COST INTERACT Working Group 1: Key Challenges and Initial Directions

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COST INTERACT Working Group 1 (Radio Channels): Key Challenges and Initial Directions

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***Abstract*—A comprehensive understanding of the radio channel is a prerequisite for designing efficient wireless communication systems. Next generation wireless systems are expected to include both new technologies (e.g., intelligent surfaces, integrated sensing and communication) and new frequency bands (in particular, above 100 GHz). These new technologies and bands will require a paradigm shift in radio channel measurement and characterization. To that end, we explore the ongoing and planned activities that COST INTERACT Working Group 1 (WG1) has been carrying out. In particular, we describe the position of WG1 as originally mandated by COST INTERACT, elaborated further by the addition of subWGs on RIS and mmWave and THz sounding. Next, we identify the key challenges faced by WG1 and the two subWGs and describe the first steps taken in order to address those challenges. Finally, we give an outlook for the activities that need to be carried out in order to contribute towards the definition of a comprehensive channel modeling framework that encompasses new scenarios and technologies that will be included in future wireless communications systems.**

I. INTRODUCTION

COST INTERACT Working Group 1 (WG1) aims at increasing the theoretical and experimental understanding of radio channels in environments of interest and at deriving models for design, simulation, and planning of future wireless systems. Wide frequency ranges from sub-GHz to THz, potentially high mobility, diverse and highly cluttered environments, dense networks, massive antenna systems, and the use of intelligent surfaces, are some of the challenges for radio channel measurements and modeling for next generation systems. As indicated in [1], with increased number of use cases (e.g., those identified by one6G [2] and shown in Fig. 1) to be supported and a larger number of frequency bands, a paradigm shift in channel measurements and modeling will be required. To address the particular challenges that come with such a paradigm shift, WG1 started the work on relevant topics, ranging from channel sounder design, metrology and measurement methodologies, measurements, modeling, and systematic dataset collection and analysis.

Furthermore, based on the large interest and impetus generated by the Temporary Documents (TDs) of initial meetings, two sub Working Groups (subWGs) have been initiated as part of WG1: i) subWG on mmWave and THz sounding (subWG THz) and ii) subWG on Reconfigurable Intelligent Surfaces (subWG RIS).

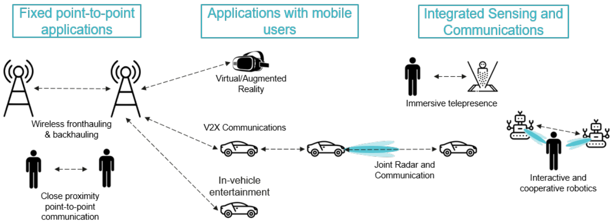

Fig. 1: Exemplary use cases that next generation wireless communications systems aim to enable [2].

This TD summarizes the key challenges that the radio channel measurement and modeling community will have to face as identified by WG1. Furthermore, it provides insight into the initial approaches to address these challenges, as presented in initial WG1 meetings. Specifically, Section II discusses the overall goals, whereas Section III identifies the main challenges for WG1 and subWGs. Section IV discusses initial directions taken in the scope of WG1 and subWGs to address the identified challenges. Section V concludes the TD and indicates the necessary steps toward the definition of a complete framework for radio channel modeling of future wireless communications systems.

II. POSITION OF WG1 (RADIO CHANNELS)

Extensive efforts are being devoted to obtaining a comprehensive understanding of radio wave propagation in several frequency bands for the development of future wireless networks. The task of WG1 is to further this understanding by providing an open and collaborative forum for the exchange of ideas, definition of key challenges, and identification of directions for research on radio channels. To that end, the efforts in WG1 relate to propagation modelling for radio systems, including the ones exploiting millimetre-waves (mmWave) and higher frequency bands (sub-THz and THz), where

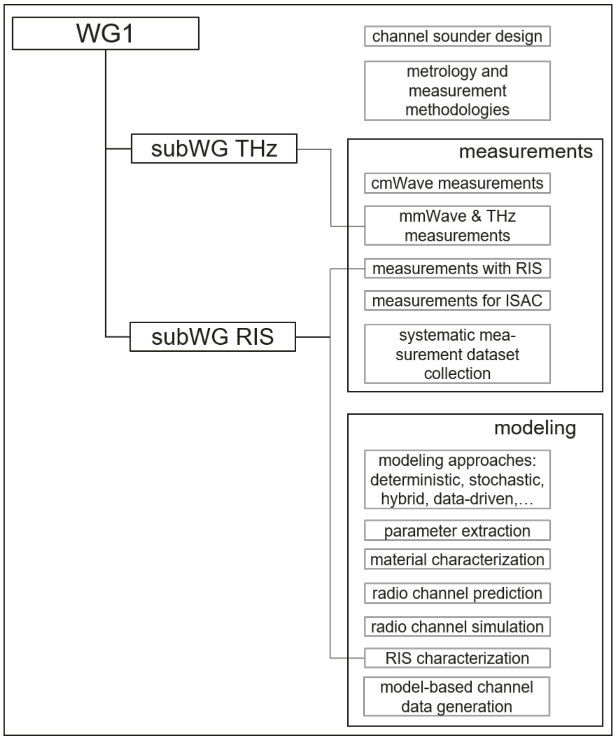

Fig. 2: Topics addressed by WG1 and its subWGs.

large contiguous bandwidths are still available, and massive Multiple-Input Multiple-Output (MIMO) and beamforming techniques, which will enable spectral-efficient connectivity in densely populated areas. Understanding radio wave propagation has also been crucial to new applications, including highly dynamic scenarios, IoT and smart grids. Efforts on propagation modelling for these systems and applications encompassed vehicular and mmWave cellular access [3], IoT and Smart Grids [4], and energy efficient cellular radio planning. These propagation modelling studies have been carried out using various measurement setups [5] or combining measurements and theory for link- and system-level simulations [6], addressing the time, angle and polarisation characteristics of multipath channels, as well as the characterisation of material properties, outdoor-to-indoor penetration loss, and link blockage [3]. Propagation models become mature once supported by a vast amount of measured and simulated evidence of radio channels, and by our understanding about them. Ultimately, such mature propagation models may be able to perform real-time prediction of radio environments and hence provide accurate-enough Channel State Information (CSI) to aid radio communication systems and applications. As an example, a few studies have addressed the real-time use of deterministic propagation models to help estimate CSI [7], along with a location-aware CSI fingerprinting [8]. Their real-time use in localisation, beamforming, and resource allocation algorithms is still in its infancy.

WG1 is also committed to collecting data and sharing them to create large reference sets for model development and training of ML approaches, with WG1 members already contributing several datasets for this purpose (datasets available at https://interactca20120.org/wgs/datasets-2/).

Based on the discussion above, Figure 2 summarizes the main topics that WG1 is addressing, along with the indication of specific topics that are handled by the subWGs. WG1 will contribute to each of these topics in order to reach its ultimate goal – definition of a comprehensive channel modeling framework that addresses new scenarios and frequency bands proposed for future wireless communications systems.

A. Position of subWG mmWave and THz sounding (THz)

The goal of the sub-group on mmWave and THz sounding is to concentrate the expertise on radio channel measurements and analysis. Novel experimental set-ups, verification of channel sounders, radio channel measurements in different environments/for different applications are some of the key aspects to be investigated. The chain to be covered ranges from the validation of the measurement equipment to the analysis of the measurement results. The objectives of this sub-WG are to extend the knowledge on propagation from empirical analysis and to develop common practices, in order to create a rich pool of harmonized data from diverse sets of measurements.

B. Position of subWG Reconfigurable Intelligent Surfaces (RIS)

The goal of the subWG on RIS is to focus on the modeling and analysis of future smart radio environments empowered by controllable and smart surfaces. These surfaces enable manipulation of the radio channels and minimization of the signal losses. This is particularly of interest at mmWave and higher frequencies to extend otherwise limited communication ranges due to high path losses and very poor penetration into the shadow regions of objects and obstructions. Taking the idea further, large numbers of smart surfaces would enable smart environments where it is possible to optimize to channels to maximize the network throughput and efficiency.

In order to understand the benefits and limitations of radio channel modulation with RISs, we have to properly understand the modeling and performance of different types of RISs (e.g., reflect arrays, metasurfaces, holographic surfaces, etc.). Modeling those properly is a key to continue to the modeling and analysis of individual links, entire systems, and smart environments. Therefore, the goal of this subWG is to extend the knowledge on three fundamental aspects of RISs: 1) proper and realistic RIS models for different RIS configurations and technologies, 2) propagation models for RIS empowered links and systems, and 3) performance of smart links, systems, and environments.

III. WG1 CHALLENGES

Compared to previous generations of wireless communications systems, new challenges arise in measuring and modeling the radio channels for next generation systems. The new frequency bands being explored (from upper GHz to THz), previously unseen amounts of continuous bandwidth (in the range of tens of GHz), and new and diverse use cases create considerable new opportunities and challenges. While WG1 will address the modeling aspects of these challenges and the more general issues related to propagation characterization, subWG THz will focus on the challenges related to efficient sounding in mmWave and (sub)THz bands and with high bandwidths.

At upper mm-wave and THz frequencies, the much larger bandwidth and the need for highly directive antennas to counter the higher isotropic path-loss, determine a much higher time- and space-resolution of the channel and mandates new channel sounding techniques and novel modeling approaches. In addition, the spatial accuracy required for communication links and use-cases in highly dynamic environments pushes the limits of current characterisation techniques. Therefore, one of the tasks of WG1 is to increase the theoretical and experimental knowledge of radio channel characteristics and to propose ways to properly exploit them. Another further significant challenge is the possibility to shape the radio channel through Reconfigurable Intelligent Surfaces (RISs) [9], which is one of the key tasks for subWG RIS.

Another distinguishing feature of (sub)THz frequency bands due to the mentioned higher resolution capabilities is the ability to both sense and communicate. To that end, there has been considerable interest in the integrated sensing and communications (ISAC) use cases [10]. In terms of radio channel measurements and modeling, ISAC use cases require particular setups that are different to traditional ones. Some examples are the location of transmitter and receiver (which for ISAC can be collocated or distributed) and the types of signals considered (e.g., variation in the required bandwidth between the communication and sensing components of ISAC), among others. Specific considerations for ISAC will be identified and worked on in WG1.

Application of machine learning (ML) to propagation modelling is another topic of interest and challenge for WG1, which could be applied to both analyze and simulate the channels and to generate additional synthetic channel measurement data. To that end, WG1 will explore combining measurements with ML-generated data for improved propagation modelling. For instance, the data can cover different scenarios, such as outdoor to indoor and indoor and outdoor in cluttered environments, while the collection of insights into radio propagation phenomena, such as scattering of radio waves due to rain and snow in the higher frequency bands will be addressed by ML algorithms. Furthermore, propagation-sensitive features can be extracted through classical propagation modelling techniques, which can then be fed to ML algorithms for training. When accurate physical models of radio environments are available (e.g., detailed maps), it is possible to use them for the prediction of radio channels and generation of radio maps. Moreover, the prediction of important radio propagation parameters, such as the characteristics of scatterers, clusters and multipath components, and delay/angle power profiles, would greatly benefit from environmental awareness. The methodological breakthrough here would be the ability to predict radio channels and environments beyond what is presently possible, by taking advantage of increasingly available environmental information for improved radio communication networks and sensing, in real-time, or even ahead of time (also called channel anticipation) by using, for example, ML techniques and/or dynamic ray-based techniques.

Although a bit outside of the main scope of WG1, ML application to radio imaging for remote sensing and detection of objects, drones, waste etc. or to lidar images (point-clouds) for environment interpretation and mapping also represent very attractive possibilities and challenges.

A. *subWG THz challenges*

1) Experimental platform development and channel sounding metrology: Frequency domain (e.g., VNA based) and time-domain (e.g., correlation-based) channel sounders at mmWave and sub-THz have been reported in the state-of-art works. However, meeting all the channel sounding requirements such as phase stability with increased carrier frequency, dynamic range and measurement range, bandwidth, sampling rate, number of simultaneously served users, and the support for multi-antenna measurements is challenging. Moreover, since knowing the geometrical properties of the multi-path components is of special interest at higher frequencies, obtaining high resolution simultaneously in the different domains demands specialized hardware and set-ups.

The verification and validation of these measurement set-ups to ensure that its performance is consistent with the designed specifications is the foundational stone for propagation analysis.

2) Phase-coherent measurements, virtual and physical antenna arrays concepts for mmWave and sub-THz: Directional antennas are typically employed to obtain the spatial profile of the channel and compensate the high transmission loss at mmWave and sub-THz bands. However, this requires a static channel and the spatial resolution is limited by the directivity of the antennas. Virtual arrays are an alternative to increase the spatial resolution, but also at the expense of a static scenario. On the other hand, physical antenna arrays enable real-time measurements with spatial resolution. Whereas this is state of the art at sub-6 GHz, it is still on its infancy at mmWave and very unexplored at THz.

An essential aspect to consider in the implementation of virtual and physical array is phase coherency. It has been seen in practice that to have accurate phase measurements at mmWave and sub-THz due to cable effects, and stability of the mechanical and RF systems is also challenging.

3) Massive collection of channel measurements: Scanning the spatial domain with high directive antennas or the implementation of virtual arrays is time consuming, as well as the frequency swept in VNA-based channel sounders. Hence, the collection of massive amount of channel measurements for channel modelling purposes becomes challenging with increasing frequency. Extensive measurements are required to reach the conclusion whether the existing channel model at mm-wave bands, such as 3GPP FR2 models, can be extended to sub-THz bands. Furthermore, it would be of importance to understand the spatial similarity of radio channels across frequency bands, since this knowledge can be utilized to enable fast beam-search at sub-THz bands based on out-of-band spatial information. The channel frequency dependence studies also necessitate extensive measurement campaigns.

4) Ray tracing simulation and its validation with measurement: Measured channels at mmWave and sub-THz are shown to be sparse and specular. Furthermore, mmWave and sub-THz channels will rely on dominant path communications. Ray tracing has gained its popularity due to its capability to accurately predict the dominant channel paths. However, little ray tracing validation with measurements have been reported, especially for the sub-THz frequency bands.

B. subWG RIS challenges

Until recently, the radio channel has been addressed as the only part of a radio communication system that cannot be engineered. Thanks to progress in meta-surfaces technology, it is now possible to change the multipath radio channel characteristics and bring system performance to a new level. The application of RIS to wireless networks is still in its infancy: besides the development of the RIS technology itself, a great deal of radio propagation modelling studies are necessary to pave the way to its successful application. Such studies include the development of models for near- and far-fields backscattering from realistic RIS meta- surfaces and the development of propagation- and system-level simulators to design RIS deployments and assess their full potential in a variety of cases. The three main challenges are shortly discussed below.

1) RIS Modeling: There are several different types of RISs based on their physical construction and configuration [11]. Those include, but are not limited to, antenna array based solutions, metasurfaces, and holographic surfaces. Understanding the reflection properties of different types of RISs, and modeling those correctly is very important for subsequent channel modeling, optimization, and analysis. Hence, one of the main challenge and important piece of the smart radio environments is to produce models and knowledge of the RISs themselves. As there are plenty of applications for RISs, similarly several types of RIS constructions are equally important, including their correct modeling of their behavior and peculiarities.

2) Propagation and Channel Modeling: RIS enhanced radio channels are largely revolving around RISs, but very important part is to model the radio environment itself. Depending on the frequency, bandwidth, the environment, and other factors, the signal propagation via RISs is important to model and understand in order 1) to understand if the RIS(s) provides any improvement on signal levels and 2) to calculate what are the requirements for the RIS(s) to benefit the propagation. The second issue is the propagation itself. Depending on the RIS properties and the surrounding channel, accurate channel models need to be derived to properly account for the static and non-static elements of the environment and RISs at the same time. That is, we need to be able to accurately model the configurable channels for accurate link models. Furthemore, with large RISs, it is possible that some or all the users are in the near field of the RIS. This increases the complexity of the channel estiamtion and potentially increases the losses of the system. These issues are among the many great challenges with compound channels between source, RIS(s), and destination. The behavior of the total channel is dependent on the entire link and it's momentary configuration. This means that we can cause strong interference to unwanted directions or cause strong reflections at unwanted frequencies. A simple RIS channel with, e.g, base station (BS), RIS, and a mobile user (MU) is rather straightforward, especially if BS–RIS link is designed to be LOS in the best case. Modeling the propagation environment with potentially a lot of MU, RISs, and BSs makes the problem of modeling the entire propagation environment and finding the optimal propagation paths very hard challenge. However, it all starts from proper understanding of the channel and propagation. Tools from machine learning can be later leveraged to optimize the channels and entire networks as well as possible.

3) Performance Evaluations: The above RIS modeling and channel modeling are important pieces to fundamentally understand the limits of the RIS aided communications. The performance evaluations require these models, but also optimization of the RISs based on the environment, users, their mobility, etc. It is relatively simple to optimize a single link. It is a great challenge to optimize the RIS link because of the fact that the channel changes from static to configurable. It is even a bigger challenge to optimize a network of users and RISs, potentially with multiple BSs. The performance of the system is dependent in the RIS optimization. That is, the ability of the RIS to configure the channels in the best possible way. There is no one way to evaluate the performance of the RIS enhanced systems as there are countless ways to deploy RISs. Mathematical tools from fundamental models all the way to machine learning and artifical intelligence can be used to evaluate problems of many scales. Ray tracing is becoming an important tool at high frequencies to aid with propagation modeling. There are a lot tools for performance evaluations, but the real challenge here is to combine the use case and scenario specific RIS and propagation models with proper tools and RIS optimization to produce relevant performance metrics. It has been shown that RISs will benefit the communications in many cases. However, they do not give answer to specific deployment in all the cases. Not even talking about massive random deployment of numbers of different types of RISs and users, where the radio environment needs to be able to self-configure and -optimize while being energy efficient and nearly performance optimal.

One important part of the performance evaluations are the functional prototypes. It is very simple to write physical model on paper. The actual prototypes and their develoment gives a lot of information on the practical challenges. These include complexity and cost, scalability, and the achievable performance. The actual implementations will suffer from losses that are not usually taken into account in the theoretical modeling. This is why the prototypes are very important in the development. They show the feasibility of the theoretical models and give feedback to what needs to be taken into account in the modeling to come up with believable performance evaluations.

IV. WG1: INITIAL DIRECTIONS

WG1 has already seen considerable activity in the two key directions related to the characterization of radio channels, namely measurements and modeling: in the next two subsections, we indicate a few exemplary directions addressed for both of them. In the two subsections after that, specific aspects related to subWG THz and subWG RIs are summarized.

A. Initial directions for radio channel measurements

As a key precursor to channel measurements, development of appropriate channel sounding equipment is required. To that end, contributions to WG1 have addressed sounder development, e.g., for MIMO [TD(22)01018], multi-link measurements for mesh-network scenarios [TD(22)02040], and sounders for (sub)THz frequency bands [TD(22)01007].

Large number of measurement campaigns have already been conducted and contributed to WG1, characterizing path loss [TD(22)02033], multi-path components [TD(22)02039], and other channel parameters [TD(22)02042]. In terms of atmospheric attenuation effects, [TD(22)02006] described rain attenuation measurements at millimeter waves. Propagation properties of materials are also important, in particular for new bands that will be used for future communication systems. To that end, [TD(22)02007] performed indoor material transmission measurements, whereas [TD(22)02008] describes material reflection measurements in millimeter and sub-THz bands. Other studies are addressing the impact of beamforming techniques on large scale channel parameters such as RMS delay spread [TD(22)01068].

B. Initial directions for radio channel modeling

WG1 contributions on channel modeling have addressed a large range of different vertical applications, environments, and modeling methods. For example, models for V2X have been presented in [TD(22)01096], [TD(22)02027], for train-to-train communications in [TD(22)01057], UAVs in [TD(22)01076], etc. Furthermore, location-specific models were also presented, e.g., for outdoor (tunnels [TD(22)02002], urban streets [TD(22)01090]), indoor (meeting room, office space [TD(22)01036]), and outdoor-to-indoor models ([TD(22)02022], [TD(22)01076]).

WG1 is addressing several methods for channel characterization, such as geometry-based stochastic models [TD(22)01057], statistical modeling of short-range paths [TD(22)01019], and comparison/trade-offs of different modeling approaches, including novel statistical-geometry approaches [TD(22)01063]. The high number of contributions on ray-based propagation modeling and related topics, including new ray-based techniques ([TD(22)02030] [TD(22)02060]), open-access platforms for efficient ray tracing field prediction ([TD(22)01002], [TD(22)01089]), ray-based modeling of diffuse scattering at THz frequencies ([TD(22)02010],[TD(22)01092]), and the use of ray-tracing to complement measurements [TD(22)01016] or to analyze propagation mechanisms

[TD(22)02039], speaks clearly of the trend toward deterministic propagation modeling, probably due to the ray-optic characteristics of propagation at mm-wave and THz frequencies and to the relatively smaller, better defined propagation environments.

New modeling methods based on machine learning have also been addressed, e.g. machine learning for reducing the noise in channel measurements [TD(22)02020], generating super-resolution channels [TD(22)02014] ; predicting EMF exposure [TD(22)02032], detection of wall materials based on CIR measurements [TD(22)02069], simulation of Integrated Sensing and Communications [TD(22)02075] and real-time prediction (or anticipation) of channel throughput [TD(22)02013].

Finally, studies are being carried out to evaluate the impact of the human body on the performance of hand-held mm-wave mobile terminals [TD(22)02072] or on the non-stationary characteristics of the channel [TD(22)02079].

C. *subWG THz: initial directions*

An over-the-air artefact for verification of frequency response calibration and joint estimation of time-of-arrival, angle-of-arrival, and Doppler at sub-THz has been presented in [TD(22)01007]. Similarly, a measurement set-up for Doppler verification in a controlled environment and its validation with measurements at sub-6 GHz and mmWave was introduced in [TD(22)02001]. The results showed similar MPCs at sub-6 GHz and mmWave. These results were also consistent with measurements conducted in a high mobile environments at different frequencies showed in [TD(22)02034].

A novel sub-THz VNA-based channel sounder supporting phase-coherent measurements from 220 to 330 GHz was presented in [TD(22)01038]. By using the radio over fiber (RoF) technique and phase compensation scheme, the long-range phase-coherent channel measurement could be conducted at 220 to 330 GHz. This proposed channel sounder is expected to be employed to support virtual array measurements at sub-THz bands in the future.

A virtual array scheme based on directive antennas for channel estimation at 28-30 GHz has been introduced in [TD(22)01037]. The proposed scheme offers better spatial resolution compared to state-of-art directional scanning scheme (DSS) with the same measurement system, and better signal noise ratio (SNR) compared to virtual array based on omni-directional antennas. The proposed channel sounder was further employed for omni-directional pathloss modeling in [TD(22)02033].

Regarding measurements for characterization of propagation in the sub-THz bands, work in [TD(22)01014] focused on vegetation loss from 110 to 170 GHz, and VNA-based measurements in indoor scenarios were reported in [TD(22)01036] on pathloss results covering 140 to 220 GHz. Analysis in [TD(22)01060] showed the usability of low frequency radio channel information for beam searching at high frequencies. Continuing this line of investigations, similar analysis based on measurements at sub-6 GHz and mmWave were presented in [TD(22)02067].

D. *subWG RIS: initial directions*

iii) the use of all models and tools to study RIS in real-life propagation environments, propose/assess novel applications and perform sound performance evaluations

There are four research directions for future researh on RISs: RIS modeling, propagation modeling, performance analysis, and prototyping and real life measurements.

The study of RIS technologies and electromagnetic models are fundamental piece of accurate analysis of links and systems utilizing RISs. Some efforts towards accurate RIS models have been taken in literature and, e.g., in TD(22)02066. Regardless, quite many of the current performance related papers use rather simple models for RISs. While ideal RISs are mostly valid way to approach performance analysis, accurate models are essential to understand technological bottlenecks and give accurate predictions for protoype testing, performance analysis, etc.

The main reason for RISs is the ability to control the uncontrollable: the channel. How to apply and optimize various different types of RISs in different environments is a major task. A lot of research has been done on control algorithms, but there is plenty of space for more, especially in terms of RIS modeling. On top of this, fundamental propagation modeling in near field and far field has been studied, e.g., in TD(22)02035, but more environment and frequency band-specific channel and propagation modeling is needed in order to understand the characteristics of RISs.

To understand the performance of RISs in realistic environments, performance evaluations are essential. Both link and system level simulations are important. Especially ray-based simulators are of high interest due to complexity of the RIS-enabled systems, particularly in higher frequencies. There are a number of link level evaluations in the literature (e.g., in TD(22)02078). In order to enable real systems that utilize RISs, system level simulations will become increasingly important.

Finally, one of the most important tasks for the future is to prove, by prototypes and demonstrations, that the RISs actually work and bring benefits to communications. The theoretical results have shown that the RISs show promise, but the real prototypes will show the actual performance, challenges, and cost of the various different technologies. There is also a need for developing testing environments, such as was done in TD(22)02070.

V. CONCLUSIONS AND NEXT STEPS

We summarized the key topics that COST INTERACT WG1 is dealing with. In particular, we describe the position and key tasks that WG1, subWG RIS, and subWG THz are dealing with. Next, we identified the key challenges for radio propagation modeling that need to be addressed, ranging from new frequency bands (e.g., above 100 GHz), inclusion of new use cases (e.g., those related to ISAC), and the introduction of RISs that shape the propagation environment and thus challenge the existing propagation modeling approaches. We also provide a summary of the first steps taken in WG1 and subWGs in order to address those challenges.

To contribute towards a comprehensive channel modeling framework that addresses new scenarios and frequency bands proposed for future wireless communications systems, extensive measured data collected in various deployment scenarios (including both short-range and long-range scenarios) are required. This is essential to address key questions such as: can existing 4G and 5G standard channel models be directly extended for 6G? are site-specific channel simulations (e.g. ray tracing) accurate enough for 6G scenarios? are developed channel models good enough to support for new 6G applications?, to name a few. Identified key challenges and initial directions from WG1, subWG RIS, and subWG THz define the guidlines to help achieve this goal. Specifically, WG1 and subWGs will collect a rich pool of harmonized data from diverse sets of measurements performed by COST member groups, identify the distinguishing features of new bands (e.g., sub-THz), characterize the most important propagation properties of candidate RIS designs, and identify the most appropriate modeling approaches to support new use cases envisioned for the future wireless communications systems. In terms of the particular steps taken to achieve these goals, the following are exemplary (i.e., non-comprehensive) directions that WG1 and subWGs will take: i) build on existing geometry-based stochastic channel models or map-based hybrid models to derive new versions with greater spatial consistency and parametrization for the new frequency bands; ii) establish best practices for mm-wave and THz channel sounding; iii) derive reference models (in particular, macroscopic ray based models) for RIS.

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