Towards the Metaverse Realization in 6G: Orchestration of RIS-enabled Smart Wireless Environments via Digital Twins

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***Abstract*—Reconfigurable intelligent surfaces (RISs) represent an emerging technology envisioned to overcome some of the late challenges for the development of the sixth-generation (6G) such as reduced end-to-end communication latency and improved network reliability compared to 5G. In particular, in addition to its cost effectiveness and energy saving features, this technology has motivated a proliferation of studies regarding its capability of improving the propagation environments in terms of enhanced received signal. In addition, digital twins (DTs) are receiving remarkable attention for the development and maintenance of various future network services. This paper discusses the complimentarity of these emerging concepts for the efficient realization of the metaverse in 6G networks. Specifically, it considers how a DT-aided RIS-based network architecture can provide substantial improvements towards the achievement of network latency and reliability necessary for the realization of metaverse in 6G. A brief overview of the latest status in the RIS and DT technologies is firstly provided, which is followed by a discussion on the potential use cases and services that can be delivered through a DT-aided RIS-based network architecture. The benefits of this architecture, in terms of communication latency, is validated through a representative simulation setup. Finally, challenges and future research directions with the proposed DT's role for RIS-enabled smart wireless environments.**

***Index Terms*—6G, artificial intelligence, channel estimation, digital twin, metaverse, reconfigurable intelligent surface.**

I. Introduction

Although the fifth generation (5G) standard has not yet been fully deployed worldwide, academia and industry have started working on technological enablers and their operation schemes for the sixth generation (6G) networks. This trend is motivated by the fact that the 5G network architecture will be incapable to address the massive amount of data expected in the next decade. This provision implies that 6G networks will be capable of substantially serving higher numbers of users (10^7 users/km^2) with larger data rates (1 Gbps downlink rate) as well as of providing 10 μs of end-to-end communication latency with 99.99999% network reliability [1].

In order to achieve the latter demanding key performance indicators (KPIs), i.e., reduced end-to-end communication latency and improved network reliability, which will permit the deployment of a wide range of immersive services, like virtual/augmented/extended reality and wireless brain-computer interactions, 6G networks are tasked to provide substantial network improvements, especially at the physical layer. They are expected to introduce novel approaches for enhancing the signal propagation over the wireless medium, consequently, improving the strength of received signals even in ultra wideband very high frequencies. This has been partly achieved within 5G networks via the introduction of massive multiple-input multiple-output (MIMO) [2] and hybrid analog and digital beamforming technologies [2], [3]. Interestingly, recent advances in the improvements in the fabrication of electromagnetic (EM) metamaterials, gave birth to the concept of reconfigurable intelligent surfaces (RISs), which enables EM wave propagation control [4], thus, serving as a powerful solution for the challenging propagation environments envisioned for 6G services. For example, 6G is expected to adopt THz frequency spectrum, where signal propagation is very challenging due to the high penetration losses and the scarcity of scatters. For those applications, designing highly efficient multi-antenna transceivers for beamforming is challenging, and RISs can contribute in either realizing cost-and energy-efficient reflective coverage extenders [5] or holographic MIMO transceivers [6].

The anticipated breakthroughs for 6G networks pursue to enable, among other services, reliable hyper-connectivity between humans and machines in an ubiquitous manner. This will foster a highly digitized society with global data. Thanks to the usage of artificial intelligence (AI), the 6G network technology will contribute to the realization of a complete new way to interact with the real world, where data is collected and processed, in order to perform advanced analysis of various

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This work is supported by the UK Department for Science, Innovation and Technology under the Future Open Networks Research Challenge project TUDOR (Towards Ubiquitous 3D Open Resilient Network). The views expressed are those of the authors and do not necessarily represent the project. The work of G. C. Alexandropoulos was supported by the Smart Networks and Services Joint Undertaking (SNS JU) project TERRAMETA under the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101097101, including top-up funding by UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee. Corresponding author is Trung Q. Duong.

situations and make accurate daily choices to improve users' quality of experience (QoE). This interaction paradigm is referred as metaverse [7]. More specifically, in the 6G vision, the concept of metaverse has been conceived as an extension of the physical reality through the interaction between physical and virtual worlds. This will be possible through the development of extended reality (XR) related technologies, like Web 3.0, virtual reality (VR) services and augmented reality (AR) services, which are envisioned to have enormous potential to transform both industry and society. However, there are some related challenges that the current 5G technology cannot tackle, e.g., related to the achievement of near-zero latency end-to-end communications, requires an efficient real-time resource allocation. In this context, the concept of DT has been recognized as a keystone concept towards the digitization of the surrounding environment. Specifically, a DT-based vision involves real-world products and systems digitally represented in cloud or edge servers. By incorporating AI and big data analytics, DTs will be able to process real-time data coming from their twinned physical systems in order to realize a clear and comprehensive models of their behavior. This will enable real-time decision-making, which will in turn improve any product development process and its efficiency [8], [9].

The potential of DTs for the digital representation of wireless propagation environments can result fully beneficial for the optimum orchestration of RIS-empowered wireless applications. As identified in the RIS research [10], the efficient design, in terms of latency, computational complexity, and control overhead, of the configuration of a plurality of RIS elements constitutes one of the core challenges of the RIS deployment in real-life dynamic environments. An accurate channel estimation (CE) procedure plays a paramount role in designing an optimal phase shift policy. Existing researches provide various approaches for solving the CE problem [11]. However, they have gradually presented various limitations, such as complicated establishment of the optimization problems, iterative solutions, and high computational complexity. Recently, the usage of AI has been highlighted as a very promising solution to the CE problem in RIS-empowered wireless networks [10]. In light of this, the design and deployment of a DT for this type of communication scenario will be beneficial. Indeed, thanks to the data collect from different underlying sensors/devices, the corresponding DT will be able to obtain a clear view of the surrounding communication environment. Such environmental awareness and the usage of appropriate AI models at DT level, will allow to enhance the performance of the underlying RIS-empowered network in terms of CE accuracy, which in turn will result into an improved networks in terms of reliability and reduced communication latency.

A. Motivation and Contribution

The above discussion witnesses the potential of DTs for providing advanced and real-time solutions for the optimal orchestration of RIS-empowered wireless communications systems. Indeed, having clear model understanding about the surrounding propagation environment will help in continuously optimizing and training the AI models with up-to-date data coming from the real network. In this way, the performance of RIS-assisted communications will be improved, paving the way for the realization of metaverse-based services. To the best of our knowledge, the current literature lacks contributions on the DT's role for RIS-enabled smart wireless environments, which motivated the focus of this article. The contributions of this paper are summarized as follows:

- It presents a clear vision on the RIS technology with its own principles and features, as well as a brief introduction on DT and its role as keystone technology for the the deployment of 6G networks.
- It discusses in Section IV, through use cases, how the possibility of having a clear view of the surrounding environment through the DT of a RIS-assisted networks represents a stronger enabler for 6G metaverse compared to conventional AI model training and optimization.
- Open challenges and future research directions for the development of a DT-aided RIS-empowered network are also provided.

The rest of the article is organized as follows. A brief background on the RIS technology and the DT concept is provided in Sections II and III, respectively. Section IV discusses the DT potential in orchestrating RIS-empowered communications systems towards the realization of the metaverse, providing relevant use cases. Future research directions are discussed in Section V, while Section VI concludes the article.

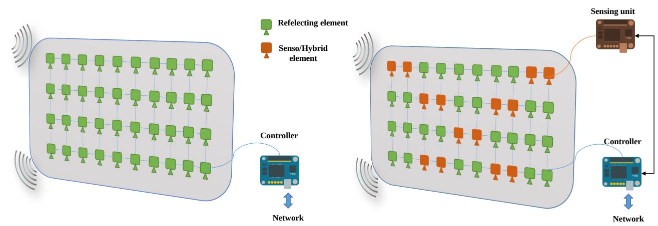

Fig. 1: A purely reflective RIS (left) and an RIS with sensing capability (right). Both include discrete elements with tunable reflection properties, and controllers for their configuration management as well as the interfacing with other network infrastructure. An RIS can also include sensors or simultaneous reflecting and sensing elements as well as relevant signal processing units, contributing to its environmental sensing capability and self configuration.

II. Background on RISs

This section provides a brief overview of RIS by illustrating its main characteristics and benefits in terms of modifying the propagation environment with the aim of improving the quality of the signal at the receiver. The referenced works represent a good starting point for a reader interested in having a broader view of this innovative technology.

A. From Smart Metamaterials to RISs

Metamaterials represent a class of particular materials artificially engineered which exhibit properties not found in nature.

More specifically, they are obtained by arranging micro or nano scale structures — they are usually referred as meta-atoms — in a specific pattern with the purpose of achieving unusual properties, such as negative refractive index and super-lensing. In these contexts, they can be designed to bend light around objects, making them invisible to certain wavelengths of light, as well as to create superlenses that can resolve details smaller than the wavelength of light. On the other hand, in the area of wireless communications, they can be used to show different macroscopic responses such as reflection, refraction and diffraction, depending on the wavelength of the incident EM wave. These effects can be controlled by modifying the shape, size, and arrangement of micro/nano structure in space.

The first appearance of metasurface with the formulation of their respective generalized law for propagation can be tracked back in 2012 [12]. At that stage of development, they were characterized of having a 3D structure, subsequently miniaturized into planar, presenting some issues related to the fact that was not possible to obtain the response to the incident EM wave in real-time. Two years later further improvements have been appointed to this technology [13]. In particular, thanks to PIN diodes and Field-Programmable Gate Array (FPGA) it has been possible to obtain the response of the metasurface, i.e., a set of meta-atoms, in real-time. This achievement opened up the way of realizing RISs. Indeed, as illustrated in Fig. 1, RISs are physical objects having structures and geometry of meta-atoms entirely programmable through the usage of appropriate external signals. This is basically done by employing electronic phase transition elements like semiconductors or graphene as switches, or by using tunable reactance/resistance elements either between adjacent or within single meta-atoms. This has enabled the development of many system-level applications, either active or passive, such as space-time coded digital communication systems and intelligent sensing systems for specific signal detection, which were previously difficult to achieve with traditional metamaterials [14]. The mechanisms behind such signal sensing and digital signal processing operations through RIS reflection/attenuation, are illustrated in Section II-B.

B. RISs for Wireless Communications

In the context of wireless communications (see Fig. 2), RIS have been mainly studied in order to understand how they can change and affect wireless signals during their propagation period. In this regards it has been find out that RISs can enable various use cases through the proper configuration of amplitude, phase, frequency, and polarization characteristics of the meta-atoms. More specifically it is possible to:

- Adjust the amplitude characteristic of the RIS, in order to absorb undesirable signals like interference. This is done by properly regulating the bias voltage of varactor diodes of each unit cell, obtaining then a metamaterial with superior absorptivity within a wide range of incident angles in the desired band.
- Change the phase characteristics which will impact on the reflection of the incident way. This will allow to create either a single or multiple beams with the reflected direction controlled in accordance with system requirements, i.e., extended coverage, jamming signals towards , and so on.
- Tune the response in the frequency domain in order to adjust and eventually expand the frequency spectrum distribution of the signal. This is possible due to the unique non-linear response which can be provided by RIS.
- Control the polarization in each direction in order to vary the phase and amplitude response of RIS elements to each incident EM wave within the considered bandwidth.

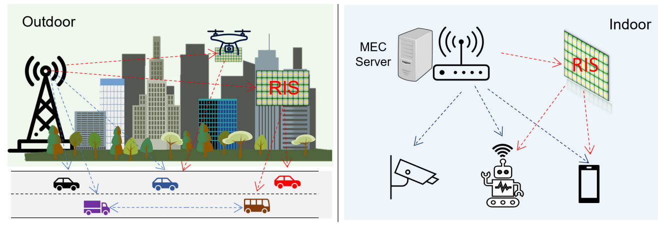

Fig. 2: RIS-empowered applications in outdoor and indoor environments.

Although a RIS can provide up to 4 degrees of freedom, at date the phase regulation feature is the most widely employed in addressing various issues in wireless communication, resulting in a powerful tool to provide substantial performance enhancements of the communication system. The most common adoption of phase-tuned RIS is aimed at providing additional source of links to compensate for significant path loss and channel sparsity, thereby enhancing the effective connections between the base station and users. Beside, RISs are also used in order to focus the reflected signal in a particular direction. These applications are possible through the joint optimization of reflection coefficients and phase matrix of RIS. Then, RIS-assisted communications can achieve higher levels of spectral/energy efficiency and of signal-to-noise ratio (SNR) of the end-to-end link in a way that results more cost effective and lightweight than the employments of large-scale MIMO systems. However, the optimization phase shift matrices in RIS-assisted communications, requires a good level of channel estimation of the surrounding environment that *i)* first of all results to be more challenging than conventional scenarios, and secondly *ii)* it is envisioned to become an even more challenging task with the usage of higher frequencies in 6G and increased number of users, since in turn higher propagation losses and interference will be introduced.

III. Overview of the DT Concept

This section provides a brief illustration of the DT paradigm as well as an explanation about how it represents a key-enabling technology for the deployment of 6G-oriented services.

A. Definition and General Structure

The concept of DT made its first appearance in 1970 during the Apollo 13 mission. However, it took roughly 40 years before the first attempt of DT defined as an integrated multi-physics, multi-scale, probabilistic simulation of an as-built

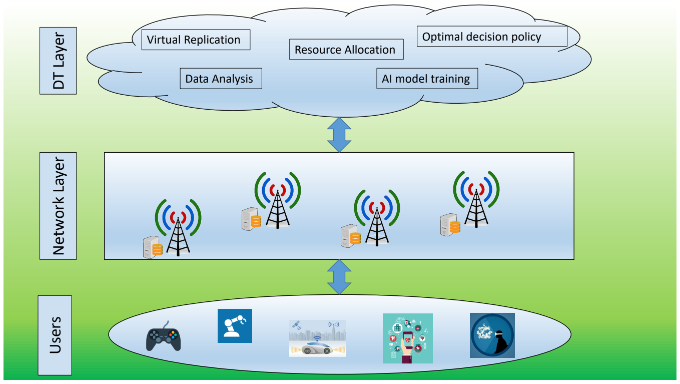

Fig. 3: General description of a DT-enabled 6G wireless network.

vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin, was provided. Generally speaking, we can imagine a DT as a set of computer-oriented models which constantly simulate/emulate the life of a physical counterpart in the real world within its surrounding environment. Keeping in mind this structure, the general architecture of a DT system can be summarized through the following three levels (see Fig. 3):

- **User level**: This level represents the physical world containing users, machines and robots all the related delivered services such as online gaming, industrial IoT, smart traffic monitoring, autonomous transportation, telemedicine and drone-based services.
- **Networking layer**: All the networking devices necessary for guaranteeing the data flow exchange between DT and the physical twin (PT), and between different DTs located in different areas of the surrounding environment, are contained in this level.
- **DT virtualization layer**: Finally, at the top level there exist systems used to store both historical static data and dynamic data reflecting the characteristics of the PT as well as its evolution. Static data can be used to perform offline simulations aimed at generating synthetic data, for example by using generative adversarial network, subsequently used for offline training of DT-embedded AI models. Regarding the dynamic data, it is stored and subsequently used as input for the AI-based algorithms, which will enable the DT to acquire consistent and accurate understanding of the real system. This will allow to obtain a complete status description about the real system, as well as to derive useful insights for system maintenance and decision policy optimization.

B. DT in 6G Networks

As mentioned earlier, thank to the data collected from its physical counterpart, DT enables the possibility to have digital representation on a cloud-based platform of large-scale physical systems, and use the collected data in order to perform and design optimal decision-making policies. This view is perfectly aligned with the ideas of software defined network (SDN) and network function virtualization (NFV) already introduced for the 5G architecture. Specifically, like SDN the introduction of DT can be viewed as a separation between the data plane — gathering measurements from the real physical world — from the control plane, i.e., the control of the physical system through optimal decision-making policies. More in details, at DT level, these policies are obtained by exploring various scenarios through the collected data, which in turn is used to train AI models able to handle all possible corner scenarios in a real environment. Once trained, these models represents the control mechanisms that can be used in order to execute a wide range of programmable functions within the same physical infrastructure. Last but not least, in line with NFV principle, DT technology allows the design of scalable and real-time virtual models monitoring and the control of corresponding physical system.

For these reasons, the concept of DT has been labeled as keystone technology for the the deployment of 6G networks. Indeed, 6G are required to achieve KPI that compared to 5G networks will results at least 10 times higher. For example, as outlined earlier it is expected to serve 10^7 users per km^2 1 Gbps data rate in downlink, as well as to provide 10 μs of communication latency with 99.99999 % network reliability. In order to achieve these ambitious KPIs, it will result necessary to put in place optimal resource allocation and management policies for underlying network which must be executed in real-time. This will be fully achievable through a successful introduction of the DT concept in the next generation networks. Indeed, thanks to the concepts of AI-aided learning in closed loop with its physical counterpart, DT technology will generalize and enhance the concepts of SDN and NFV to meet all the necessary KPIs for 6G networks. This will represent a complete new way to interact with real-world where collected data will be processed in order to perform advanced analysis and make accurate choices for the sake of enhanced users' QoE. This vision is referred as metaverse [7].

IV. DT-Aided RIS-Empowered Communications

Based on the above discussion, and as already mentioned in section I, one can notice how the usage of DT ca result beneficial in order to further support the deployment of RIS-assisted communications, as well as how these two technologies can be considered as complementary towards the realization of the metaverse in future 6G networks. This section illustrates some of the most relevant use cases achievable trough the combination of these two technologies. An high level representation of a DT aided RIS network can be observed in Fig. 4. Due to the nature of RIS the most relevant use cases are related to the physical layer. Furthermore, we also conducted some simulations in order to show how these improvements will can also potentially provide further improvements at upper layers of a RIS-assisted network.

A. Acquisition of Channel State information (CSI)

In contrast to the conventional base station (BS) based communications, RIS-assisted communications have to deal with a more complex and challenging procedure for CSI

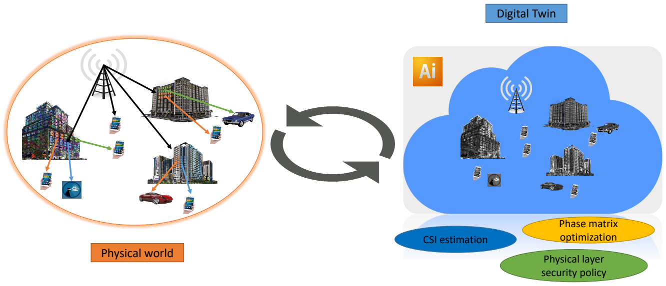

Fig. 4: DT-enabled digital representation of RIS-enabled smart wireless environments.

acquisition. This because the CSI estimation process consists of two different estimation phases: *i)* the direct channel between the BS and the UE (BS-UE), and *ii)* the cascaded channel which involves the RIS (BS-RIS-UE). Then, this means that new effective algorithms must be deigned. Although the usage of deep-learning and in general of neural network based algorithm resulted to be a very effective solutions [10], sometimes these approaches result to be very time consuming, causing then huge transmission overhead in the communications, especially when the model training is performed at the BS. In this context, having a digital representation of the propagation environment through a DT, can provide improved CSI estimation performance as well as a reduced transmission overhead. Indeed, having a DT of the propagation environment can permit to simulate different channels which in turns will represents a training input for the AI-based model trained offline in the DT and not directly at the BS. Furthermore, AI models can be fine-tuned with real data coming from the physical entities located in the real world, i.e., BS, RIS and user equipment (UE). Then, once the model is adequately trained and tested, it can be directly used at either BS or RIS controller in order to perform an optimal signal transmission/detection with reduced time overhead and improved system performances in terms of downlink/uplink throughput and QoS/QoE.

B. RIS Reflection Optimization

In the context of RIS-enabled communication, having the proper optimal phase shift matrix represents the key part in order to enhance the system performances. Indeed, having the optimal phase matrix permits to reflect the signal in the desired direction and/or reduce the noise effect. For this reason, several optimization algorithm have been investigated and proposed in the recent literature. In particular, due to the non-convexity of the optimization problem, most of the proposed solutions do not provide a closed from expression for the optimal phase shift matrix coefficients, but only sub-optimal solution on the basis of the semi-definite relaxation (SDR) technique. Nevertheless, the resulting algorithms result too complex and not suitable for real-time applications. Also in this case the adoption of AI-based solutions, and in particular deep reinforcement learning (DRL) approaches, resulted into a very attractive solution in order to solve the optimization time while lowering the computation overhead. Indeed, in contrast to classical supervised-learning approaches, DRL-based methods avoid huge training labels thanks to their property of online learning and sample generation. However, in order to find the optimal policy, they constantly needs inputs from the physical environment which are not available sometimes. In this way, the DT can be used to represent the propagation scenario and to simulate the channel characteristics which are fine tuned thanks to data provided from the respective physical twins. These channel simulations will help the embedded DRL intelligence to converge into the optimal policy able to deal with all the possible corner scenarios by guaranteeing the desired KPIs.

C. Improved Physical-Layer Security

As 6G networks are expected to serve a high density of users, the task of preventing eavesdroppers from overhearing and stealing sensitive and valuable information, as well as intercepting them in such busy traffic environments, poses significant challenges. Under these perspectives, RIS-enabled physical layer security (PLS) techniques are expected to provide substantial security related enhancements. In particular, since the aim of the attacker is to listen to the legitimate communications, the majority of works presented in literature focus in providing optimization algorithms for the RIS phase-shift matrix in order to maximise the secrecy rate of the transmission defined as the difference between the rate of the legitimate receiver and the rate of the eavesdropper. Furthermore, when a jamming attacker uses high-power noise signals to disrupt legitimate communications, the adoption of RIS communications is aimed at increasing the quality of the legitimate signal at the receiver. In both cases, the implementation of the proposed algorithms requires some information about the surrounding propagation environment which is either partially or not completely available at the transmitter or at the network operator managing the RIS-aided network. Then, it is evident that the availability of the data from the area of interest through its DT representation will provide a substantial boost of the PLS performance of next 6G networks.

D. A Latency Reduction Use Case

To demonstrate impacts of DT-aided RIS on the latency in 6G metaverse-sbased applications, we conducted some simulations by considering the indoor system model illustrated in Fig. 2. In particular, there is a BS associated with an edge server (ES) used to execute offloaded computational tasks from 20 user equipments (UEs). DT and RIS technologies are applied to empower both computation and communication aspects for the system. The considered RIS system, consisting of R elements, is aimed at improving the wireless transmissions from UEs to the BS. In terms of computation, DT services provide estimation of processing rate for all physical devices and enable intelligent edge caching to minimise the latency [15]. In particular, it has been assumed total computing capacity of ESs, in terms of processing rate, varying between 30 GHz and 38 GHz, while the processing rate of each UE is limited to a maximum value of 500 MHz. Following [15], task complexity is uniformly distributed a range of $[100, 300]$ cycles/byte and the caching capacity of ESs is up to 40%. The considered RIS system, consisting of R elements, is aimed at improving wireless transmissions from UEs to the BS. Furthermore, it has been assumed the presence of communications links with ultra-reliable and low latency communication (URLLC) constraints. These in order to guarantee the deployment of time-sensitive applications in metaverse ecosystem.

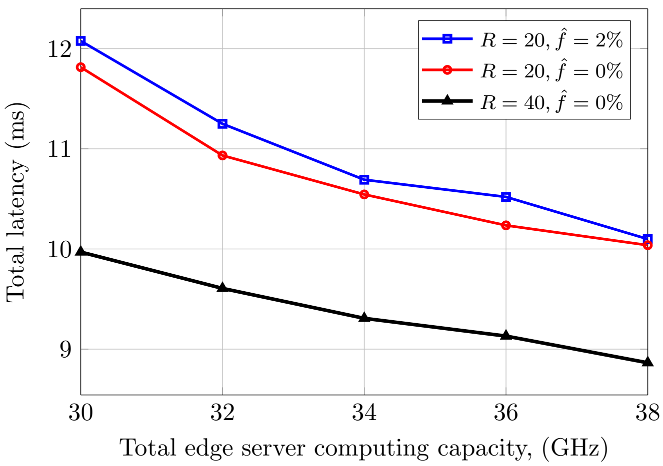

Fig. 5: Impact of DT-aided estimation and the number of RIS elements on the total latency in a DT-aided RIS-empowered MEC system.

The main goal was to jointly optimise both communication and computation resource management of the underlying DT-based edge computing and RIS-assisted network. Form Fig. 5 is evident how DT virtualization error, number of RIS elements and computing capacity of ESs affect to the total latency of UEs. More specifically, it is possible to notice how to an increase of the computing power of ESs leads to a sustainable decrease of latency for all scenarios. That indicates the task offloading mechanism works appropriately in reducing processing latency of offloaded tasks. Furthermore, perfect estimation of DT in processing rate (i.e., $\hat{f} = 0\%$) noticeably contributes on the improvement of system performance. Importantly, Fig. 5 also indicates that RIS play a significant role in reducing the total latency by improving the transmission channel. Indeed, when the number of RIS element increases, the obtained total latency experiences a considerable drop under the same simulation setting. These results effectively validate the importance of DT and RIS technologies in novel wireless applications for the metaverse ecosystem.

V. Challenges and Research Directions Ahead

Although the combination of DT and RIS technology represents a very successful combination towards the realization of a reliable, fast and zero-touch 6G architecture for metaverse realization, both technologies are still at their infancy stage. Therefore, some important issues and challenges that at the time of writing still need particular attention are discussed within this section.

A. RIS deployment strategies

In the context of RIS-aided communication, it is clear how the performance of the system is considerably affected by the deployment strategy of RIS. Indeed, based on the above discussion, in order to find the optimal location of RIS, several important factors must be considered such as user distribution, type of service to deliver in the area of interest and interference avoidance with other existing networks. Indeed, an optimal RIS deployment strategy can considerably reduce unintentional interference among operators, as well as the CSI estimation time when RIS with sensing capabilities are optimally deployed [11]. Thus, it is necessary to provide planning tools which will allow to perform optimal RIS deployment in line with the underlying requirements. Further, strategies are required to reduce and/or completely eliminate the potential interference of RIS reflected signal with other BS in the surrounding area. As already discussed in section IV, a DT representation of the considered network represents a potential tool for addressing some RIS related issues. For example, having a DT of the environment of interest can be used for support the optimal placement of RISs, which in turn will reduce the timing for the channel estimation procedure. However, for the best of the authors' knowledge, the current literature lacks of studies related to the development of DT-aided RIS planning policies as well as the investigation of mechanisms for interference mitigation.

B. Real-time Synchronization

One of the primary challenges to consider in the context of digital representation of physical systems is ensuring real-time synchronization between physical entities and their DT implementations. This aspect needs significant attention. In fact, it is not only associated to reducing the end-to-end communication latency between DT and its physical counterpart, which partly impacts on this aspect, but it is mainly related on guaranteeing a high fidelity digital representation of any underlying physical system in order to provide an optimal up-to-date decision policy in line with the current network status. Indeed, the absence of data from one or more physical devices, or receiving it with a significant delay, can adversely affect the accuracy and performance of the entire DT-aided RIS network, ultimately leading to a decrease in the QoS provided. For instance, having inaccurate information of the surrounding environment will result in low performance of the AI-based algorithms trained at the DT level. Then, since it is envisaged that a huge amount of IoT devices will be deployed within the 6G network infrastructure, that in turn will generate a huge amount of data traffic towards edge/cloud servers providing computing services, providing good levels of connectivity and having optimization strategies for the deployment of DT cloud/edge servers represents a future direction in order to guarantee optimal levels of synchronization rate in the DT representation process.

C. Scalability and Data Security

Another research direction necessary for the deployment of DT-aided RIS enabled metaverse is the scalability of the system. Indeed, the implementation of such DT-based system will require a massive amount of user data from all the underlying users/sensors for training the AI/ML models. Then, it is clear how a centralised approach will not represents the best solution since it will inevitably incur into high system latency not in line with requirements for deploying metaverse services. In this view, the adoption of federated learning (FL) approaches has gained widespread attention as a promising alternative to centralized approaches. This is due to its ability to avoid the significant overhead associated with transmitting large amounts of data. Indeed, when local datasets are extensive and the resulting AI-based model at the DT results complex, it is preferable to distribute the optimization of model parameters across multiple local devices and generate a global model at an aggregation server through model aggregation. Furthermore, in addition to reduce communication latency, FL also improves user privacy and data security, especially against data poisoning attacks where through illegitimate data injection and data manipulation the AI models trained at the DT level will be led to learn inaccurately. Then FL approaches enriched with the principles of homomorphic encryption and differential privacy techniques represent the most promising and powerful tools in order to overcome the aforementioned issues. However, more research efforts should be undertaken in this direction.

VI. Conclusion

This article presented the potential of the DT concept for offering advanced and real-time solutions for the optimal orchestration of RIS-empowered communications to enable the deployment of metaverse-based services. The latest status in the RIS and DT technologies was discussed, and use cases as well as services that can be delivered through a DT-aided RIS-based network architecture were introduced. Challenges and future research directions with the proposed DT's role for RIS-enabled smart wireless environments were highlighted.

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