Brussels, 25 May 2021

COST 060/21

DECISION

Subject: Memorandum of Understanding for the implementation of the COST Action "Intelligence-Enabling Radio Communications for Seamless Inclusive Interactions" (INTERACT) CA20120

The COST Member Countries will find attached the Memorandum of Understanding for the COST Action Intelligence-Enabling Radio Communications for Seamless Inclusive Interactions approved by the Committee of Senior Officials through written procedure on 25 May 2021.

Funded by the Horizon 2020 Framework Programme of the European Union

MEMORANDUM OF UNDERSTANDING

For the implementation of a COST Action designated as

COST Action CA20120
INTELLIGENCE-ENABLING RADIO COMMUNICATIONS FOR SEAMLESS INCLUSIVE INTERACTIONS (INTERACT)

The COST Members through the present Memorandum of Understanding (MoU) wish to undertake joint activities of mutual interest and declare their common intention to participate in the COST Action, referred to above and described in the Technical Annex of this MoU.

The Action will be carried out in accordance with the set of COST Implementation Rules approved by the Committee of Senior Officials (CSO), or any document amending or replacing them.

The main aim and objective of the Action is to make future wireless networks become intelligent by taking advantage of cutting-edge technologies to cope with the increasing demand for connectivity and traffic density, in order to enhance the human experience of both human-to-human and human-to-machine communications, to make it seamless, with the perception of no intermediary. This will be achieved through the specific objectives detailed in the Technical Annex.

The present MoU enters into force on the date of the approval of the COST Action by the CSO.

TECHNICAL ANNEX

OVERVIEW

Summary

INTERACT vision is to go beyond the capabilities of the 5G and to make the radio network itself intelligent. This is required in order to enhance the human experience of both human-to-human and human-to-machine communications, and make it seamless, with the perception of no intermediary. Machine learning is an important tool in implementing this vision, since along with advanced network architectures and distributed content provision, it provides a means of implementing many aspects of this network intelligence. However, its use must be informed by theoretical and experimental research on radio channel models, network architectures and signal processing algorithms.

Hence, the main scientific objectives of INTERACT are:

1. To perform fundamental research in the fields of antennas and propagation, signal processing and localisation, and network architectures and protocols, to design intelligent-enabling radio communications.

2. To make the wireless network intelligent, meaning aware, adaptive, and parsimonious. Similarly to cities and buildings, future wireless networks should become intelligent by taking advantage of cutting-edge technologies to cope with the increasing demand for connectivity and traffic density and to bring the user experience to a new level.

3. To contribute to the creation of intelligent environments. Not only will mobile radio networks become intelligent, but they will constitute the nervous system to foster intelligence in other systems and verticals, such as ehealth, transportation, industry, buildings and cities.

Areas of Expertise Relevant for the Action	**Keywords**
● Electrical engineering, electronic engineering, Information engineering: Communications engineering and systems (select for additional explanation) ● Computer and Information Sciences: Machine learning algorithms ● Electrical engineering, electronic engineering, Information engineering: Signal processing, 1-D and multidimensional signal processing, compression, signal acquisition ● Electrical engineering, electronic engineering, Information engineering: Statistical data processing and applications using signal processing (eg. speech, image, video) ● Electrical engineering, electronic engineering, Information engineering: Networking	● Radio Channel Modeling ● Radio Access Networks ● Internet of Things ● Vertical Applications ● Machine Learning

Specific Objectives

To achieve the main objective described in this MoU, the following specific objectives shall be accomplished:

Research Coordination

- To perform fundamental research in the fields of antennas and propagation, signal processing and localisation, and network architectures and protocols, to design intelligent-enabling radio communications.
- To make the wireless network intelligent, meaning aware, adaptive, and parsimonious.
- To contribute to the creation of intelligent environments, with emphasis on health and well-being, transportation, industry, buildings and cities.
- To support the research by making available datasets on real world scenarios, radio channel data and signal data.

Capacity Building

● To give Europe the capacity to continue being a leader in telecommunication networks, proving a significant push towards the development of disruptive intelligent networks.
● To enable interdisciplinary research, exploiting machine-learning tools, that can provide a means for implementing many aspects of the intelligent radio network.
● To train researchers in all stages of Research and Development, and create a generation of young researchers with technical competencies.
● To facilitate technology and knowledge transfer toward industry, sharing Research and Development in a non-competitive way and addressing open problems.

COST
EUROPEAN COOPERATION
IN SCIENCE & TECHNOLOGY

TECHNICAL ANNEX

1. S&T EXCELLENCE

1.1 Soundness of the Challenge

1.1.1. DESCRIPTION OF THE STATE-OF-THE-ART

Previous wireless networks (up to 4G) have focused on providing communication links, first between human users (telephony), then between human users and centrally-located content and service providers, such as video streaming and online shopping. Each new generation has had a new radio interface based on a disruptive approach. 5G is the first one to have a radio interface that is an evolution of the previous generation, still, it introduces de facto a feature, researched for quite a while but never actually implemented in a cellular system, i.e., active antennas with beamforming (4G has references to them, but does not really use the technology in a widespread mode). In other words, 5G is aiming at making full use of the spatial dimension. In parallel to the radio interface (which has already been standardised), 5G has also new approaches concerning the network architecture and features, e.g., virtualisation, slicing, cloud and edge, which extend from the radio component to the very core of the network (still under standardisation, but mostly already defined). In addition to the development of higher data rates, 5G extends the network beyond human users to embrace machines [5GP15]. Doing so brings two new constraints, namely Massive Machine-Type Communications (mMTC) and Ultra-Reliable Low Latency Communications (URLLC) [ITU17], which attracted a large number of works in recent years and opens many applications beyond the mere human usage, like those of Internet of Things (IoT) [ITU12]. However, the 5G network still aims to provide communication links between these machines/devices and some centralised coordinating and data-gathering entity, often located remotely in the cloud rather than within the network, and its human users are typically not expected to interact directly with these devices. As research in 6G has already started, the many explored directions address a large set of key components. One of the main aspects is to increase the intelligence in the network at all levels, to manage the ever-increasing heterogeneity in communicating devices and key performance indicators. In what follows, one presents a selection, necessarily incomplete, of state-of-the-art results in wireless networks design [JSN18].

First, extensive efforts have been devoted to obtaining a comprehensive understanding of **radio wave propagation** for the development of 5G wireless networks. The efforts concerned propagation modelling for 5G-enabling radio systems, including the ones exploiting millimetre-waves (mmWave) and higher frequency bands (THz), where large contiguous bandwidths are still available, and also massive Multiple-Input Multiple-Output (MIMO) and beamforming, where spectral-efficient connectivity to densely populated areas is made possible. Understanding radio wave propagation has also been crucial to new 5G applications, including highly dynamic scenarios, IoT and smart grids. Efforts on propagation modelling for these systems and applications encompassed vehicular and mmWave cellular access [SDF16], IoT and Smart Grids [SGG18], and energy efficient cellular radio planning. These propagation modelling studies have been carried out using various measurement setups [Car16] or combining measurements and theory for link- and system-level simulations [WWA17], 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 [SDF16]. 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 predict radio environments and hence provide accurate-enough Channel State Information (CSI) at link ends 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 estimating CSI [FZV19], along with a location-aware CSI fingerprinting [TMR14]. Their real-time use in localisation, beamforming and resource allocation algorithms is still in its infancy.

The stringent requirements in terms of increased data rates, reduced latency or massive number of devices served that are associated to 5G services call for a more efficient **design of the radio interface**. As data rate is no longer the single performance indicator for a radio link, many fundamental works have been done, e.g., to adapt Shannon's theory to a non-asymptotic regime [YCDP18] or to introduce new tools for network performance evaluation, such as stochastic geometry [BaRC20]. To support this heterogeneity requirement, the 5G New Radio (NR) standard [3GP17] specifies a much more flexible numerology for Orthogonal Frequency Division Multiple Access (OFDMA). However, OFDMA requires a tight synchronisation, which is difficult to achieve for mMTC. Other waveforms have less stringent synchronisation requirements, but no consensus on their adoption has been reached yet [JHA17]. Concerning the provision of URLLC, a range of shorter but capacity-approaching codes have been designed [BCL19], but substantial work is still needed, e.g., to assess their performance with realistic channels in ultra-dense networks. To fulfil these goals, a new approach to signal processing and physical layer communication techniques for radio interface design is required, since increasing the access network density forces the physical layer to operate over the network rather than simply on individual links [SyB18]. While techniques such as physical layer network coding have enabled the physical layer to operate over networks, these developments remain primarily theoretical and are not yet ready for inclusion in standards. Moreover, the aforementioned over-the-network operation indicates that future radio interfaces should become more intelligent and be capable of operating in a more cognitive manner. Artificial intelligence (AI) and Machine Learning (ML) are poised to play a pivotal role towards the provision of such intelligence operation [OsH17]. Besides, communication theory has established optimal algorithms for many signal processing problems, including localisation, which can be built upon. For instance, such known algorithms and approaches can inform the structure of data-driven approaches, such as Deep Learning (DL) networks, to warrant performance or speed up convergence.

Network resources management and communication techniques also underwent significant changes with the arrival of 5G. Sharing and efficient use of resources have been extensively investigated, more than in all previous generations. Technologies like Software Defined Networking (SDN) and Network Function Virtualisation (NFV) have improved interoperability and enabled infrastructure sharing among operators. Similarly, network slicing helped the operators to slice their networks and satisfy different end-to-end requirements. New caching techniques, device-to-device communication and edge computing enhance low-delay multimedia delivery. New resource management and orchestration challenges appear with these technologies [JZY16]. Future intelligent networks are intended as capable to learn from the past and to auto-configure themselves in real-time, in order to optimise not only the use of radio resources (e.g., spectrum) but also computing and caching ones. Given the sheer number of parameters to be configured, together with the need for quick adaptability, ML techniques have been applied in network management and planning since the introduction of cognitive radio networks, mainly for spectrum resource allocation [MBYL13, ANMR17]. More recently, unsupervised and reinforcement learning techniques have been applied in dense small cell deployment and self-organising networks to improve scheduling, user association, coverage and network capacity [LZZ17]. However, how to accomplish intelligent network management and precise resource orchestration still needs to be solved. Indeed, current traffic control still takes only current network situations into account, being reactive and prone to repeated congestions if similar traffic conditions persist in the future, due to the lack of prediction capabilities [YZZF18, HS17]. In addition, even though ML empowers intelligent resource management, it calls for new network architectures and system models. As an example, a new layer, namely “cognition layer”, can be foreseen in the protocols stack, offering comprehensive awareness to the cognitive engine [MLYZ20].

1.1.2. DESCRIPTION OF THE CHALLENGE (MAIN AIM)

Societal challenge. Radio communications have significantly changed the way we make content available or the way we interact with others. These words are written while communications via cell phones and Wi-Fi are a lifeline for hundreds of millions of people, who must remain confined because of the current pandemic. In the future, **wireless communications will have an even broader purview, enabling new interactions** that will make industries more efficient, lives more convenient, transportation safer and contribute to better well-being.

Where the Action goes. To contribute to the societal transformation, the development of the next cellular networks cycle, 6G, will further address the spatial dimension and the “way back to humans”. Beyond being a means of transferring information, the network must become aware of the world around it. The amount of information available suggests the possibility of an extremely fine description of the world and therefore the ability for the network to bring the necessary information where it is useful. This requires not only to analyse data but also to interpret, adapt and anticipate them, in order to offer the desired experience to everyone. This advocates for **making the radio network itself intelligent**, meaning **aware, adaptive and parsimonious**, which is INTERACT’s vision. In a long-term vision, beyond INTERACT, wireless networks will not only become intelligent, but they will constitute the nervous system to foster intelligence in other systems, such as transportation, factories and cities.

Why the Action need to go in that direction. Radio network intelligence is required to enhance the human experience of both human-to-human and human-to-machine communications and make it seamless, with the perception of no intermediary. This will enable application servers to be located much closer to users and a much better local coordination of IoT, thus greatly reducing latency. In INTERACT’s vision, theory and techniques from the different fields of computer science, network theory, signal processing, and antennas and propagation must be more interwoven to radically improve emerging applications’ performance.

And what the Action will do. Future wireless networks should become intelligent by taking advantage of cutting-edge technologies to cope with the increasing demand for connectivity and traffic density, and to bring the user experience to a new level. An intelligent network needs to understand the amount and quality of information it needs to transmit to ensure the appropriate end-user services, but also to evaluate the resource accessible in all its dimensions (time, frequency and space). It can then adapt to an efficient and real-time network self-organisation, resource allocation, CSI estimation, channel coding and beamforming. Making future wireless systems intelligent also means **fostering a new kind of environment awareness**, by developing accurate localisation and sensing techniques that can be used within the system to enhance performance, energy efficiency and user experience. The use of a large number of connected devices with sensing capabilities in future wireless networks represents an unprecedented opportunity and opens the way to a vast field of environment (or location) aware communications. When accurate localisation and environment mapping are available, real-time deterministic propagation models can be embedded in the system to help estimate - or even predict - CSI, therefore reducing the signalling overhead, improving performance and fostering novel applications, for instance in the field of reliable vehicular communications for traffic management and safety enhancement. The intelligent network will also **embed signal processing functions optimally located to minimise latency**. It can also **shape the medium**, for instance using Reconfigurable Intelligent Surfaces (RIS), and techniques like ML, and especially DL, can help to make appropriate choices. In addition to making every individual component of the network intelligent, network management should incorporate intelligence for **managing and orchestrating intra-network interactions**, e.g., placement of virtualised network functionalities, SDN resource discovery and orchestration, and edge/cloud computation and networking. In summary, with the long-term vision of providing humans with a seamless interactive experience, INTERACT main scientific objectives (O) are:

- O1: to perform fundamental research in the fields of antennas and propagation, signal processing and localisation, and network architectures and protocols, to design intelligent-enabling radio communications;
- O2: to make the wireless network intelligent, meaning aware, adaptive, and parsimonious;
- O3: to contribute to the creation of intelligent environments, with emphasis on health & well-being, transportation, industry, buildings and cities.

In the next section, details about the research directions are provided, with reference to the above identified objectives.

1.2 Progress beyond the state-of-the-art

1.2.1 APPROACH TO THE CHALLENGE AND PROGRESS BEYOND THE STATE-OF-THE-ART

The overall challenge of making the network intelligent requires closely interconnected working across many disciplines and application areas. To provide the necessary points of focus, INTERACT has identified, on the one hand, three required technical disciplines, and on the other hand, four application areas, or “Verticals”. Radio frequency channels and hardware are of course a fundamental technical issue for wireless networks, and embedding intelligence into the network requires detailed knowledge of **radio propagation** to be embodied within it: this is the first discipline, including also research into new frequency bands and new application environments. Similarly, the intelligent network must process the radio signals by which information is conveyed: **signal processing** is the second discipline, making use of the understanding of hardware, channels and radio propagation. **Network planning and resource management** provide the focus for the third discipline. To cover the breadth of the applications of the intelligent network, four generic areas with particular challenges have been chosen as the focus for the Verticals: **Health & Well-Being, Transportation, Industrial Automation, and Smart Buildings & Cities**. Finally, the growing importance of data advocates for making all possible data openly available.

One issue transversal to all working groups concerns the achievable trade-offs in model-driven vs. data-driven communication engineering (O2, O3). Contrary to other more empirical disciplines (computer vision and natural language processing), communication systems are often well represented by accurate mathematical models that have been acquired over decades of intense research. However, it is generally agreed that the increasing complexity of foreseen 6G systems will rapidly exceed the modelling possibilities of standard mathematical tools. In situations where system models become either too complex (there is a model deficit) or simply too difficult to optimise (there is an algorithm deficit), data-driven approaches arise as very attractive alternatives. By and large, learning-based approaches are called to play a pivotal role in the design of 6G systems. The INTERACT vision, however, is that statistical learning tools should not be used to systematically replace conventional model-based designs, but rather as an enhancement that can provide enormous potential advantages in difficult situations where model-based approaches alone are simply unable to work. INTERACT aims therefore to **explore data-driven enhancements to conventional wireless system models and designs**. The relative importance of model-based vs. learning-based approaches will effectively depend on a case-by-case basis, and in some complex situations the best option will be to disregard the model altogether. Such trade-offs will be systematically analysed and assessed. Moreover, the two approaches might be combined together, as models can be used to complement or interpret data, if not to replace them, in order to speed-up the learning phase and improve performance.

1.2.1.1 Methodological Progress in Radio Channels

Radio channel modelling (O1, O2). Radio resources carry information and, as a consequence, are the elementary key knowledge to any further development. Much is still to be learnt with the new frequency bands being explored (from upper GHz to THz), over unprecedented continuous bandwidths. In addition, the spatial accuracy required for communication links and applications in highly dynamic environments pushes the limits of current characterisation techniques. INTERACT will work to **increase the theoretical and experimental knowledge of the radio channel**. One significant challenge is to shape the radio channel through RIS [HHAZ20]. Until recent times, the radio channel has been notoriously 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 is 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.

Application of machine learning to propagation modelling and spectrum sharing (O1). Currently, radio propagation models are used to assess compatibility and coexistence scenarios for different services. Improved prediction accuracy of interference between radio links and services is essential for more efficient spectrum sharing among services. To this end, the present Action will **combine measurements with the semi-supervised and possibly automated ML** for improved propagation modelling. For instance, the data will 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 essential inputs to ML. Propagation-sensitive features can be extracted through classical propagation modelling and spectrum sharing techniques, and can be fed to a set of ML algorithms. The possibility of choosing the base functions to be used within ML using propagation-aware techniques might also be an interesting solution to be investigated.

Improved prediction of radio channels to support environment-aware communications (O2). When accurate physical models of radio environments are available, e.g., through detailed maps, it is possible to use them at the mobile cloud edge for the prediction of radio channels. Physical models of radio propagation have been part of the ordinary work of cellular deployment, but their accuracy is adequate only for average path loss prediction and is insufficient for providing statistics of CSI that radio communication devices may actually exploit for data transfer and sensing. 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 this environmental awareness. The methodological breakthrough here is to be able 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 slightly ahead of time (also called channel anticipation) using extrapolation and dynamic ray-based techniques, in the best case. Radio channel anticipation is particularly attractive for intelligent transportation.

1.2.1.2 Methodological Progress in Signal Processing and Localisation

Novel physical layer technologies (O1, O2). The interest in ultrashort and medium length block channel codes has recently increased due to the huge demand for the URLLC mode, whose stringent latency requirements enforce short code lengths. However, most traditional designs and code families have focused on the long block length regime based on models, assumptions and tools (e.g., EXIT charts) suitable for that regime. Data-driven encoder and decoder designs may soon come to complement conventional engineered solutions by helping discover competitive local optima in the space of short codes, proposing alternative DL based reformulations of decoding algorithms (e.g., deep unfolding, recursive neural nets as decoders and genetic algorithms for code design) or end-to-end encoding/decoding approaches, such as auto-encoder [OsH17]. Besides, particular attention must be paid to the scalability aspects (in the code length). Channel estimation is also a key building block of the physical layer. In scenarios where information is transmitted in very short block lengths, the high channel variability requires updating of the CSI every URLLC transmission. One possible solution to improve spectral efficiency is to reduce (or even suppress) the presence of pilots in the transmission and rely on blind (or semi-blind) channel estimation at the receiver; however, those solutions are often plagued with local minima. The idea is to **combine the information coming from data using statistical learning with the expert knowledge of the transmitted signal structure**. On the one hand, data-driven classifiers can exploit the signal structure in order to detect the presence of outliers as the outcome of blind/semi-blind channel estimates. On the other hand, one can exploit generative models to create convenient initialisation instances for these algorithms according to the past experience in the same type of scenario. Complementarily, beamforming and (massive) MIMO processing are very much needed to support services demanding high-bandwidth and/or frequent access to remote servers, such as video-streaming or infotainment services, in both the sub 6 GHz and the mmWave bands, the latter being very suitable for the implementation of beamforming technologies. Instrumental to them is the design of effective beam management technologies, as evidenced by 3GPP. In this context, ML-based techniques (and, in particular, reinforcement learning) are called to play a pivotal role by learning from the environment to avoid problems associated with exhaustive search approaches (computational complexity) or current greedy/hierarchical ones.

Positioning and localisation (O1, O2). Positioning is recognised as a key application for 6G, which is due to its potential for massive commercial use cases, e.g., industry automation, remote operation and emergency calls. In Line-of-Sight (LOS) conditions, there are many positioning methods based on time-of-arrival/angle-of-arrival information that can be used to position terminals with high accuracy; in non-LOS ones, the estimated position obtained by classical methods becomes unreliable. Instead, **ML-based methods can help build non-linear functions mapping radio measurements onto specific locations more effectively**. For instance, [Mal18] resorted to Bayesian regularised artificial neural networks or random forests, in combination with Kalman filtering (i.e., again a model/data-driven approach) to improve tracking properties. Complementarily, **data-driven approaches can also help improve the accuracy of fingerprinting-based** positioning for indoor environments. Here, the best match between the observed Received Signal Strength (RSS) values and existing ones from predefined reference points in the radio map is established as the predicted position. A number of ML/DL-based classifiers (e.g., Nearest Neighbours, Adaboost or Bagging) can be used.

1.2.1.3 Methodological Progress in Network Architectures and Protocols

The increasing complexity of wireless networks, paired with the wide variety of applications with significantly different performance, causes traditional network planning and management to be no longer suitable. **Effective real-time network resource orchestration in the presence of multi-dimensional resources, many service types and unknown traffic models,** is an important challenge addressed by INTERACT.

Machine Learning for network management and orchestration (O1, O2). Future networks will be required to take decisions on network configuration parameters in real-time, based on a huge amount of network and traffic information (e.g., CSI, delay spread, Doppler speed, latency, throughput, signal power and users location), made available with a much larger capillarity, in terms of both space and time, comparing to nowadays networks. Highly precise localisation algorithms, embedded into the network, will provide geo-referenced data with a space resolution in the order of tens of centimetres, while better resolution time will be guaranteed by higher data rates and lower latencies. Various ML algorithms (e.g., neural networks, regressions and clustering) can exploit this plethora of data to proactively predict traffic demand and network failures, and to enable autonomous real time network reconfiguration. These intelligent resource management algorithms will be used to address cell association, radio access technology selection, frequency allocation, handover and power control, and they **will have the ultimate goal of improving the users' experience exploiting situation awareness**. In addition, the use of Reconfigurable Intelligent Interfaces, that may be opportunistically deployed, could become an essential degree of freedom for radio resource management since they allow to configure the radio channel itself in real-time based on traffic needs. **Joint optimisation of both network management and environment using RIS** will be addressed by INTERACT. As far as edge computing and caching are concerned, distributed training at the network edges including small-cell base stations and user equipment will be studied. In contrast to the use of conventional ML algorithms running at the network controller in a centralised way, the notion of **collective Machine Learning, where multiple distributed mobile radio learning agents will coexist and contribute to the global benefits**, will be investigated.

Dynamic networks (O2). Another important element of future networks will be the dynamic nature of the infrastructure, due to the presence of on-demand base stations, possibly mounted over drones. ML algorithms will be used to identify potential coverage holes and capacity constrained areas, and react by moving base stations to where and when needed. **Orchestration of networks characterised by high dynamicity**, due to user and base stations mobility, and changing of traffic load distribution, still represents a challenge to be addressed, together with the **joint optimisation of flights patterns and resource allocation**.

Novel networking paradigms in the long-term view of providing humans with a full interactive experience (O1, O2). To make human-to-machine communication seamless, a digital real-time experience that mimics the full resolution of human perception is needed. **Extended Reality (XR), five-sense communication, also denoted as Internet of Senses, and haptic communication will be essential for the realisation of the full experience**. XR refers to all combined real and virtual environments and human-machine interactions generated by computer technology and wearables. A true XR engages the five senses of hearing, sight, taste, smell and touch, and uses the neurological process through sensory integration. It detects the sensation from the human body and the environment, and uses the body effectively within the environment. Finally, haptic communication is a branch of nonverbal communication that uses the sense of touch. The research in the above fields is at a very early stage and will be investigated into INTERACT. In addition, the perception of no intermediary imposes very stringent latency requirements that call for distributed approaches to communication/processing of data generated by human-worn devices and sensors/actuators carried by machines, such as the definition of novel architecture for proper balance between edge and cloud networking.

1.2.1.4 Application/Vertical-Specific Progress

The chosen verticals are not exhaustive and others can be added if needed in the course of the Action. Those below combine some of the most significant bottlenecks facing wireless networks. These verticals will also be the opportunity to facilitate technological transfer between academic and industrial partners.

Health and Well-Being (O3). Mission-critical body-centric wireless applications, such as implant radios, are not yet in wide use owing to fears of losing the radio link during treatment and services. Absorption of radio signals by living tissues, due to radio devices operating in the proximity of or inside a body is another concern that hinders widespread deployment of wireless devices in such scenarios. This lack of sufficient confidence will be addressed by INTERACT. The outcomes of this research will foster the study of ad hoc technical solutions to tackle connectivity, hardware and network management problems in novel human-machine interaction applications in the fields of health, sports, and augmented reality, among others. INTERACT also aims at investigating nano- and molecular-communication networks, due to their fundamental role in the five senses transmissions, for the realisation of a fuller experience.

Transportation (O3). Future transportation scenarios will be characterised by high mobility and involve cars, trains and unmanned aerial vehicles flying at low altitudes. The dynamic nature of radio links and networks in the transportation scenarios is the key feature to be addressed. Specific radio link measurements with high mobility will be a key element here, particularly for trains, cars and drones. Measurements at frequencies higher than 6 GHz are another gap that will be fulfilled. In addition, INTERACT will study efficient allocation of radio and processing resource to different network entities under inherent dynamics of data and control traffic.

Industrial Automation (O3). Industry 4.0 aims at monitoring and controlling industrial machines via wireless technologies; however, some applications have particularly strict requirements. For example, high-precision manufacturing requires very high reliability – below 10-5 packet loss – and extremely low latency – in the order of 0.1 to 1 ms of round-trip time. Furthermore, industrial control networks require real-time data transfer and strong determinism, which translates into a very low delay jitter, in the order of 1 µs. This calls for the design of novel transmission techniques, for example moving to the use of mmWave and THz bands, and the need of CSI in harsh environments, hence for an extremely large number of radio link observations. In addition, since moving to such higher frequencies bands increases channel multipath, solutions based on RIS to reduce this effect will be also investigated.

Smart Buildings and Cities (O3). INTERACT will also address smart cities and buildings. They require seamless interactions. The radio communication networks play a central role and the need for data transfer capability always soars so that the legacy radio network capabilities may soon be insufficient. To satisfy all needs, new radio frequency bands (upper mmWave and THz for indoor applications) and Visible Light Communications (e.g., for smart cities) will need to co-exist. At these frequencies, the interaction of waves with material and propagation media may differ significantly from the lower frequencies. INTERACT will provide evidence of such sensitivity, if any, both from theoretical and experimental viewpoints. Environment-aware communication is necessary to satisfy the different needs that the wide range of applications can request, but also to adapt between ultra-dense areas and isolated nodes, low rate low energy or very high rate communications. In addition, coexistence and interoperability among different technologies, inevitably deployed in the field will also be considered. ML will act as key enabler to allow intelligent interactions among the different available networks (cellular and wireless) and select the best solution to be used in a given situation (environment awareness).

1.2.1.5 INTERACT Datasets

The evolution of networks leads to an ever increasing complexity. Whether to validate models or to implement ML algorithms, data is at the heart of the problem. The situations are so numerous and varied that it is unthinkable that a single institution, academic or industry, will be able to collect the amount of data required to develop future networks. INTERACT aims at collecting sufficient evidence of real-world data and **making them available to the research community by building the INTERACT datasets**. It will define the technical and legal tools enabling as many participants as possible to exchange data and create a significant database. While the data will initially be used by the members of the Action (the large size of the original network of proposers ensures the availability of a large and diversified amount of data, providing very representative datasets for the training of algorithms, as well as for validation and testing), they will also be made publicly accessible. Furthermore, existing datasets from public repositories (ETI-MLC, IEEE DataPort, CRAWDAD, European Union (EU) Open Data Portal, etc.) will also be used in an initial step.

Channel. It is crucial but challenging to characterise and model radio channel properties, owing to the inherent randomness and enormous variability. Yet the extent of evidence available to the scientific community is surprisingly low, because it is intellectually protected by device manufacturers, service operators, other companies or a handful of research institutions and universities with measurement capabilities. This lack of real-world data does not give the conditions to the scientific community to make true breakthroughs on intelligent wireless links, networks and user experience. One significant objective of INTERACT is that participating institutions will share their measurement data by building a radio channel database. The database will also serve as a proof of concept for network deployment. This approach is in accordance with the forthcoming EU Open Data and Public Sector Information Directive.

Signal Processing. Whereas previous research is mainly based on theoretical works or simulations, the rise of AI makes it necessary to have real-world signals, e.g., to test a full decoding strategy. Similarly, while localisation needs the channel impulse response or transfer function to be tested and optimised, it is significantly different to work with a high-cost channel sounder or a low-cost IoT device. The objective will be to gather large collections of signals from different physical layers and environments. Open experimental laboratories can also allow to go from simulation to real environments on dedicated software defined radios. Access to such facilities with open software will be encouraged.

Networks. The scientific approach from the networking viewpoint aims at collecting a large dataset of information useful to develop real-time network self-organisation and resource allocation. With reference to the main applications considered in INTERACT, these data can be from networks (e.g., all signalling generated during handover and synchronisation to base stations) and from users (e.g., their behaviour in terms of service requests for voice or video). Data can be taken from sensors deployed in different environments, cellular operator datasets, up to drones and surveillance images, or be generated through network simulators developed by INTERACT partners and made available to the research community.

1.2.2 OBJECTIVES

1.2.2.1 Research Coordination Objectives

The Action will coordinate its research along the scientific objectives O1 to O3 stated in Section 1.1.2.

However, research in wireless communications nowadays is highly conditioned by industrial partnership and success in competitive calls. Especially, wireless communications have become instrumental and are often integrated into projects focusing on specific applications, making it difficult to develop long-term research. Therefore, it is important to keep collaborative spaces for sharing ideas and data, and to enable contact among researchers. Open to the whole research community (from academia to industry), INTERACT has the objective of facilitating such collaborations and creating the conditions for a highly interactive network. In particular, the Working Groups (WGs) will be cooperative environments to develop theoretical disciplinary work. In addition, interdisciplinary work will be addressed in Vertical Teams (VTs), enabling a coordinated effort among experts of separate disciplines, focusing on specific applications. VTs will also foster interaction between academia and industry to better focus the research effort. The work on the sharing of knowledge will be structured into Horizontal Activities (HAs), including dissemination, training and database activities, promoting the creation of open data sharing tools and databases. The Steering Committee will hold virtual meetings after each INTERACT meeting to debrief the coordination and find new ways to encourage cross-fertilisation. Furthermore, one of the objectives of the research coordination will be to facilitate the adoption of new concepts and inter-disciplinary challenges into new communication solutions and selected verticals. For instance, INTERACT has identified AI as one of the key-enabling technologies for developing intelligent networks. Efforts will be made to create active links between AI and Wireless Communication communities. The final objectives of the research coordination will be the increase of the research results and competitiveness of the individual members and their institutions. As a result, it is expected that INTERACT will enhance the scientific productivity, in terms of publication of papers, thanks to the edition of joint papers to be submitted to international conferences and journals. This will also encourage the submission of project proposals to the European Commission (EC), involving consortia composed of both academics and industries, as well as submission and contribution to international bodies and standards. Therefore, to further support these outputs it is an objective of the Action of making available datasets on real-world scenarios, radio channel data and signal data to the research communities (O4).

1.2.2.2 Capacity-building Objectives

Based on 6 dimensions, INTERACT will address three capacity-building objectives: (i) **giving Europe the capacity to continue being a leader in telecommunication networks**, proving a significant push towards the development of disruptive intelligent networks, in close collaborations with major industries and stakeholders; (ii) **enabling interdisciplinary research, exploiting machine-learning tools**, that can provide a means for implementing many aspects of the intelligent radio network; (iii) **training researchers in all stages of R&D and creating a generation of young researchers with technical competencies; iv) facilitating technology and knowledge transfer toward industry**, sharing R&D in a non-competitive way and addressing open problems.

1. The **Scientific Dimension** will bring together the efforts of many research teams in both academia and industry working in the areas addressed by INTERACT. Given the background of these teams, it will enable the combination of several stages of Research and Development (R&D), i.e., from initial theoretical modelling to final mature models, encompassing measurements and simulations as well as common scenarios, with an intense sharing of knowledge, information and results, and a focus on AI tools. To this end, some of the 8 (at least) training schools and/or special sessions in meetings organised by INTERACT will bring together major experts of AI to train the Action's members.

2. The **Technological Dimension** will be a joint place for industry companies from various sectors in wireless communications to share R&D in a non-competitive way, addressing the open problems of INTERACT jointly with universities. INTERACT will foster the technology transfer capabilities of member institutions, allowing them to focus the research towards specific applications and addressing the needs of industries. These capabilities will be developed in the framework of the VTs, aiming at involving industries leader in these sectors and favouring applications to funding programmes supporting exploitation. Besides, periodic workshops (at least two per year, possibly co-located with meetings), hosting invited speakers and keynotes given by industrials, will be organised.

3. The **Multi-Area Dimension** will address key application areas (human body environments, vehicular communication, industrial automation and smart environments) that are fundamental for the future development of wireless communications, since this development has to go beyond human communications, as 6G has already started to address. Interaction with researchers from these application areas will be a pursuit, to enable a proper knowledge and information transfer, implemented through the VTs.

4. The **International Dimension** will lead to a broad international coverage of researchers, despite COST being a European research framework. INTERACT intends to invite and attract researchers from other world regions. This global international reach of the work developed within the Action, will enable to increase the visibility of INTERACT in particular, and of the COST framework in general. Furthermore, it is our vision that intelligent networks can only be deployed at a global level.

5. The **Human Dimension** will address the transversal skills of researchers. For this purpose, INTERACT will periodically organise scientific training schools, including soft-skill-oriented training sessions. Action meetings (12 in total) will also be an opportunity for young researchers to improve their skills by getting in touch with senior researchers in a friendly environment, to discuss their research findings and explore new, sometimes difficult to identify, pathways.

6. The **Social Dimension** will create the conditions to address the various social dimensions that are currently part of the R&D landscape. The openness of COST Actions will be used to attract further researchers from Inclusiveness Target Countries during the course of the Action, thus contributing to the development of R&D in these countries. Other social dimensions will also be sought, with precise actions, such as gender balance (which, in the area of wireless communications, leans towards male researchers) and the further development and training of Ph.D. students and Early Career Investigators.

This will be addressed through Short Term Scientific Missions (STSM – about 50 in total), allowing researchers to visit other institutions for medium or long periods, and via grants to foster the participation of researchers involved in the different WGs in INTERACT events.

2. NETWORKING EXCELLENCE

2.1. Added value of networking in S&T Excellence

2.1.1. ADDED VALUE IN RELATION TO EXISTING EFFORTS AT EUROPEAN AND/OR INTERNATIONAL LEVEL

European R&D programmes co-funded by the European Commission in the upcoming Horizon Europe framework (similarly to the current ending one), e.g., FET Projects and Marie Skłodowska-Curie Actions in “Excellent Science”, or ICT Projects within the Leadership in Enabling and Industrial Technologies in “Industrial Leadership”, have all basically one thing in common, i.e., they are based on closed project consortia established at the proposal stage. The COST framework is different, since an Action is an **open research networking tool** open to participation during its course to all of those that qualify, without any legal burdens of consortium extension or prior partners’ approval. This means that an Action is a very powerful tool to create an active network of researchers to collaborate on a given topic, being possible to extend collaborations with researchers from all around the world, as mentioned in the International Dimension. The area of wireless communications features a few **key industrial players**

from all world regions, e.g.: in infrastructure vendors there are basically two from Europe and two from China; in devices manufacturers, the number is larger, but key ones are from the USA, South Korea, and China; and in Internet services (no longer distinguishing between fixed and mobile), key players are from the USA and China. This situation means that an Action in wireless communications needs to establish industrial links beyond Europe, reaching the USA and Asia/Pacific countries. Again, the uniqueness of the openness of COST enables the Action to establish research collaborations that are not possible via other frameworks (even industrial ones, like 3GPP or ETSI), leading to the exchange of information at the level of reference scenarios, theoretical modelling, measurement results, simulation approaches and ultimately final models. This exchange opens the way to **agreements in global standardisation bodies**, given the wider assessment of models.

2.2. ADDED VALUE OF NETWORKING IN IMPACT

2.2.1. SECURING THE CRITICAL MASS AND EXPERTISE

Given the openness of COST Actions, there should be a strategy to establish from start and maintain during the course of the Action the required critical mass and expertise to cover the tasks addressed by the Action, and to reach the end of the Action with all objectives being fully and properly achieved. The goals of the academic and industry communities are different by nature, even if both are performing R&D in a joint initiative: the former, composed essentially of professors, researchers and Ph.D. students, aims at disseminating their results to the widest audience (e.g., publishing papers in high-quality journals and conferences), besides training students and getting projects in calls of competitive nature for funding; the latter, composed essentially of research engineers, follows strategies defined by their own companies, aims at exploring ideas within their own areas and establishing models that can be used later on for product development, participation in projects being oriented in that direction. Within this context, establishing the critical mass of researchers with the required expertise to cover the tasks of the Action has been already achieved by the original network of proposers. Therefore, the Action will involve a large team of people, from all communities, which was able to set goals of global interest for this Action at the proposal stage. The structure and themes of INTERACT have been designed to serve the interest of the involved stakeholders, therefore, creating the interest to participate in and contribute to the tasks of the Action. As examples, one can mention the training activities for Ph.D. students, the joint development of models and databases, and the networking leading to the proposals of projects in competitive calls. Maintaining the critical mass of researchers with the required expertise to reach the end of the Action with all objectives being fully and properly achieved requires the involvement of all stakeholders in the definition of the specific activities, so that they fit their own interest, and **reaching other groups of researchers** that were not included in the network of proposers and may be interested in participating and contributing at a later stage. To sum up, the critical mass is likely to be achieved and will without a doubt be maintained during the course of the Action, enabling the ambitious objectives of the Action.

2.2.2. INVOLVEMENT OF STAKEHOLDERS

In the area of wireless communications, there are a number of institutional stakeholders, covering both the academic and industry communities, besides others that are not directly linked to R&D: **universities (UNs), institutional research centres (RCs), network infrastructure and solutions vendors (IVs), human and machine device manufacturers (DMs), operators (OPs), IT providers (ITs), Vertical Industries (VIs), SMEs (SMs), standardisation bodies (STs), industry associations (IAs), regulators (REs) and policy makers (PMs)**. INTERACT will involve all these stakeholders in the Action activities, so that they participate and contribute to them as listed below (in between parentheses, one shows the involved stakeholders):

- the network of proposers (NoP) already included many stakeholders, including key institutions and organisations (UNs, RCs, IVs, DMs, OPs, ITs, SMs),
- given the NoP's links to industry, many companies will be invited to join INTERACT (IVs, DMs, OPs, ITs, VIs, SMs),
- given the NoP's large European footprint, a list of research groups in the area will be invited to participate and contribute (UNs, RCs, IVs, DMs, OPs, ITs, VIs, SMs),
- given the NoP's large number of academic researchers, a list of contacts in universities awarding Ph.D. degrees will be established, to disseminate training activities to their students (UNs, RCs),
- given the NoP's contacts with non-European R&D institutions (e.g., Australia, Canada, China, Colombia, Japan, New Zealand, South Africa, South Korea and USA), their researchers will be invited to participate and contribute to the Action (UNs, RCs, IVs, DMs, OPs, ITs, VIs),
- given the NoP's participation in several EC frameworks projects, with a track record of links and joint collaborations within these projects, invitations will be sent to encourage participation in training schools/workshops, possibly jointly organised (UNs, RCs, IVs, DMs, OPs, ITs, VIs, SMs),
- given the NoP's links to European and International standardisation, regulator and industry association bodies, even participating in some of them (e.g., Networld2020 ETP, 5G-PPP, 3GPP, ETSI, and ITU-R), the Action will be presented to them and invitations to participate and contribute to some activities (e.g., workshops) will be issued (STs, IAs, REs, PMs),
- given the NoP's involvement in the Steering Committee of key conferences, at both European and world levels, some of them with a direct involvement of COST, contacts will be established for the organisation of events for dissemination of the Action (UNs, RCs, IVs, DMs, OPs, ITs, VIs, SMs),
- given the NoP's involvement in key bodies of international R&D organisations (e.g., IEEE, EURAAP, EURASIP and URSI), contacts will be maintained for the organisation of events for dissemination of Action outcomes (UNs, RCs, IVs, DMs, OPs, ITs, VIs, SMs).

2.2.3. MUTUAL BENEFITS OF THE INVOLVEMENT OF SECONDARY PROPOSERS FROM NEAR NEIGHBOUR OR INTERNATIONAL PARTNER COUNTRIES OR INTERNATIONAL ORGANISATIONS

Given the above description of the area of wireless communications and the positioning of INTERACT, it is clear that the participation of institutions from International Partner Countries (IPC) and Near Neighbour Countries (NNC), as well as International Organisations, has a number of mutual benefits, among which one can highlight: the exchange of information at the level of scenarios, models, measurements and assessments; the extension of model assessment to a wide range of scenarios and environments; the participation of key industrial companies, with the corresponding access to information by INTERACT participants, and dissemination by these companies; the extension of the expertise areas beyond the core one within European institutions, enlarging critical mass and enabling to tackle more global views in a joint and collaborative approach.

3. IMPACT

3.1. IMPACT TO SCIENCE, SOCIETY AND COMPETITIVENESS, AND POTENTIAL FOR INNOVATION/BREAK-THROUGHS

3.1.1. SCIENTIFIC, TECHNOLOGICAL, AND/OR SOCIOECONOMIC IMPACTS (INCLUDING POTENTIAL INNOVATIONS AND/OR BREAKTHROUGHS)

From the scientific viewpoint, INTERACT will work on the research and design of intelligent-enabling radio communications, impacting on Mobile Network Operators (MNO) and communication infrastructure manufacturers. Pervasive wireless communication is becoming a fundamental part of modern society lives through the emergence of "smart everything" – which of course requires ubiquitous communications. The Verticals identified in Section 1.2 continue to revolutionise our daily lives. Our vision of the intelligent network has the potential to enhance this impact and provide a full integration between the human experience and the intelligent environment discussed above. The following paragraphs explore these impacts on the development of smart environments, on human activities and on industry as well as on society at large, showing the mapping on the VTs defined in Section 4.

Smart cities & buildings and transportation. The combination of IoT and intelligent wireless networks is a potentially disruptive technology that can have a great social and economic impact: experts estimate that by 2025 hundreds of smart cities worldwide will generate two thirds of the world's Gross Domestic Products [CDS16]. However, the complexity of such a large-scale deployment of devices and information processing has so far limited the deployment. Making the **network itself intelligent** is needed to handle and exploit the huge amounts of data [DMP18]. For example, in smart buildings, Building Information Modelling (BIM) will facilitate the application of ICT technologies to improve energy efficiency and the interaction experience between smart buildings and humans. Accurate positioning, sensing and cooperative radar techniques will control traffic, including traditional as well as unmanned terrestrial and aerial vehicles, thus supporting autonomous driving technology. Smart communications and sensor networks are also a key technology to mitigate the climate emergency, by helping to realise low-emission transportation, buildings and cities [ZWT18]. INTERACT technologies will also minimise the carbon emissions of wireless technologies themselves. VT2 and VT4 address these issues.

Human activities. Intelligent networks will hugely impact daily life and human activities in a wide range of areas, for example by facilitating smart-connected healthcare, holoportation-based new socialising and meetings, **Extended Reality-based network education** and gaming, and privacy-aware secure social networks. These applications – studied in VT1 – heavily depend on reliable and high data rate networks with intelligence on the edge to reach their potential. Additionally, intelligent networks aim to provide **services to all communities**, including those in rural and hard-to-reach areas by reducing capital and operational expenditures on the deployment of the network.

Industrial activities. Many of the industrial impacts of the INTERACT vision may be realised through what is commonly known as "Industry 4.0" [KWH13], that is the so-called **fourth industrial revolution**. This revolution will aim at increasing productivity and safety, while ensuring the quality of products and contributing to reducing material and energy wastage, thus addressing several of the key sustainable development goals identified by the United Nations. This vision encompasses Industrial IoT (IIoT), cyber-physical system, autonomous decentralised control, ML and model-based systems (the Digital Twin). Embedding intelligence in the network fits perfectly with these concepts, which are addressed in VT3. Some examples of applications include automated warehousing, monitoring and control of chemical and other plants, and distributed automation of assembly lines.

Society at large. Several other societal challenges will be addressed by INTERACT. Indeed, intelligent networks play a pivotal role in many cases, for instance to predict extreme weather events and help the rescue teams in case of emergency, but also in the **mobility transition** (as illustrated by autonomous cars), in **health** (to support new care technologies and the autonomy of an aging population). INTERACT will address these issues, as they should be addressed in parallel radio communication problems and solutions. In particular, INTERACT aims at organising **tutorials with experts on these topics** (e.g., experts on privacy and on autonomous car energy).

3.2. MEASURES TO MAXIMISE IMPACT

3.2.1. KNOWLEDGE CREATION, TRANSFER OF KNOWLEDGE AND CAREER DEVELOPMENT

The various measures aiming at maximising the impacts as well as pursuing the career development of researchers will rely on the various dimensions outlined in Section 1.2.2.2, implemented via Horizontal Activities, Has, described in Section 4.

Knowledge creation. The knowledge creation, through the size of the Action, will arise from the number of partners and their collaborative work. Facilitating measures include the number of meetings (three per year), the various training schools/tutorials (in particular, those enabling researchers to adopt AI as a tool), as well as the extensive share of knowledge, information and results (through the INTERACT database under the supervision of HA1 (Database)).

Transfer of knowledge. This will be implemented through the Scientific, Technological and Multi-Area Dimensions. Examples include **periodic workshops** (hosting invited speakers and keynotes given by industrials and standard committee members), **deliverables**, as well as a **final book**, summarising the work of the Action, under the coordination of HA2 (Dissemination). It will also be one objective of the Verticals to facilitate exchanges between academics and industrials.

Career development. The sheer number of scientific and transversal training sessions offered by INTERACT within its Human Dimension will provide Early Career Investigators (ECIs) with scientific training. INTERACT will also actively pursue the involvement of ECIs in the management of the Action, e.g., by proactively inviting them to chair WGs (this also depends on the nominated Management Committee members, whose choice does not depend upon the Action; however, ECIs not belonging to the Management Committee might be invited as WG co-chairs) and by having an ECI representative within the Core Group. Scientific meetings will contribute to knowledge creation, whose transfer will also be encouraged by STSM. Moreover, the involvement of ECIs at every level, and non-scientific training sessions will foster the career plan of researchers. HA3 (Training) will coordinate these activities.

3.2.2 PLAN FOR DISSEMINATION AND/OR EXPLOITATION AND DIALOGUE WITH THE GENERAL PUBLIC OR POLICY

Dissemination. In addition to the development of technology, and training early career researchers, dissemination is a key activity within INTERACT. Dissemination activities will include but are not limited to the following: organisation of **Training Schools** by INTERACT lecturers, and jointly with other EU projects and COST Actions, which will be open to all; organisation of **topical workshops, special sessions and tutorials** in top-tier conferences including EUCNC, GLOBECOM, ICC, WCNC, PIMRC and EuCAP; presentation of INTERACT in **EC coordination (or equivalent) meetings**; establishment of **strategic liaisons and joint activities** (e.g., joint meetings and workshops) with other COST Actions, H2020 and Horizon Europe R&D projects in this area; creation/maintenance of the **INTERACT website**, with links to activities, deliverables, news, etc.; issue of an **Action Leaflet**, by the beginning of activity, explaining the key aspects of INTERACT, to be distributed to stakeholders and updated after every meeting; maintenance of an active presence in **social media**, such as Facebook, LinkedIn and Twitter; issuing a **Newsletter** (3 editions per year) including key INTERACT news, introducing/interviewing one INTERACT ECI and one senior researcher, covering key technical and scientific developments, and announcing future events and activities (this newsletter will be edited by the ECI representative in the Core Group); publishing **White/Position Papers**, e.g., on the relevant use of ML in wireless communications. These activities will be coordinated by HA2 and HA3.

Exploitation. An important factor in R&D is exploitation of INTERACT results by relevant parties and stakeholders. In the wireless communication sector, this becomes ever more important due to the short cycle between research and product release. To this end, INTERACT will take the following measures: set up consortia with some of its members to propose European projects; **collaboratively develop models and methods** to be published by the proper means (e.g., scientific journals, but not exclusively); submit contributions on models and methods to **standardisation bodies**, jointly with industry, towards the conclusion of the Action; identify possible business plans for future COST Innovator Grants; establish and maintain the INTERACT **databases**, enabling sharing of measurements, simulation scenarios and models, internally or externally; edit a **book** at the end of the Action, with its main results, to be published in an open-access scheme by a commercial company in the area of R&D. These activities will be coordinated by HA1, HA2 and HA3.

Dialogue with the general public. To establish such a dialogue, INTERACT aims at promoting application-oriented research works carried out by its participants, through several means: each Newsletter issue will feature one such result, using language tailored to the general public; a public corner on INTERACT website will also be dedicated to such results; at the Action's midterm, the featured application-oriented results will be outlined in a specific video, posted on a widely accessible channel (e.g., YouTube); one of the White Papers will be dedicated to human exposure, contrasting facts and myths. These activities will be coordinated by HA2.

4. IMPLEMENTATION

4.1. COHERENCE AND EFFECTIVENESS OF THE WORK PLAN

4.1.1. DESCRIPTION OF WORKING GROUPS, TASKS AND ACTIVITIES

4.1.1.1 Core Group and Steering Committee

The Core Group (Chair, Vice-Chair, Grant Holder Scientific Representative, STSM Coordinator, and Training School Coordinator, Science Communication Manager and ECI Representative) is the daily management body of the Action. Together with the Chairs of Working Groups (WGs), Vertical Teams (VTs) and Horizontal Activities (HAs) (see Fig. 1), they form the Steering Committee, in order to implement and coordinate the activities towards the achievement of the Action's goals, under the control of the Management Committee.

4.1.1.2 Working Groups

Matching the disciplines outlined in Section 1.2, the Action is organised in three WGs, concentrating the methodological activities, providing cooperative environments to develop the scientific work. Sub-WGs can be created on topics that gather a significant amount of contributions.

WG1 – Radio Channels. The objective of WG1 is to increase the understanding and modelling of radio channels in any type of environment. High mobility, wide frequency ranges from sub-GHz to THz, dense networks and massive antenna systems are seen as key challenges. Special attention will be paid to **collecting data and sharing them to create large training sets for models and ML approaches**. The WG will follow a sequence of tasks: Task WGT-1-1: identification of scientific and technical challenges, and definition of objectives; Task WGT-1-2: theoretical research and experimental campaigns towards improved radio channel knowledge; Task WGT-1-3: data analysis and model development; Task WGT-1-4: model integration and publication.

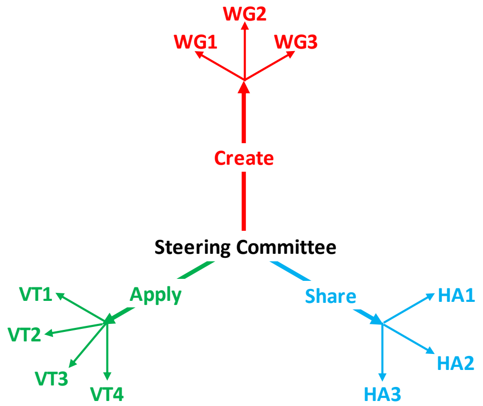

Figure 1: How INTERACT globally addresses knowledge.

WG2 – Signal Processing and Localisation. An important goal of WG2 is to explore the **trade-offs between data-driven and conventional wireless system design** methodologies and propose novel physical layer technologies, for instance encoders for short block lengths, channel estimation schemes, beamforming and (massive) MIMO processing in sub 6-GHz and mmWave bands. The WG will also address localisation issues, relevant at an application level but also for a better network scheduling. It will follow a sequence of tasks: Task WGT-2-1: identification of the scientific challenges and definition of objectives; Task WGT-2-2: theoretical work on new PHY layer designs; Task WGT-2-3: localisation solutions in complex environments; Task WGT-2-4: implementation of new solutions and evaluation; Task WGT-2-5: publication and evaluation of the benefit of data-driven solutions.

WG3 – Network Architectures and Protocols. The main goal of WG3 is to propose **new networking paradigms** to perform human-to-thing communication suppressing perception of any intermediary. This fluid communication will require a network database for different use cases, dynamic infrastructure management, possibly with the help of ML, and adequate distribution of the computing load between the different components of the network. The WG will follow a sequence of tasks: Task WGT-3-1: identification of network architectures for seamless communication; Task WGT-3-2: theoretical considerations for the design of new algorithms and protocols; Task WGT-3-3: implementation and test of the proposed solutions; Task WGT-3-4: publications and identification of new paradigms and recommendations for a smart network design.

4.1.1.3 Vertical Teams (VTs)

WGs must find common places to address smart network challenges that cannot be solved within a single discipline, which will be addressed through VTs, each addressing a societal challenge. VTs will foster interdisciplinary work - as optimal solutions will be the result of joint research - but also interaction with industrials and all relevant stakeholders.

VT1 – Health and Well-Being. VT1 covers an important societal challenge about health and well-being. It will emphasise scientific challenges dealing with **communications around or inside the human body**, including energy absorption by human tissues, communication reliability inside and outside the body, nano-networks, data access, privacy and security. It also requires accurate positioning systems.

VT2 – Transportation. VT2 is a significant challenge for mankind in the coming years and communication has an instrumental role to play, for instance in **autonomous vehicles**. It will emphasise scientific challenges dealing with high mobility, needing to better know the channel and its time evolution, to develop new PHY layers able to support this high mobility and to design the network consequently.

VT3 – Industrial Automation.VT3 refers to the industrial challenge which Europe is facing. The future industry will heavily rely on smart communication environments. This specific context raises challenges in dealing with **ultra-reliability and low latency**. This implies better knowledge of the environment, which can be really harsh in some cases, and consideration of short-packet transmission that challenges Shannon's theory and ensures that the network can get the data, analyse it and answer quickly enough.

VT4 – Smart Buildings and Cities. VT4 refers to several societal challenges including cities or buildings, which raises many scientific challenges. It will emphasise both **very high rate communications and/or ultra-dense networks**. Efficient CSI acquisition, massive MIMO, mmWave, ultra-low power, adaptability, scalability, etc., are all essential to the smart network.

All verticals will follow the same sequence of tasks. Task VTT-x-1 defines the specifications and technical requirements, and in order to achieve this goal, during the first year of the Action, INTERACT will invite industrials to present the challenges of the four VTs during the Management Committee Meetings. In year 2, Task VTT-x-2 will work with each WG on its own roadmap to identify disciplinary challenges, significant results and missing solutions. In years 3 and 4, Task VTT-x-3 will foster multi-disciplinary and inter-disciplinary efforts to create technologies able to support intelligent networks. Efforts will be made to encourage interaction with the end-users, industrials and all relevant stakeholders that will be invited as ad hoc participants to the meetings and, if possible, as WG and VT members.

4.1.1.4 Horizontal Activities (HAs)

The work on the sharing of knowledge will be structured into HAs. They will not only interact with the

WGs and VTs but also will have their own areas of work.

HA1 – Datasets (see section 1.2.1.5) – will address the set-up and maintenance of the **INTERACT dataset(s)**. The expected large number of participants and the open collaborative environment provides INTERACT with a unique opportunity to feed these datasets. HA1 will be responsible for creating a favourable environment to share measurements, simulation scenarios and models, open to selected participants, all participants of the action or even to the world. The following tasks will be performed: Task HAT-1-1: identification of storing means and data sharing rules; Task HAT-1-2: encouraging participants to share their data and maintain the database.

HA2 – Dissemination (see section 3.2.2) – is led by the Science Communication Manager. The following tasks will be performed: Task HAT-2-1: strategic liaisons and joint activities, and organisation of workshops and special sessions; Task HAT-2-2: creation and maintenance of the website, and social media, besides presentation of the Action in external entities and to the general public via a video; Task HAT-2-3: issuing of a Newsletter (3 editions per year) and of an Action Leaflet (updated with every Newsletter issue), under the responsibility of the ECI representative; Task HAT-2-4: publishing White/Position Papers.

HA3 – Training – is led by the STSM and Training School Coordinator. In addition to lecturing activities described in Section 3.2.2, it also includes personal training via STSM. The following tasks will be performed: Task HAT-3-1: tutorials in conferences, scientific Training Schools (with topics defined by WGs and VTs), and transversal tutorials addressing the Human Dimension, aiming at providing INTERACT participants, and especially ECIs, with the necessary tools to efficiently share their research through publication and other communication tools related to career development. Non-technical transversal sessions (dedicated to soft skills) will be organised the day before or after MC meetings. Training Schools will be organised either physically or virtually, using online course platforms to maximise the audience while minimising CO2 emissions. Task HAT-3-2: organisation of the STSMs.

4.1.2. DESCRIPTION OF DELIVERABLES AND TIMEFRAME

Already described in the WG and VT description, the Action will take place in three main phases, summarised in the following. First, the context, the objectives and scenarios will be studied. Each WG will establish the state-of-the-art and identify the key challenges on which INTERACT can have a significant impact. During this phase, VTs will identify the needs from the different societal challenges. Secondly, theoretical and experimental research, both disciplinary and interdisciplinary, will be carried out. The third phase will synthesise the research to provide answers to Verticals. Dissemination and exploitation will follow the plans of Section 3.2.2. The scientific deliverables will be as follows:

- t0+12: D1: State-of-the-art and key challenges on disciplinary and interdisciplinary research

- t0+12: H1: Database structure and content requirements

- t0+36: D2: Disciplinary and interdisciplinary solutions to the scientific challenges

- t0+48: H2: Database with data sets available

- t0+48: FR: Final report (open-access book)

One innovative outcome of the Action is the **shared datasets**, maintained by HA1 and including radio channel data but also data sets to test PHY/MAC layer algorithms or localisation strategies. Regarding HA2, high-impact outputs (see 4.1.4 GANTT Diagram) will consist of **White Papers** (WG1-WG3) addressing a selected set of identified challenges. At least three will be edited during the course of the Action (among them, one will be oriented to the general public, dealing with the human exposure issues). Additional outputs from HA2 and HA3 include: one **application video** (AV1); **10 to 15 STSMs per year and two training schools per year** (S1-S6); specific trainings for ECIs, both **scientific and transversal** (T1-T5); **joint workshops** with other European Actions or projects and special sessions/workshops in major conferences (J1-3).

4.1.3. RISK ANALYSIS AND CONTINGENCY PLANS

The major risk inherent to COST Actions is the absence of any contractual obligations among participants, in contrast to most other R&D frameworks. It is minimised by the inclusion of researchers who exhibit solid experience in collaborative projects and their networking instruments (exchange of researchers, joint publications, measurement campaigns, training schools, etc.). The monitoring of the Action by the Core Group and Steering Committee and the frequent physical meetings (3 times/year) further reduce these risks, in particular through virtual debriefing meetings after each MC meeting. Finally, the critical mass and the diversity within the original network of proposers minimises the risk of not meeting the objectives. Another risk caused by this absence of contractual obligations lies in the database construction. In this respect, HA1 will take all necessary pro-active steps to maximise data sharing. In particular, existing datasets from public repositories (ETI-MLC, IEEE DataPort, CRAWDAD, EU Open Data Portal, etc.) and from many Action members will be used in an initial step to mitigate the risk. Then, the large number of existing measurement equipment in the original NoP is another safeguard against the risk of not having enough data. Finally, the Steering Committee will periodically contact other EU-funded projects, dealing with wireless communication and networking, and possibly generating their own databases for ML-based research, in order to investigate the possibility to share such database with the INTERACT Action.

4.1.4. GANTT DIAGRAM

TASKs \ Project year			Y1			Y2			Y3			Y4		
Trimester	Start	End	1	2	3	4	5	6	7	8	9	10	11	12
WG1 – Radio Channels														
WGT1-1 – Objectives	1	4			D1									
WGT1-2 – Theory/experiment	3	10												
WGT1-3 – Data Analysis	5	10												
WGT1-4 – Models	8	12									D2			FR
WG2 – Signal Processing and Localisation														
WGT2-1 – Objectives	1	4			D1									
WGT2-2 – PHY Layer; theory	3	11												
WGT2-3 – Localisation	3	11												
WGT2-4 – Implementation/test	5	12									D2			FR
WGT2-5 – Data driven benefit	7	12									D2			FR
WG3 – Network Architectures and Protocols														
WGT3-1 – Objectives	1	4			D1									
WGT3-2 – Protocol design	3	12									D2			FR
WGT3-3 – Tests	5	10									D2			
WGT3-4 – Recommendations	10	12												FR
VT1 – Health & Well-Being														
VTT1-1 – Specifications	1	4			D1									
VTT1-2 – Roadmap	4	10									D2			
VTT1-3 – Inter-disciplinary	7	12									D2			FR
VT2 – Transportation														
VTT2-1 – Specifications	1	4			D1									
VTT2-2 – Roadmap	4	10									D2			
VTT2-3 – Inter-disciplinary	7	12									D2			FR
VT3 – Industrial Automation														
VTT3-1 – Specifications	1	4			D1									
VTT3-2 – Roadmap	4	10									D2			
VTT3-3 – Inter-disciplinary	7	12									D2			FR
VT4 – Smart Buildings & Cities														
VTT4-1 – Specifications	1	4			D1									
VTT4-2 – Roadmap	4	10									D2			
VTT4-3 – Inter-disciplinary	7	12									D2			FR
HA1 – Datasets														
HAT1-1 – Setup	1	2												
HAT1-2 – Filling/maintenance	3	12			H1									H2
HA2 – Dissemination														

HAT2-1 – Liaisons/joint events			J1			J2			J3			J4	
HAT2-2 – Website/social media								AV1					
HAT2-3 – Newsletters		N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12
HAT2-4 – White Papers					WG1				WG2				WG3
HA3 – Training													
HAT3-1 –Schools and tutorials			T1	S1	T2	S2	S3	T3	S4	S5	T4	S6	T5
HAT3-2 – STSM													