, reliable resource utilisation and energy management schemes, efficient cross-layer analytical tools, and novel cross-band selection combining approaches. One critical question immediately emerges: what ML tools can shake hands with RIS-assisted hybrid LiFi-RF systems to support real-time dynamic network decision making?

VII. CONCLUSION

The merit of RIS technology opens the door for a whole new realm of wireless applications in which the propagation medium is no longer an impediment, but rather an additional degree of freedom. This article discussed how the interplay between RIS and LiFi can lead to innovative and progressive applications by enabling intelligence in the transceiver's operations as well as in the environment. More research on the deployment of RIS in LiFi is fundamental to understand their capabilities and limitations, and to address the practical considerations that are required to translate this disruptive concept into real-world applications.

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