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Abstract*— With the increasing usage of robots in numerous vertical industries, the need for standardised solutions has intensified. A number of research and industrial communities and other Standards Developing Organisations (SDOs) have been actively working to identify areas in the robotics and automation sector that are suitable for standardisation. On top of that, each generation of mobile communications brings in new features and a wealth of new standardisation possibilities. While the deployment of 5G New Radio (5G NR) networks is expanding, the race for 6G is already starting to take shape with a number of proposed enabling technologies such as the integrated communication and sensing (ISAC) which can revolutionize the robotic technology. Since the two sectors of robotic and communication technologies advancements have overlapping areas for research and development, the SDOs' activities need to address the commonalities, to allow a harmonized and unified platform that formally adopts and confirms best practices in 6G and robotics as standards. In this work, we present relevant industry standardisation, associations, and fora for both mobile communication and robotic industries based on the ETSI Classification of SDOs. We present the standardisation landscape for 6G and robotics and highlight the gap in this multidisciplinary standardisation, sharing key recommendations.

***Keywords*—6G architecture, 6G standardisation, robotic application requirements, standardisation landscape, tele-robotics**

I. Introduction

Networked robots have their roots in teleoperation systems, as remotely controlled devices. Thanks to the recent evolution of wireless communication networks in the roadmap to 6G, networked robots quickly expand their scope from a traditional lead/follower teleoperation relationship to a global integration of robots, humans, off-board sensors, databases, and edge/cloud computing platforms. With advancements and integration of capabilities, the fields of robotics and 6G communication need to collaboratively present their respective requirements and capacities, to identify new market opportunities and pinpoint existing gaps. Multidisciplinary research and standardisation are required to address these gaps as Standards Developing Organisations (SDOs) are mainly focused either on the communication side or on the Robotics and Automation Systems (RAS) side.

To this end, 6G aims to unleash the potential of mobile connectivity for secure, resilient, and sustainable development, empowering the robotic sector with capabilities that enhance robotic connectivity, perception, and control in the automation process. To successfully support the foreseen demand of robotic applications in different scenarios, future mobile communication systems must be capable of supporting stringent and conflicting performance requirements to guarantee the required service quality and availability at anytime and anywhere to ensure safety for cage-free robotic operation in human-robot collaboration scenarios. Moreover, mobile communication infrastructure also needs to be equipped with an enhance sensing capability to fully support vertical use cases empowered by robotics. On the other hand, improvements to communication can also be provided by robotic advancements e.g., Simultaneous Localisation and Mapping (SLAM) can be used for User Equipment (UE) positioning or Autonomous Mobile Robots (AMRs) can carry 6G access points, which could enhance the network coverage and Quality of Service (QoS). Similarly, active multimodal sensing and data collection by the robot's internal sensors or ambient sensors can be used for optimising 6G services.

Researchers who are actively working in the robotic domain need to discuss what has been learned from existing connectivity solutions (such as 5G), which topics will continue to evolve towards 6G, and which new robotic related features will appear in 6G that could be promising for different vertical sectors. In contrast to previous generations of mobile communication systems, 6G will be characterised by the adoption of Integrated Sensing and Communication (ISAC). The goal of ISAC is to integrate positioning and radio sensing capability (e.g., using Radra and/or Terahertz imaging) with the communication functionality in the future 6G standard.

Based on the standardisation activities in both robotic and communications standardisation associations and the approach to convert research outcomes into harmonised solutions, this paper aims to provide an overview about the standardisation and research association in networked robotics ecosystem.

The rest of the paper is organised as follows: Section II presents multidisciplinary research highlights leading to the definition of relevant use case examples, requirements and Key Performance Indicators (KPIs). This includes identifying new and more stringent requirements of connectivity for RAS, and emphasising where the shortcomings are and how they can be addressed by 6G standardisation. Section III provides the RAS standardisation process and organisations having mobile communications in their scope. Section IV provides a similar discussion with Section III from the communication perspective. Finally, Section V discusses the 6G robotics standardisation landscape, shares multidisciplinary standardisation challenges and recommendations about facilitating the robotics and communication experts to work together to address these interrelated challenges.

II. Multidisciplinary Research, Use Cases, Requirements and KPIs

This section presents a multidisciplinary research overview and highlights those use case examples where the symbiosis of robotics and mobile communications influences the KPIs (in given occasions conflicting with each other) that need to be included in the forthcoming 6G research and standardisation. To this end, we have listed a number of multidisciplinary projects with related use cases to indicate some of the ongoing research, which could potentially lead to standardisation. The main goal of these and similar initiatives is to identify relevant use cases, user requirement, KPIs, and Key Value Indicators (KVIs).

A growing number of potential use cases at the intersection of robotics and 6G networks is identified in the current landscape; a high-level representation of this convergence is shown in Fig. 1. Examples include cooperative robots in industrial environments (Cobots), interactive educational robots (EduBots), flexible service robots in healthcare, drone-enabled connected systems, robots in metaverse (metarobots), and others [18]. Identification of relevant KPIs and KVIs is currently under way and represents one of the principal goals of research initiatives. Some of the KPIs known to play key role range from traditional ones such as requested data rates, end-to-end latency, jitter, connection density, to more recently identified ones such as age of information or the ones related to Artificial Intelligence (AI) and Machine Learning (ML), e.g., training and inference delay, complexity, and resource footprint as well as resilience, safety, security, and privacy in the training process of the models. Exact KPIs and KVIs as well as range and thresholds for various scenarios and use cases are still in the early identification stage. Certain research initiatives indicated in Table I will help to formalise their definitions and future use.

In expectation of future definition of KPI/KVIs arising from the activities of the above projects, a set of KPI/KVIs are discussed in one6G "6G and Robotics" whitepapers [6] such as: accuracy of robot positioning and velocity, sensing service latency, uplink/downlink/sidelink data rate, latency and reliability, device density, AI model transfer parameters, size, latency, etc.

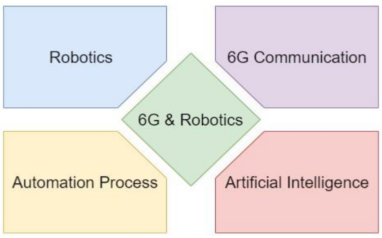

Fig. 1. 6G enabled Robotics, automation industries and enabling technology convergence.

TABLE I. MULTIDISCIPLINARY ROBOTIC & COMMUNICATION PROJECTS AND RELATED KPIS & KVIS

Project acronym & Short Description	Use Cases	KPIs & KVIs
Umbrella: Open, programmable, universal industrial IoT research and development testbed	Collaborative robotics-developing warehouse of future using swarm driven AI robotics	Enhanced flexibility and collaborative engagement (KVIs), while reducing task duration and battery consumption (KPIs)
TARGET-X: Trial platform for 5G cross-industry evaluation	Robotics – Lineless mobile assembly at RWTH Aachen	Focuses on KVIs such as safety, security, privacy, and sustainability. KPIs to be defined and measured in trials
ADROIT-6G: Next-gen AI driven 6G network architecture	Extreme URLLC for collaborative robots (Cobots)	Targets definition of relevant KPIs and KVIs which are not yet available.
DESIRE 6G: Near real-time end-to-end via extreme URLLC	E2E Digital Twin system for robotics	Evolution of extreme URLLC KPIs and KVIs
5G-SWARM: Focused on swarm manufacturing, private 5G networks with edge integration	Swarm manufacturing within a mobile robot and vPLC scenario	Deployment of reliable 5G private network and low-latency processing on the edge
5G-ERA: 5G Enhanced Robot Autonomy – 5G and robotics test and experimentation	Public safety, transport, healthcare, manufacturing	Quality of Experience for networked robotic applications

III. ROBOTICS AND AUTOMATION SDOS AND ASSOCIATIONS

In this section, we present the main robotic SDOs and associations that have communication scope and highlight the activities relevant to 5G and 6G communications and networking.

A. Robotic SDOs

ISO/TC Robotics: Defines standards in the field of robotics, excluding toys and military applications and has two relevant Technical Committees (TCs), i.e., TC 299 & TC 184.

ISO/TC 299 [7] - Defines standards for the industrial robotics sector, and for the non-industrial robotics sector with topics on performance criteria, modularity, and vocabulary.

ISO/TC 184 [8] - Automation systems and integration; 5 subcommittees, 24 participating members/21 observing members, 4 published and 2 under development ISO standards under direct responsibility of ISO/TC 184 Subcommittee SC 2. Areas of standardisation include information systems, automation and control systems, and integration technologies.

Robotic Industries Association (RIA) [9] - RIA is a USA trade group organised to serve the robotics industry and a member of American National Standards Institute (ANSI). Member companies include leading robot manufacturers, system integrators, vendors, research groups, and consulting firms, and end-users.

Example standards are listed and categorised in Table II.

TABLE II. ISO TC 299, ISO TC 184, AND ANSI/RIA ROBOTICS STANDARDISATIONS AND SCOPE

SDO	Topic	Scope
	ISO TC 299	
8373:2021	Robotics vocabulary	General
11161	Industrial manufacturing systems	Industrial robots
19218-2	Industrial robots	
10218-1&2:2011	Safety requirements for industrial robots	
22166-1:2021	Modularity — P1: General requirements	Service robots
18646-2:2019	Performance criteria and related test methods — P2: Navigation	
18646-3:2021	Performance criteria and related test methods — P3: Manipulation	
18646-4:2021	Performance criteria and related test methods — P4: Lower-back support robot	
13482:2014	Safety requirements	Personal care robots
TS 15066:2016	Robots and robotic devices	Cobots
PD ISO/PAS 5672	Test methods for measuring forces and pressures in quasi-static and transient contacts with humans	Cobot devices
	ISO TC 184	
SC 2/WG3	Safety	Industrial
SC 2/WG7	Safety	Personal care
	ANSI/RIA	
R15.08-1-2020	Industrial Mobile Robots - Safety Requirements - Part 1: Requirements for the Industrial Mobile Robot	Industrial robots
TR15.06-2012	Industrial Robots and Robot Systems-Safety Requirements	
TR R15.306-2016	Task-based Risk Assessment Methodology	
TR R15.406-2014	Safeguarding	
TR R15.606-2016	Industrial Robots and Robot Systems - Safety Requirements- Collaborative Robots	
TR R15.506-2014	Applicability of ANSI/RIA R15.06-2012 for Existing Industrial Robot Applications	

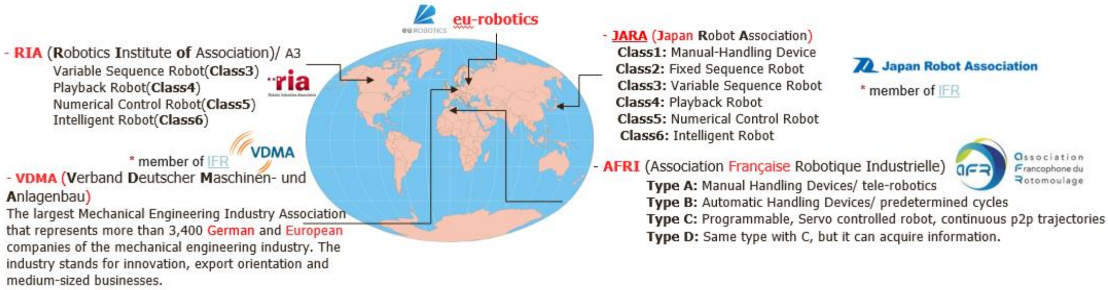

Fig. 2. Worldwide Robotics and automation associations by geographical scope.

B. *Robotics Professional Organisations*

Fig. 2 shows some of the major robotics and automation associations around the globe with their geographical scope. In the following, we will review these associations and their main activities, including RAS standardisation.

1) *International Federation of Robotics (IFR)*

A professional non-profit organisation to promote, strengthen, and shape the position of the robotics industry worldwide. IFR [10] was established in 1987 with Headquarter in Frankfurt, Germany and has 86 members (2022). The IFR covers topics like industrial robots, service robots, and robotics research (including 5G), and its activity ranges from publishing position papers and case studies to standardisation (ISO) [7][8]. IFR's main activities are to provide worldwide market data for surveys, studies and statistics which can shape the position of the industry on key topics like collaborative robots, AI, and the workplace of the future and help manufacturers and integrators of robotics to enter new markets. IFR organisation also stimulates research in robotics and promote links between science and industry (e.g., IERA Award, International Symposium on Robotics (ISR) conference) or partnerships among its members.

2) *IEEE Robotics and Automation Society (RAS)*

IEEE RAS is a professional society that supports the development and the exchange of scientific knowledge in the fields of robotics and automation, including applied and theoretical issues as well as ontological and ethical aspects. The approved IEEE RAS standards are the following:

- 1872-2015: IEEE Standard Ontologies for Robotics and Automation.
- 1872.2-2021: Standard for Autonomous Robotics (AuR) Ontology.
- 1873-2015: IEEE Standard for Robot Map Data Representation for Navigation.
- 7007-2021: Ontological Standard for Ethically Driven Robotics and Automation Systems.

Besides, the IEEE RAS Working Groups are developing the following standards:

- P1872.1: Standard for Robot Task Representation.
- P2751: Standard for 3D Map Data Representation for Robotics and Automation.
- P2817: Guide for Verification of Autonomous Systems.
- P2940: Standard for Measuring Robot Agility.
- P3107: Standard Terminology for Human-Robot Interaction.
- P3108: Recommended Practice for Human-Robot Interaction Design of Human Subject Studies.

IEEE RAS is known as a reputable technical society organising well known academic-led conferences and events as well as reputable publications, e.g., RA-L - IEEE Robotics and Automation Society [12].

3) *Association for Advancing Automation (A3)*

Association for Advancing Automation (A3) is the North America's largest automation trade association, involved in robotics, AI, machine vision and imaging, motion control and motors, and related automation technologies. A3 was founded in 1974 and consists of 1119 members in AI, motion control & motors, Robotics, and Vision. The Robotic Industries Association (RIA), Automated Imaging Association (AIA), and the Motion Control and Motors Association (MCMA) merged into the A3 Association in 2021.

As part of their activities, A3 sponsors trade shows, conferences, and other networking events; hosts the leading global website on automation technologies; collects industry statistics; generates market research; develops consensus standards; provides certification programs; hosts webinars and podcasts; and engages in a wide variety of other educational activities. The main focus is on leading global standards and offering robot safety training and certification.

There is no connection between the association activities and cellular industry; it does not include members from mobile industry and only few member's activities include 5G/MEC such as Verizon robotics.

4) *Japan Robot Association (JARA)*

Japan Robot Association (JARA) is a trade association made up of companies in Japan that develop and provide robot technology. JARA was formed in 1971 and was the world's first robot association. The association was reorganised and renamed as the Japan Industrial Robot Association (JIRA) in 1973 and later renamed to its current one in 1994 to accommodate non-industrial robots such as personal robots. The Japan Robot Association aims to advance the growth of the robot manufacturing industry by encouraging research and development on robots and related system products, and by promoting the use of robot technology in industry and society.

The activities of JARA include organising the International Robot Exhibition (IREX) every two years in Tokyo, the Jisso Process Technology Exhibition every year, promoting standardisation in the robot industry, and hosting the ORiN (Open Robot interface for the Network) Forum to promote standard network access to robots and programmable machines. JARA is a member of IFR.

5) *Mechanical Eng. Industry Association (VDMA)*

(Verband Deutscher Maschinen - und Anlagenbau (VDMA) represents over 3,200 members, mainly Small and Medium-sized Enterprises (SMEs) in the engineering industry, is one of the largest and most important industrial associations in Europe. As part of the VDMA Robotics & Automation association, VDMA Robotics unites more than 75 members: companies offering robots, components of a robot, control units and motion device system integrations. The objective of this industry-driven platform is to support the robotics industry through a wide spectrum of activities and services such as standardisation, statistics, marketing, public relations, fair trade policy, networking events and representation of interests. Regarding membership, only manufacturers of products can become members of the respective VDMA trade associations and their specialist departments. VDMA is a member of IFR.

The joint VDMA and OPC (Open Platform Communications) Foundation Working Group: The goal of VDMA OPC Robotics Initiative is to develop an Open Platform Communications Unified Architecture (OPC UA) information model in order to reach the level of machine-to-machine communications required for Industry 4.0. The aim is to empower all current and future robotic systems, including fixed industrial robots, mobile robots, control units, and peripheral devices that do not have their own OPC UA server. The OPC UA specification is defined in IEC 62541 standard series, which currently includes 26 parts (Part 1-24, Part 100, and Part 200). The standard specifies technical requirements for implementing OPC UA, including the data model, transport protocol, security mechanisms, and information modelling. It ensures interoperability between different vendors' implementations of OPC UA and promotes the adoption of a common communication protocol in industrial automation systems.

6) European Robotics Association (euRobotics)

Association Internationale Sans But Lucratif (euRobotics AISBL) [2] founded in 2012 is a Brussels-based international non-profit association for all stakeholders in European robotics with the aim to strengthen Europe's competitiveness and ensure industrial leadership of manufacturers, providers, and end-users of robotics-based systems and services. The association has been nurtured by a Coordination Action funded by the European Commission (EC) under FP7 (2010-2012) and built upon the success of the European Robotics Technology Platform (EUROP) and the academic network of EURON. From 2014 to 2020, euRobotics collaborated with the EC in the Public-Private Partnership in Robotics (SPARC) under Horizon 2020 to develop and implement a strategy and a roadmap for research, technological development, and innovation in robotics, representing the private side of the Partnership as illustrated in Fig. 3.

The European Commission has issued its Robotics and autonomous systems Rolling Plan 2023 forecasting that the robotics market is set to exceed 90 billion EUR by 2030 and emphasising the need for standardisation [1]. In 2021, robotics standardisation has continued its work in all fronts in both the International- and the European- SDOs (ISOs, ESOs). R&D projects on robotics funded by the EU Framework for Research and Innovation set the scientific basis for new key technologies, interoperability between robots, and the use of robots to achieve societal challenges.

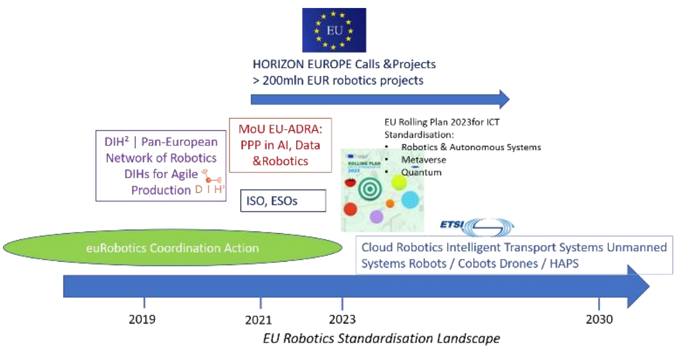

Fig. 3. Eu-Robotics roadmap.

The impact of Artificial Intelligence (AI) techniques is set to vastly improve the capacities and autonomy of robots. In June 2021, the European Commission signed a Memorandum of Understanding with the AI, data and Robotics Association (ADRA), setting up a public-private partnership that will support the development of the European AI, data and robotics ecosystem and uptake of AI, data and robotics solutions. The most relevant standards on robotics are led by ISO. The association roadmap is focused on European robotics research, development, and innovation to foster a positive perception of robotics through promoting 1) the uptake of robotic technologies and services for industry and consumer markets, and 2) the excellence of European robotics science.

7) European AI, Data and Robotics Association (ADRA)

On May 2021, BDVA (Big Data Value Association), CLAIRE (Confederation of Laboratories for AI Research in Europe), ELLIS (the European Laboratory for Learning and Intelligent Systems), EurAI (European Association for AI) and euRobotics founded ADRA (AI, Data and Robotics Association) [4]. With the end of SPARC's term, a new public-private partnership was established between the EC and ADRA under Horizon Europe programme (2021-2027) in May 2021. Through ADRA, euRobotics represents the private side of the Partnership [3] in digital, industry and space (Pillar II - Cluster 4 of Horizon Europe programme). The key benefit to Europe from AI, Data and Robotics is the Partnership driven by innovation, acceptance, and uptake of these technologies. By 2030, European sovereignty is expected in the development and deployment of trustworthy, safe, and robust AI, and Data and Robotics, following the European fundamental rights, principles and values. To that end, this Partnership is to boost the application of these technologies in different vertical market sectors and attract new investments and create technical, economic and societal value for business, citizens and the environment.

The Partnership is described in its proposal application and the Strategic Research, Innovation and Deployment Agenda (SRIDA). The EC plans to invest 1,3B€ in this Partnership, amount to be matched by Industry with investing a total of 2,6B€ by 2030. The Memorandum of Understanding (MoU), basis for the cooperation in a Partnership, has been officially signed on June 2021 and since December 2021, Adra is open to receiving membership applications.

8) Converge Robotics Group

A consortium formed in 2020 by different companies to look into advances in haptics and robotics (e.g., including HaptX, Shadow robotics, SynTouch BioTac, and Tangible Research). The idea is to create a framework under which the tactile telerobot can be further developed [15]. Converge Robotics Group seeks to extend the reach of human dexterity through the integration of advanced haptic and robotic technologies. Converge's Tactile Telerobot is the world's first robotic system that transmits realistic touch feedback to a remote operator. The remote operators can use their hands to control and train robotic equipment(s) and feel what robots feel as they manipulate objects. The Tactile Telerobot began as an avatar concept, catalysed by All Nippon Airways.

IV. Mobile Communications SDOs

A. 3GPP standardisation for robotic services

3rd Generation Partnership Project (3GPP) Technical Specification Group (TSG) Service and System Aspects (SA) is the 3GPP TSG responsible for the overall architecture and service capabilities of systems based on 3GPP specifications. There are subgroups on different topics, namely: SA1: Services; SA2: Architecture; SA3: Security; SA4: Codec; SA5: Telecom Management; and SA6: Mission-critical Applications. In SA1 particularly, the requirements form vertical use cases is a starting point to bring forward the needs from other verticals such as robotics. There are currently a number of related features that are discussed in more detail in subsection B below. From the outset, 3GPP 5G System (5GS) was designed to provide service based, highly reliable (e.g., URLLC, Time Sensitive Communications, Edge Computing) low latency communications and enablers for Industrial Automation, e.g., network analytics and network slicing. Although great progress was achieved, many existing and new use cases still remain to be addressed, e.g., use cases with stringent requirements, as those needed to support robotic and tactile services over the 5GS.

B. *Robotic vertical requirements and features*

Currently, a number of 3GPP Working Groups (WGs) are active on the robotic related topics. One study item, specifically relevant to service robots, is the 3GPP SA1 SOBOT (Study on Network of Service Robots with Ambient Intelligence) feature, having as main players LG and Nokia. While this feature has not progressed and is being criticized due to its way of operation, having a feature related to service robots shows that similar features related to robotic technology use cases are likely to be discussed in 3GPP.

Key vertical use cases (especially for factory and process automation) are studied in the 3GPP System Aspects (SA) WG1 (SA1) 3GPP22.104, whereas 3GPP approved in 2021 to investigate architectural enhancements for Extended Reality and Media (XRM) services, which are usually characterized by high data rate and low latency. To address these challenges, 3GPP TR 22.847 (multi-modality SA1 feature) and 3GPP TR 23.700 (XRM SA2 feature) intend to create a gap analysis between new potential requirements and existing requirements and functionalities supported by 3GPP – especially, for use cases that require immersive real-time experiences, including closed-loop feedback and control for robot arms, under varying Degrees of Freedom (DoFs).

Requirements for use cases under consideration include (but are not limited to) parallel transmission of multiple modality representations associated with the same application. Moreover, their reliability, availability, security, privacy, charging, and KPI identification for specific use cases are considered. The 3GPP multi-modality feature provides an example of new requirements motivating 3GPP 5GS enhancements to meet the needs of demanding applications, e.g., as those seen in the healthcare industry [22] [23].

SA2 takes requirements specified in SA1 [3GPP22.847] on tactile and multi-modal communication services for enhancing 3GPP system functionalities. In particular, relevant Rel-18 features are: support for multi-modal services (i.e., voice, video, and haptic communications), Personal Internet of Things (IoT) and Residential networks (PIRates), enablers for Network Automation (eNA), enhancements of network exposure to support interaction between 5GS and application, QoS and policy enhancements, enhancements of power management and traffic characteristics, and performance requirements for AI/ML Model Transfer (AMMT) in 5GS.

Key vertical use cases (especially for factory and process automation) are studied in 3GPP SA WG1 (SA1) [3GPP22.104] and SA6 [3GPP TR 23.745]. XR-based services are an essential part of "Metaverse" services to provide immersive experience accessed either by users in proximity or remotely. The 3GPP Localised Mobile Metaverse Services Study Item (Rel19)[24] supports the XR KPI requirements, prediction and adaptation, where coordinating input perception/sensing data from different user devices (such as sensors and cameras) and coordinating output data to different devices at different destinations to support the same application is required.

IEEE Tactile Internet 1918.1.1 standard [20] was the first standardisation activity for haptic communication started in 2017. IEEE 1918.1 has been further adopted in 3GPP 5GS Specs in TACMM (Tactile Mobile Manipulators), XRM features, cyberCAV (cyber-physical Control Applications in Vertical domains) and Metaverse as well as in IEC TC100 PT63448, standardising ultra-low latency communication for control-centric applications, addressing the use case requirements and enabling technologies.

C. *Internet Engineering Task Force (IETF)*

IETF Tactile Internet (TI) was also discussed in a number of groups within IETF, primarily as a use case which demands improved networking technologies to satisfy stringent resource requirements namely, the INTAREA working group which presents specific requirements of emerging use cases, such as Tactile Internet services [22].

D. *ITU-T Focus Groups (FGs)*

The ITU-T FG on Technologies for Network 2030 that concluded its work in 2020, made a study for the foreseen network capabilities in the year 2030 and beyond. The group selected Tactile Internet as a representative use case for network 2030, among other use cases such as holographic type communications and Space terrestrial integrated networking. Recently, the Metaverse focus group (MV-FG) was established under TSAG. The group aims to analyse the technical requirements of the metaverse to identify fundamental enabling technologies in areas from multimedia and network optimisation to digital currencies, IoT, digital twins, and environmental sustainability.

In addition to new communication-specific usage scenarios such as Immersive Communications, ITU-R has also envisioned a number of beyond-communication capabilities for IMT-2030 systems with potentially significant effect on Robotic systems and networks. In particular, ISAC and integration of (native) AI in every layer of the communication ecosystem are expected to make substantial changes in the way robots will perform in future. ITU-R expects that "*future connected devices may become fully context-aware for more intuitive and efficient interactions among humans, machines, and the environment. Autonomous networks may also be capable of performing self-monitoring, self-organising, self-optimising and self-healing functions without human intervention.*" Furthermore, it expects that cobots will play a major role in future automated industries. On the other hand, ISCA in IMT-2030 will provision ubiquitous sensing. This capability will extend the IMT-2020's mMTC usage scenario, and provide machines, and robots with new sensing-related abilities.

E. Alliance for IoT & Edge Computing Innovation (AIoTI)

AIoTI is a European association that has members both from the academia and the industry, including SMEs, and also other stakeholders such as policy makers. AIoTI has multiple workgroups promoting innovation, standardisation, security, policy, as well as research and innovation. The goal is to enhance European digitisation and competitiveness in the broad field of IoT and Edge Computing. Thus, delivering substantial value across verticals. The body was founded by the EU commission, and it is now established as an independent torch bearer for ecosystem helping to build business opportunities and support the European society. In the last six years, AIoTI has been able to support multiple standardisation reports. In addition, it has established many alliances and liaisons with different standards bodies. The major work in the standardisation workgroup was the High-Level Architecture (HLA) for the IoT verticals and deployments, and also identifying gaps within IoT vis-a-vis 5G. The body works democratically and with transparency – thus, new thoughts and ideas can flourish. Some indicative reports are the following: *i) IoT and Edge Computing impact on Beyond 5G: enabling technologies and challenge; ii) Role of IoT and Edge Computing in addressing biodiversity and environmental monitoring; iii) White Paper on IoT and Crisis Preparedness; and iv) Replicability and Scalability Assessment Tool.*

F. International Electrotechnical Commission (IEC)

The IEC TC100 has been focusing on standardisation of an ultra-low latency communication technology (PT-63448) for multimedia-centric control applications. Such technologies become necessary with the emergence of various new applications centred around mixed reality, wireless teleoperation and metaverse. The activity is largely aimed at bridging the gap in existing wireless standards for meeting the stringent performance requirements of control-centric applications, especially in terms of timeliness (guaranteed latency). The emphasis of the standard is on control in local environments which are characterized by a lean protocol stack compared to their global counterparts. The standardisation activity is specifying a Medium Access Control (MAC) layer for closed-loop wireless control along with system management aspects. This MAC layer can be realized over different Physical (PHY) layers including that of Bluetooth, Wi-Fi, and mobile/cellular technologies like and DECT-2020 New Radio.

V. Standardisation Landscape of 6G Robotic Services

Based on the identified robotic SDOs and associations in Sections III and IV, in this section, we further map the robotics related industry associations and SDOs based on their covered functionalities, use cases, sector, and geographical scope. A list of standardisation bodies listed in Fig. 4. The industry landscape aims to map the relevant industry standardisation, association and fora across robotic industry from telecom and verticals to the robotics manufacturing industries. The main robotics SDOs with relevant communication scope is ISO, the two professional bodies are IEEE RAS and IFR, while A3 is the most relevant industry association. IFR can be a key organisation for communication researchers to join and contribute to since 1) IFR feeds into ISO; and 2) IFR has research connection to 5G, and the use cases show relevance for a closer investigation.

A. Standardisation topics on 6G robotic services

6G technology capabilities can enhance robotic connectivity, perception and control in robotic fields, and vice versa. Therefore, it is essential for the research and standardisation bodies to work together to provide unified solutions. Examples of 6G influence on robotics are:

- 6G networked sensing to complement device-based sensing, increasing the sensing coverage and reliability of the desired perception. It could be made possible through environmental sensor fusion, or exploiting data in dense 6G deployments.
- 6G Network AI and native intelligence to enhance the robotic cognition via knowledge abstraction from all types of fused data, such as robot positioning and decision making, or through robot's collaboration service enhancement using 6G connectivity.

Examples of robotic technologies that can improve the performance of 6G networks are the following:

- SLAM for UE positioning;
- AMR for carrying 6G access points on demand to enhance network capacity, coverage, and resilience.
- Exploiting data collection by robot's onboard sensors for 6G network and service optimisation.

B. Standardisation gaps in 6G robotics

Robotic requirements: One key topic for multidisciplinary research and standardisation is understanding the robotic requirements, e.g., what the human and robot interaction and communication requirements are and how they can be measured. Moreover, robotic requirements should be expressed in appropriate KPIs and KVIs whose definition is a work in progress, as we indicated in Section II. To this end, for identifying and presenting new/enhanced 6G features that help robotic technology, ICT researchers require an understanding of the robotic industries' needs.

Enabling technologies: What are the main elements that may allow us to achieve the stringent requirements? How can robotic technologies improve the performance of 6G networks and vice versa?

6G architectural aspects: Which feature needs to be considered in 6G system architecture for full integration of sensing/computation/control to support robotic use cases?

Harmonised standards: Route for 6G research outputs for standardisation and cross SDO collaborations need to be streamlined for harmonised and interoperable standards.

Lessons learned for networked robotics: What are the lessons learned from commercial 5G for vertical use cases (particularly for robotic and automation), and what are the implications for 6G?

C. Recommendations for increasing the synergies between robotics and 6G

Following are some recommendations to increase the synergy of the robotics and communications experts to better understand the requirements of robotics services and address the existing challenges in both robotics and mobile sectors.

1) Encourage Cross-Pollination: Foster involvement of researchers from the 6G and robotics communities in each other's SDOs to contribute to the creation of a unified standard for robotic services. This could involve leveraging ISO standards related to communication research, and working with Technical Committees (TCs) responsible for areas such as information technologies, multimedia

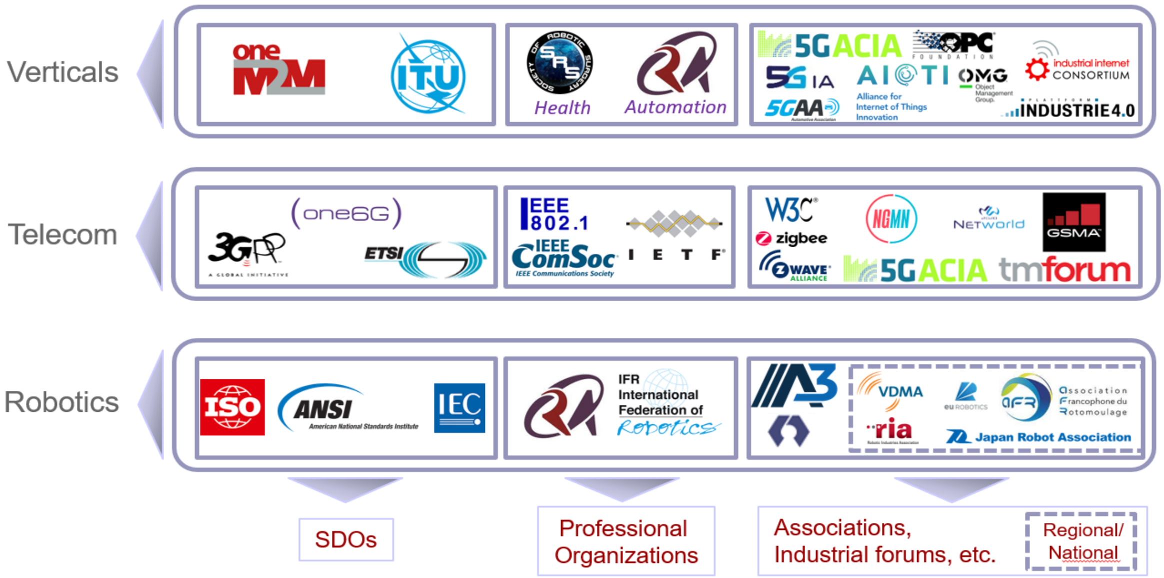

Fig. 4. Robotic Communications Standardisation landscape

capabilities, multi-modal communication networks, and collaborative robots. One promising route for standardisation is through IFR, which maintains connections not only with ISO but also with 5G and specific relevant use cases.

2) Facilitate Communication: Promote the exchange of Liaison Statements (LSs) between standardisation and professional bodies. For instance, sending LSs from one6G association Working Group 1 whitepaper on 6G & Robotics to bodies such as ITU-R IMT2023 vision and ETSI THz ISG groups can help bridge the gap.

3) Joint Workshops: Organise joint workshops, such as the annual one6G summit, where researchers from academia and industry can communicate their requirements. This collaborative platform can lead to a unified and comprehensive standardisation effort.

4) Collaborative Projects: In addition to standardisation, engage in collaborative projects. Consider building partnerships and affiliating with professional organisations. For instance, you can join euRobotics, BDVA, DAIRO, and ADRA in EU-funded projects. Initially, become a member of these organisations and closely monitor their activities. Eventually, participate in their open initiatives, like the Europe Robotic Forum in March 2023.

VI. CONCLUSIONS

The increasing demand for robotics applications across various scenarios and use cases necessitates the advancement to 6G technology. Although 5G communication systems have initiated the integration of wireless communication into robotic applications, the transition to 6G is essential for several reasons. It is required to enable a higher density of secure communication links (encompassing both inter-robot and intra-robot communication) with strict performance criteria. Moreover, 6G is essential to guarantee service availability everywhere and at all times, facilitate highly precise environmental awareness, support dynamic QoS adjustments for safety in close proximity to humans, and enhance sensing capabilities to aid in decision-making. Therefore, collaboration between various SDOs and robotic and communications experts is essential for the human-centric stimulation of synergies between these sectors.

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