ETSI White Paper No. 61

ETSI Technology Radar

Second edition – December 2023

ETSI
06921 Sophia Antipolis CEDEX, France
Tel +33 4 92 94 42 00
info@etsi.org
www.etsi.org

Document Co-Editors: Christian Toche, David Boswarthick

Document Contributors:
Xueli An
Aldo Artigiani
Gianmarco Baldini
Mate Boban
Jorge Bonifacio
Angel Boveda
Isabella Cerutti
Muriel Deschanel
Roberto Ercole
Ray Forbes
Lindsay Frost
Beniamino Gorini
Jens Johann
Alex Leadbeater
Luigi Licciardi
Diego Lopez
Alain Mourad
Markus Mueck
Luca Pesando
Dario Sabella
Matthias Schneider
Shahar Steiff
Dao Tian
Chonggang Wang
Martin Ward

Contents

Executive Summary

The principal activity of ETSI is the development of high-quality ICT standards to serve the needs of both industry and civil society. ICT Standards are an essential enabler for the development of new and innovative digital services and for the overall digital transformation of business, industry, and society in general, being increasingly pervasive in all sectors of activity. The digital world shapes our future and ETSI is a key player in the global digitization activity, ensuring the development of the standards that enable fully interconnected, interoperable, secure, and sustainable solutions.

One of ETSI´s principle strategic directions as described in the ETSI Strategy [1] is “to be at the heart of Digital”, expressing the clear intention for ETSI to be one of the leading organizations providing ICT standards for both present needs and designing tomorrow’s world by addressing the ICT needs for future services and applications. In this framework, the intent of the ETSI Technology Radar (ETR) is to highlight probable technology trends for ICT that may impact ETSI’s quest to remain at the forefront of ICT standardization.

The initial edition of the ETR (April 2021) has been developed by ETSI Board members, TB/ISG officials and ETSI secretariat representatives, using the following methodology:

- A thorough technology trend analysis considering over 15 publicly available technology reports, as well as questionnaires and other inputs from ETSI members and technical groups on expected technology trends.
- Joint agreement in the ETR editing group on the key technology trends that could be of most relevance for ETSI, today and in the near future.
- For each selected technology trend, the identification of affinities and/or eventual gaps with respect to current ETSI activities as documented in the ETSI Work Programme [2], the definition of a time frame of maturity for standardization, and a set of recommendations for future more detailed analysis at OCG and/or Board level on the eventual way forward to fill the identified gaps in a timely manner.

The revised edition of the ETR (December 2023) has been developed by ETSI Board members, TB/ISG officials, experts from ETSI members and ETSI secretariat representatives, with the following methodology:

- A re-examination of the selected 10 technology trends as contained in the initial ETR (April 2021). Updates to the trend titles and a re-actualization of the technology trend overview and status text.
- A thorough analysis of the most recent technology vision and framework documents, particularly the numerous global 6G vision papers published late 2022 and early 2023.
- Identification of all relevant new technology trends not captured in the initial ETR (April 2021).
- Joint agreement in the ETR editing group on the addition of new technology trends are of most relevance for ETSI today and in the near future.

- For each of the selected new technology trends, the identification of affinities and/or eventual gaps with respect to current ETSI activities as documented in the ETSI Work Programme [2], the definition of a time frame of maturity for standardization, and a set of recommendations for future more detailed analysis at OCG and/or Board level on the eventual way forward to fill the identified gaps in a timely manner.

The technology trend analysis has been focused on several key technology trends as shown in Figure 1. This selection does not exclude future revisions or integrations to reflect the continual cycle of technology evolution.

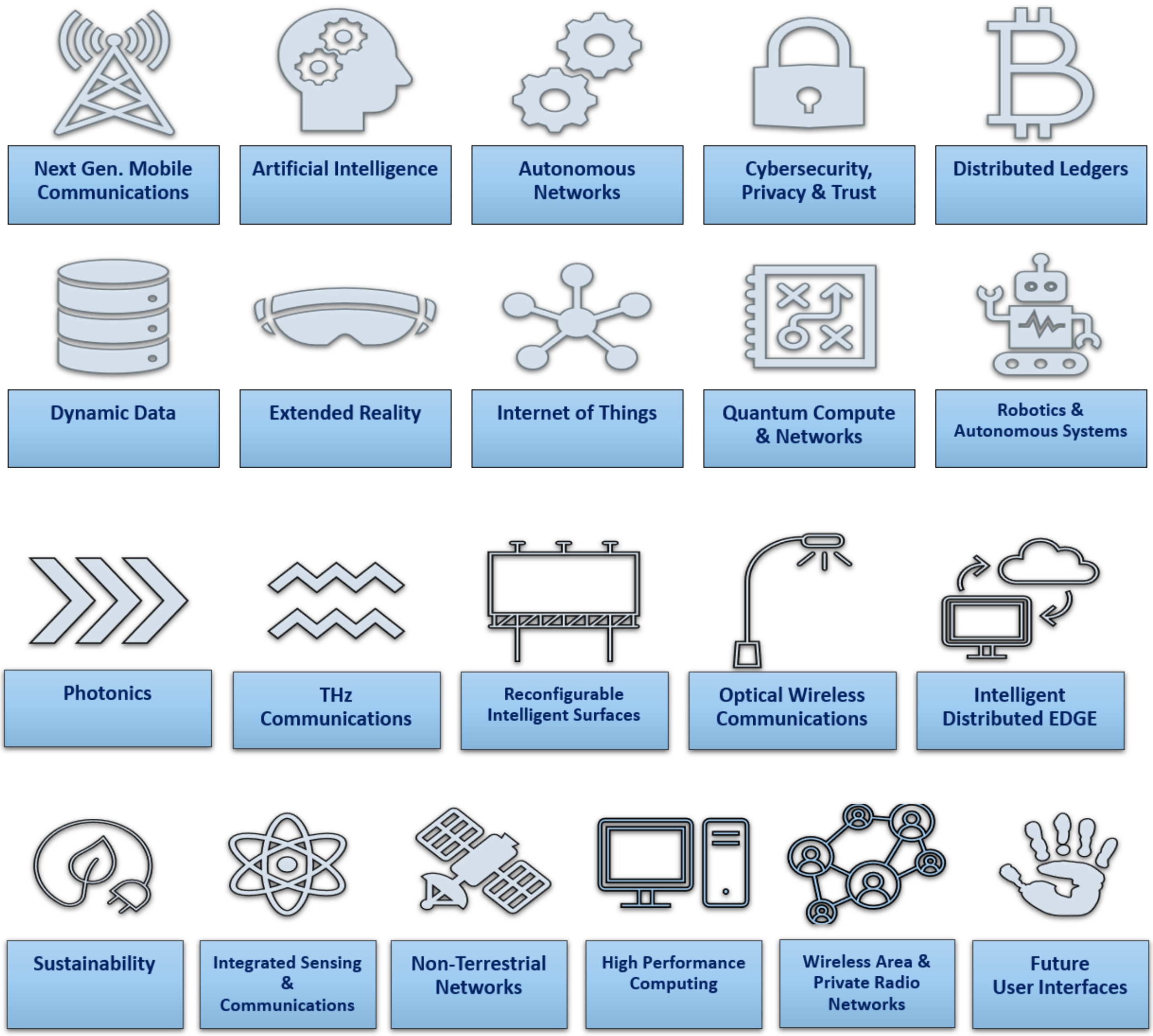

Figure 1: Overview of selected technology trends in the ETR

The initial analysis demonstrates that ETSI is already active in several of the identified trends, giving clear assurance that ETSI is already on the right track. Other trends are still emerging, and it is important for ETSI to promote the discussion, verify the requirements, and be positioned at the frontline of these upcoming technology developments.

The time frame identifies different maturity levels of the selected trends, with respect to standardization needs, starting from 2020 up to the end of the present decade.

The ETR has classified the various recommendations for ETSI into four main clusters:

- **MONITOR**, when the technology trend is still considered immature for standardization, or further exploration work is necessary to identify the appropriate ETSI contribution to the standardization efforts by other SDOs.
- **INITIATE**, when the technology trend is considered mature for further evaluation and action in ETSI.
- **DEVELOP**, when the technology trend is already addressed by the ETSI Community, shaping future standards.
- **PROMOTE**, when ETSI is already fully engaged in the development of standards related to the concerned technology trend, and further outreach and promotion activities could be envisaged.

Considering the overall trend analysis, the ETR main findings can be summarized as follows:

- **Non-exhaustive:** The selected technical trends are key examples of technology evolutions that are likely to impact not only the present work of ETSI but also the future work and even the future ETSI membership. However, the pace of technology innovation is so high that other previously non-identified technical areas could rapidly appear and require further analysis.
- **Interdisciplinary:** Many of the trends are strongly interleaved and can partially overlap. This results in the necessity of a stronger coordination between the various ETSI technical groups that, today or tomorrow, could be involved in related standardization activities. The ETSI secretariat, the Board, and the OCG are in the best position to manage, whenever appropriate, the requisite coordination efforts.
- **Evolution not disruption:** Many of those trends are evolutionary technologies, therefore it is natural that many of them are already addressed by the current work of existing ETSI technical groups. The level of maturity, and indeed scope of these technology trends will certainly evolve in the coming years. Therefore, it is not just a matter for ETSI to address "the next big thing" in order to remain at the forefront of innovation, but ETSI must also adopt the right strategy to cope with the standard opportunities that could arise from these trends, finding the right balance between innovation, partnerships, and ETSI strengths in the industry with respect to other SDOs.

No matter which of the identified technology trends advances at the fastest rate, it is clear that in all of the identified domains ETSI can play a significant role and further develop its own role and activities in the forthcoming years.

1 Introduction

Over recent years, business and society have become increasingly digital, enabled by an ever-increasing number of applications on computers, smartphones and other telecommunication services. The arrival of innovative technologies in the domain of software defined networking, the virtualization of network functions, and the increasing demands for decoupled IT capabilities, such as cloud computing and storage, as well as major new network technologies, such as 5G, enable and enhance the users of ICT to not only evolve their business but also to develop new ones.

Information and Communications Technology (ICT) is an exciting and dynamic area that is in constant innovation, through the evolution of existing concepts and technologies but also through the emergence of disruptive technologies and even sometimes unexpected new use cases.

One of ETSI´s principle strategic directions as described in the ETSI Strategy [1] is "*to be at the heart of Digital*", expressing the clear intention for ETSI to be one of the leading organizations providing ICT standards for both present needs and also designing tomorrow's world by addressing the ICT needs for future services and applications.

The purpose of the ETSI Technology Radar (ETR) is to highlight probable technology trends for ICT that may impact ETSI's quest to remain at the forefront of ICT standardization. The ETR is also intended to promote the awareness and discussion of such technology trends among ETSI members and enable ETSI to create and evolve the tools and methodologies ("*being versatile*") that can leverage the Institute as the preferred collaboration hub for such developments ("*an enabler of standards*").

Therefore, the ETSI Technology Radar has the following objectives:

- Report the outcome of a thorough analysis that has considered publicly available technology reports, questionnaires and inputs from ETSI members on the major technology trends.
- Identify the major technology trends that could be of most concern/interest for ETSI.
- Contribute, for each selected technology trends, to the identification of eventual gaps with respect to current ETSI activities as documented in ETSI Work Programme [2] and promote future more detailed analysis at ETSI OCG and/or Board level on the eventual way forward for ETSI to fill the identified gaps.

Throughout the ETR document it is evident that ETSI is already involved in many of the identified trends, giving clear assurance that ETSI is already on the right track. Other trends are still emerging, and it is important to promote the discussion, check the requirements, and be ready to be at the forefront of these upcoming technology developments.

ETSI is a member-driven organization with a major strength being the highly diverse and knowledgeable membership, willing to come together and develop the standards that fulfil needs across all sectors of industry and society that make use of ICT.

The final decision for the take-up of some or all of these trends will come from members who voluntarily decide to further explore these new and evolving technologies. However, analysis and preparation is an essential step for success, and the ETSI Technology Radar is designed to help formulate ETSI's readiness to embrace innovation and also to allow our members to have their say in future work evolutions, and in doing so, help ETSI to shape the future.

2 Setting the scene

2.1 Socio-Techno-Economic-Political Trends (STEP)

This ETR document and the ETSI Strategy [1] are intended to be complementary and are aligned.

ETSI is member-driven and technology-focused. However, the members and the technologies exist in a global and European context of socio-political forces, economic changes, ageing populations, disruptive innovation, climatic changes, and also sudden challenges such as the COVID-19 pandemic. The digital transformation of industry and society offers new challenges and new solutions. The ETSI approach and strategy must continue to evolve accordingly.

Standardization for ICT plays an important role in the digital transformation to drive interoperable solutions and a productive business environment that enables exchange and stimulates innovation and competitiveness. Based on wide-consensus, standards provide an agreed technical basis and widely adopted technology platforms and are an enabler for a sustainable and securely connected society.

Societal and economic trends are in permanent fluctuation, and this has a strong influence on policy motivators, industry priorities and the subsequent technology developments.

The economics of digital technologies have the power to de-centralize and de-construct entire industries, requiring fundamental changes to their processes and work forces. Global Navigation Satellite Systems (GNSS) and mobile map applications enabled companies such as Uber and many other logistics solutions to flourish. 3D-CAD, additive manufacturing (3D-printing) and computer-controlled machining have allowed a physical separation between design and construction and also from assembly, not just for small simplistic objects such as plastic toys but also for customized consumer goods, circular-economy products and complex items such as ocean liners, space launchers and aircraft.

The social impact of ICT is gradually removing the concept and limitations of distance. Fifty years ago, people spoke of the global village, because anyone could hear news from anywhere. Today, we have the connected global village, where we can communicate with a majority of people on the planet and have cellular (e.g., 4G/5G) video call capabilities available for more than a quarter of the world population. IoT and enhanced-reality interactions will soon give the concept of "remote working" a whole new meaning. Such technologies also expand the possible impacts of hacking, for theft or disruption. Online collaborative efforts in science, authorship, creation of software, (self)education and the freelance economy are literally re-organizing our conditions of working and living. Even more in recent times, we have seen the value of ICT services when living under COVID-19 pandemic conditions with social distancing and confinement situations.

The economic impact of Artificial Intelligence (AI) and Machine Learning (ML) was previously easily underestimated. Today's AI is however almost decoupled from the “expert-guided recommendation systems” of the past and AI can now autonomously “learn-how-to-learn”, identifying patterns and rules in diverse digital information, from extremely complex systems, including totally novel ones. Applications in finance, optimization of processes, handling of legal information, collating of enterprise information, etc., are already big business.

The *digital revolution*, the *ICT evolution* and the new *AI computing process transformation* are like three overlapping waves that will reinforce each other, causing a technology swell in opportunities and also in the related risks. As these three technical trends move forward together, we need to ensure that the basic digital information is authenticated, accurate, compiled with respect for personal data and IPR, and secured. ICT systems need sufficient bandwidth availability to provide data in a timely way. AI systems must be robust against cybersecurity attacks and not influenced by bias, remaining ethical in all instances.

Alongside the three technical trends are other related technology trends such as *softwarization, cloudification and virtualization*. In turn they introduce aspects such as Open Software, Open Interfaces and Open Hardware.

All those involved in the ICT industry, particularly standardization practitioners and policy makers, need to actively consider and control the way these technologies are defined and eventually used, in order to ensure that fundamental human rights such as privacy, self-determination, freedom of thought and movement are not ignored or undermined. That role of human oversight is needed in every part of the global ecosystem, from service providers to manufacturers, to users and to government administrators, and fortunately the ICT evolution itself makes such oversight possible. The standardization process is capable of creating “security-by-design”, dynamic testing of "self-modifying" AI systems or of creating interoperable single-use quantum key distribution for privacy protection and cybersecurity in general.

How we *use* that control and oversight is a purely socio-political-economic question: do we care *enough* about climate change, do we care *enough* about creating circular economies with little waste and high energy efficiency, do we care *enough* about protecting our private information at the cost of additional layers of cybersecurity on the ICT infrastructures? Standards are enabling tools; it is people's values and social collaborations that should determine what is built and how it is used.

The global trends in policy directions react to the above socio-economic ones, but with "amplifying" influences due to strong human fears that the economic disruptions will ruin the economy, that economic or natural disasters in one part of the world will flood neighbouring countries with (economic) refugees, that the removal of the concept of distance means also the removal of (local) jobs, that digitalization may bring a perception of Big Brother control in the form of an AI dystopia. Politicians are reacting, not by trying to stop the trends, nor (usually) by piecemeal stopgaps, but by harnessing the trends, and developing "frameworks". A great advantage in Europe is that the political processes strongly favour collaboration and human values, resulting in a number of notable consensus frameworks.

Digitalization is linked with open data but also with security (EU Cybersecurity Act EU2019/881) and privacy regulations (GDPR EU2016/679). ICT and IoT should be linked with generic laws for machine safety and liability, as well as the Green Deal. AI is linked with requirements for ethics and explainability. Such frameworks establish a myriad of niches where people and business can flourish, with overall direction-setting achieved by regulations promoting e.g. the UN Sustainable Development Goals[1] and targets. Standards are a part of this policy and legal machinery: the EU New Legislative Framework (Regulation 1025/2012) and a number of EU government/industry consultative committees, all support the collaborative creation of interoperable standards that can be referenced wherever government organizations need transparency in procurement and reliability through multi-vendor support.

[1] https://sdgs.un.org/goals

2.2 Methodology for developing the ETSI Technology Radar

The ETSI Technology Radar aims to capture the main trends in the industry that may be relevant for ETSI in order to remain "*at the Heart of Digital*", fulfilling its vision of being at forefront of the standardization of new and existing digital technologies.

The ***initial*** ETSI Technology Radar (April 2021) was developed in three distinct phases:

Phase 1 focused on gathering global information on ICT technical trends, using two complementary approaches: top-down and bottom-up:

- The *top-down* approach consisted of analysing a significant number of publicly available reports on future technology trends.
- The *bottom-up* approach involved collecting information on future trends from the ETSI technical groups (TBs/ISGs) with the help of the OCG and the Board. Also, TB/ISG Chairs and Board members have replied to questionnaires prepared by the ETR editing team.

Phase 2 focused on analysing the information collected during Phase 1 to identify commonalities between the various reports and questionnaires and in doing so to highlight the ICT technical trends that are most relevant for ETSI. Once a wide list of technical trends was identified, a reduced number of ten priority technologies were selected, based on commonality with ICT technologies, expectation that fundamental research had already been successful and expected relevance to the ETSI membership. Finally, one topic was chosen to perform a deep analysis and make a test of the possible ETSI responses (in Phase 3).

Phase 3 focused on developing a methodology to promote the discussion and possible evolution of one technology trend within ETSI. Artificial Intelligence (AI) was agreed as the most relevant to be studied in depth, evaluating the landscape of AI related activities in ETSI, sharing knowledge and lessons learned and identifying possible directions on AI in ETSI. The results of this study can be found in the ETSI White Paper No. 34 [3] on impacts of AI in ETSI. Furthermore, a method of achieving coordinated action within ETSI is being trialled in the form of an ETSI sub-group on AI, created under the Operation Coordination Group (OCG).

Finally, the output of the ETSI Technology Radar was compiled into the initial edition of the ETR report, providing information on the methodology, the selected technical trends, and the identified gaps, challenges, and opportunities for ETSI. The various sources for the ETR are shown in Figure 2.

The ***revised*** ETSI Technology Radar (December 2023) was developed using the following methodology:

- A re-examination of the initial technology trends contained in the initial ETR (April 2021).
- Updates to the original trend titles and a re-actualization of the technology trend overview and status text.
- A thorough analysis of the most recent technology vision and framework documents, particularly the numerous global 6G vision papers published late 2022 / early 2023.
- Identification of any new technology trends that were not captured in the initial ETR (April 2021).
- Joint agreement in the ETR editing group on the addition of new technology trends that could be of most relevance for ETSI today and in the near future.

- For each of the selected new technology trends, the identification of affinities or eventual gaps with respect to current ETSI activities as documented in the ETSI Work Programme [2], the definition of a time frame of maturity for standardization, and a set of recommendations for future more detailed analysis at OCG and/or Board level on the eventual way forward to fill the identified gaps in a timely manner.

It is recommended to maintain the ETSI Technology Radar up to date using a recurrent process to detect new technical trends in order to keep ETSI in line with the latest technological developments.

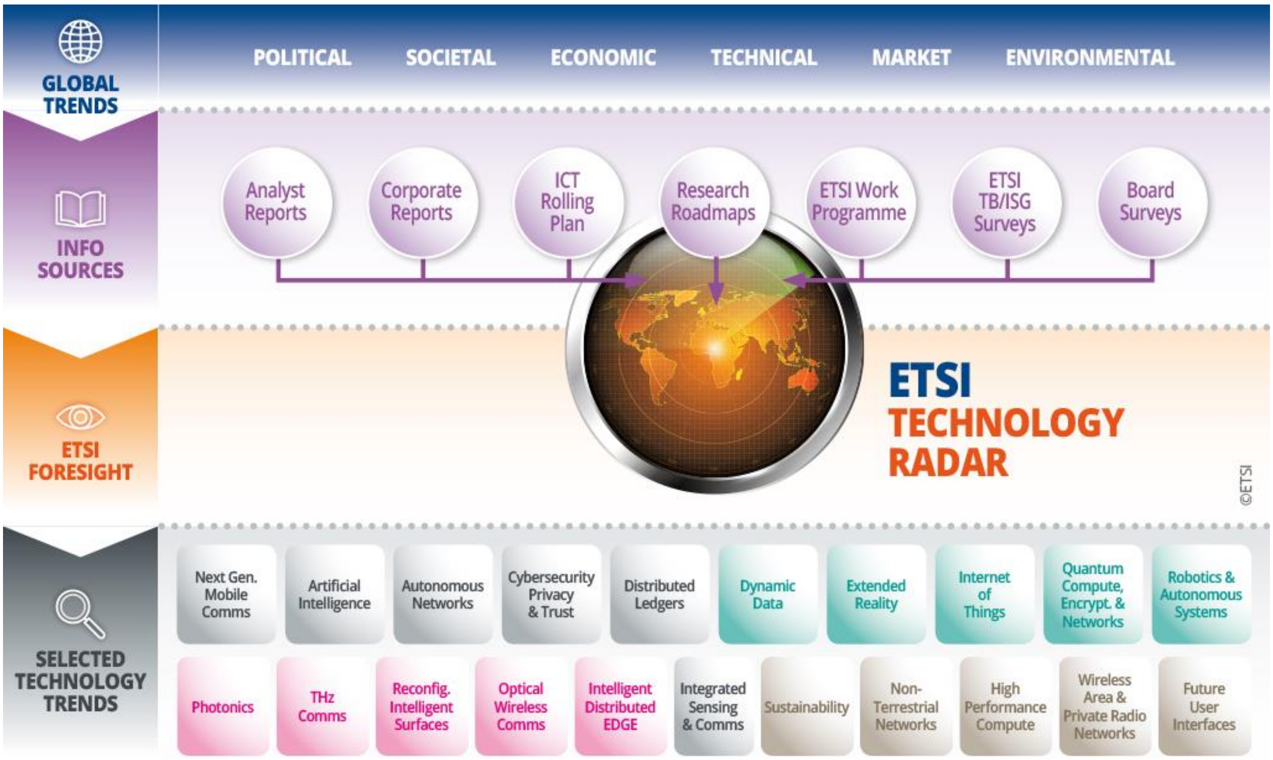

Figure 2: Sources used to build the ETSI Technology Radar

3 Major trends impacting ETSI

3.1 Selected technical trends

The ETR editing team selected several technology trends from the wider set of trends identified during the analysis of ETR inputs.
Figure 3 provides an overview of the selected trends that are further described in clause 3.2.

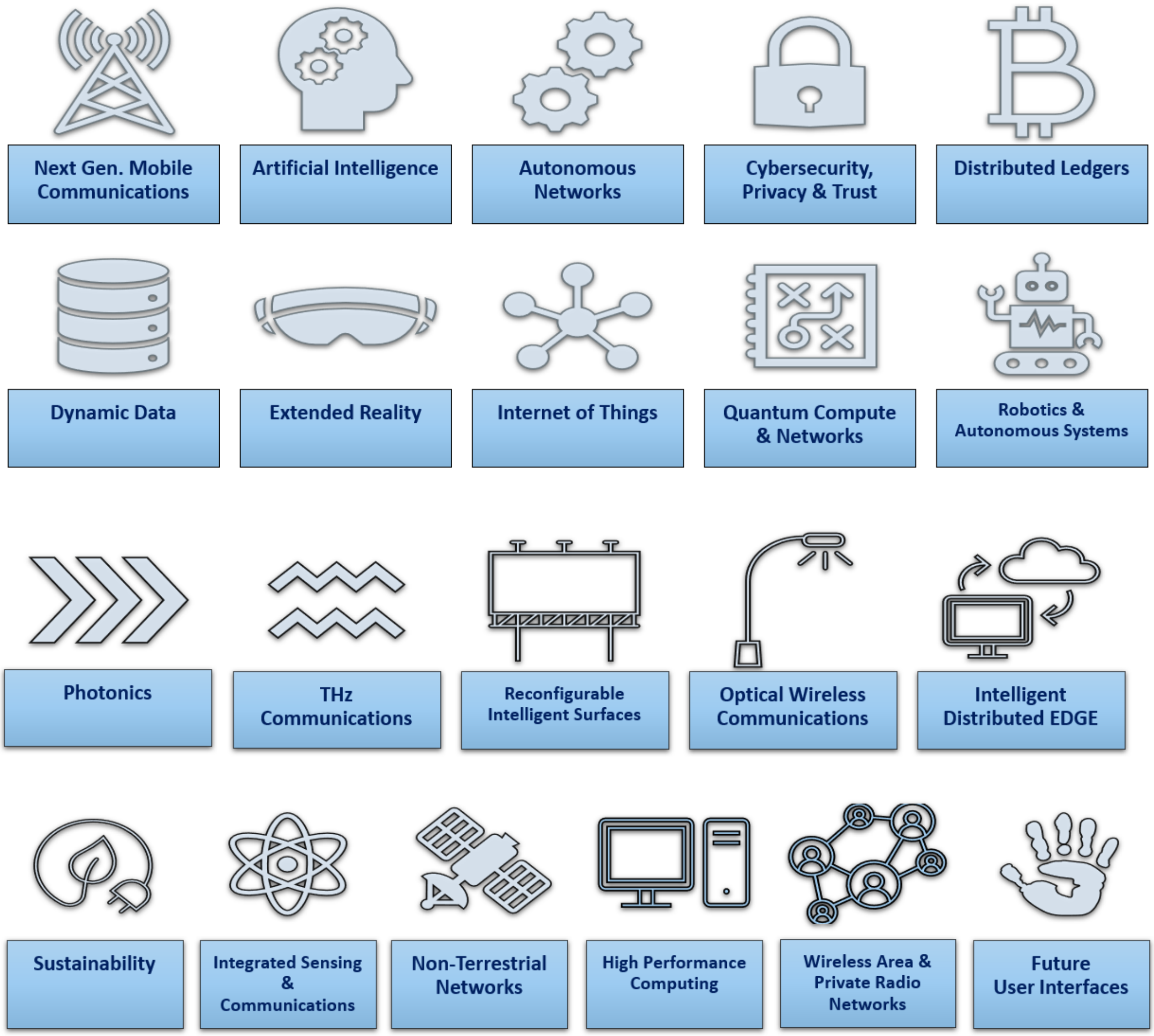

Figure 3: Overview of the selected technology trends

3.2 Analysis of technology trends

3.2.1 Next Generation Mobile Communication System

3.2.1.1 Description

The advanced next-generation mobile communication system will go far beyond the concept of simply wireless communications. It will serve as a distributed network that provides links with integrated communication, sensing, and computing capabilities that enable the connection of the physical, biological, and cyber worlds, ushering in an era of true Intelligence of Everything. Building upon 5G and 5G-Advanced, 6G will continue the transformation from connecting intelligent people with Internet of Things to truly connected intelligence (as illustrated in Figure 4). In essence, it aims to bring intelligence to every person, home, and business, leading to a new horizon of innovations and services to better serve humanity and the planet. The development of the next-generation mobile communications is driven by three important factors, i.e. new applications & new business, proliferation of intelligence and sustainability & social responsibility.

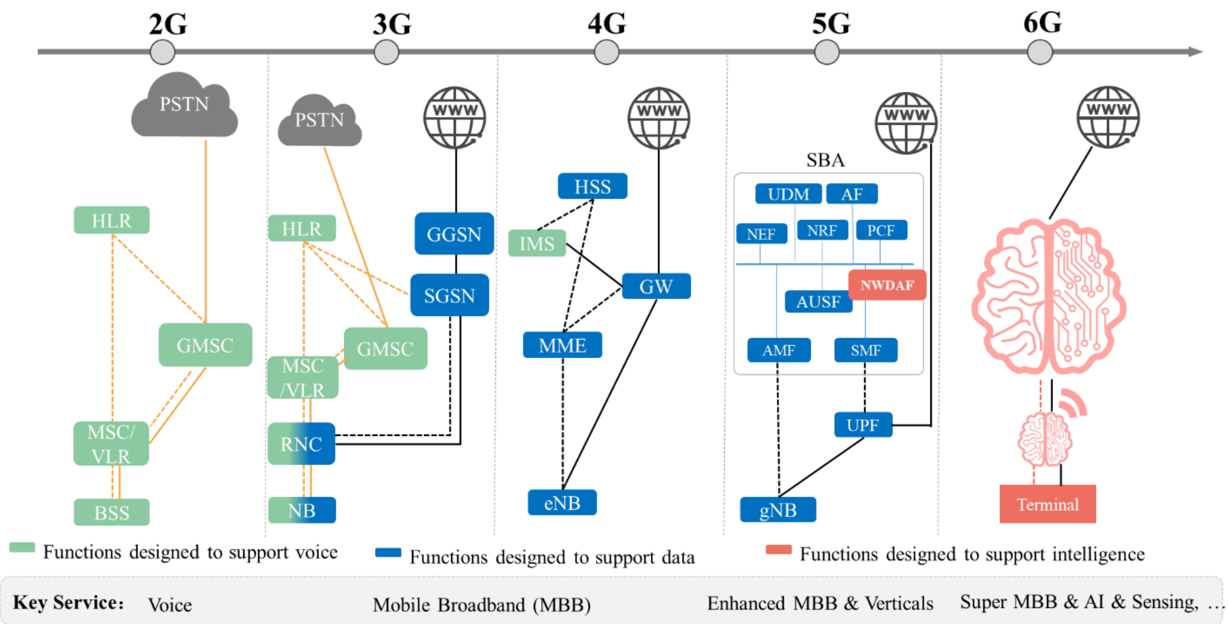

Figure 4: Mobile communication system evolution trend

ITU-R WP5D recently completed the Recommendation Framework for IMT-2030 (Global 6G Vision) [4] in June 2023, which is a fundamental milestone for 6G development. The fundamental usage scenarios and overarching aspects of IMT-2030 are shown in Figure 5, and these will further guide the relevant 6G enabling technology discussions. Based on the study of several global 6G visions and research projects [4], [5] and [6], a number of fundamental technology pillars have been identified that will shape the next-generation mobile communication system.

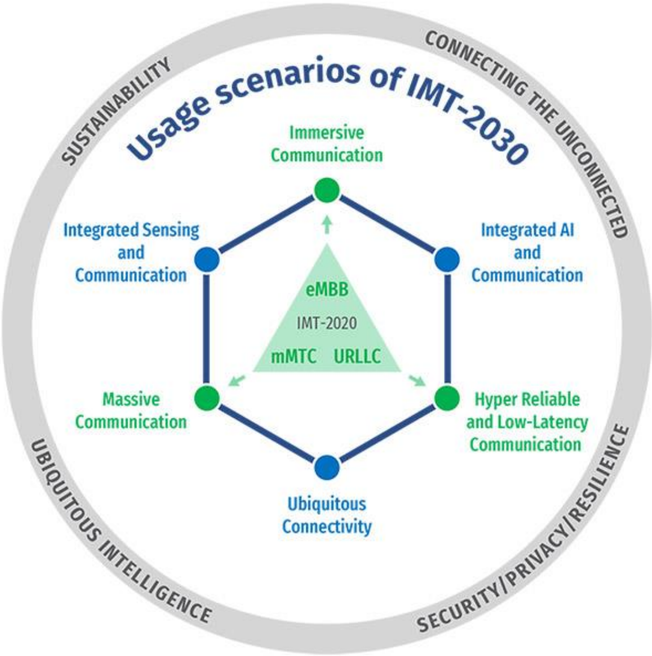

Figure 5: Usage scenarios and overarching aspects of IMT-2030 [4]

1) **Native AI (described further in clause 3.2.2)**

One of the primary objectives for 6G is to support AI everywhere. AI will be both a service and a native feature in the 6G communication system, and 6G will be an E2E system that supports AI-based services and applications. Specifically, 6G air interface and network designs will leverage E2E AI and ML to implement customized optimization and automated operation, administration, and management. This is known as "AI for Network". In addition, each 6G network element will natively integrate communication and computing capabilities, facilitating the evolution from centralized intelligence in the cloud to ubiquitous intelligence on the edge. This is the concept of "Network for AI", which indicates that 6G functions as a native intelligent architecture that integrates communication, information, and data technologies into wireless networks, serving all types of AI applications (for consumer purposes as well as industry purposes) with large-scale distributed training, real-time edge inference, and native data desensitization.

2) **Integrated Sensing and Communication (described further in clause 3.2.17)**

6G will feature the Integrated Sensing And Communication (ISAC) capability. Being different from conventional sensing as a standalone function, 6G can perform sensing upon mobile communication infrastructure. Therefore, it will significantly reduce the cost of additional sensing equipment and leverage the large-scale cooperation between widely deployed base stations and user devices for improved sensing performance. Higher frequency bands (from mmWave up to THz), wider bandwidth, and denser distribution of massive antenna arrays in future 6G systems will enable a single system to integrate wireless signal sensing and communication, each of which mutually enhance the other. The communication system as a whole can serve as a sensor, exploring radio wave transmission, reflection, and scattering in order to sense and better understand the physical world, ultimately providing a broad range of new services.

In terms of sensing, it enables high-accuracy localization, imaging, and environment reconstruction capabilities that could help improve communication performance — for example, more accurate beamforming, faster beam failure recovery, and less overhead to track the channel state information.

3) Extreme connectivity (see Wireless area and private networks evolution TREND in clause 3.2.20)

6G will provide universal high-performance wireless connections and ultimate experience with speeds comparable to optical fiber. Up to Tbit/s peak rate, 10–100 Gbit/s experienced rate, sub-millisecond level latency, a tenfold increase in the density of 5G connections, centimeter level localization, millimeter-level imaging, and E2E system reliability based on controllable error distribution will not only enable human-centric immersive services in the future, but also accelerate full-scale digital transformation and productivity upgrade of vertical industries.

Extreme connection density is also an expected scenario in 5G and 6G private networks (see clause 3.2.20).

4) Integrated NTN (described further in clause 3.2.18)

6G will integrate terrestrial networks and Non-Terrestrial Networks (NTNs) to deliver complete coverage worldwide, improving rural coverage and connecting the unconnected. As the cost to manufacture and launch satellites decreases, huge fleets of low- or very low-earth orbit (LEO/VLEO) satellites will become reality in NTNs — it is a strong possibility that 6G will integrate VLEO satellite mega constellations. A VLEO satellite system, in addition to delivering worldwide coverage, offers a number of new capabilities and advantages. For example, it eliminates the issue with communication latency inherent in conventional Geostationary Earth Orbit (GEO) and Medium Earth Orbit (MEO) satellite systems. It can also provide coverage to areas uncovered by terrestrial networks, offering complementary radio access. VLEO satellite systems can also provide more accurate positioning, which is critical for autonomous driving and important for earth sensing and imaging. In addition to satellite communications, new radio nodes such as drones, Unmanned Aerial Vehicles (UAVs), and High Altitude Platform Stations (HAPS) will be an integral part of 6G, functioning as either mobile terminals or temporary infrastructure nodes.

5) Native Trustworthiness (described further in clause 3.2.4)

The 6G network will integrate various capabilities such as communication, sensing, computing, and intelligence, making it necessary to redefine the network architecture. The novel network architecture should be capable of being flexibly adapted for tasks such as collaborative sensing and distributed learning to proliferate AI applications on a large scale, where trustworthiness should be guaranteed as a native feature. The concept of "trustworthiness" here covers topics including security, privacy, resilience, safety, and reliability.

6) **Sustainability (described further in clause 3.2.16)**

Green and sustainable development is the core requirement and ultimate goal of network and terminal designs in 6G. By introducing the green design concept and native AI capability, 6G aims to improve the overall energy efficiency (defined in bits per Joule) 100-fold across the network and keep the total energy consumption (in unit of Joules) lower than 5G while also ensuring optimal service performance and experience.

Sustainability factors (including power efficiency and low carbon-footprint, etc.) are relevant for the entire lifecycle of 6G, including infrastructure deployment for terrestrial and non-terrestrial networks. As the core infrastructure of the digital economy, 6G will have to make unique contributions to the sustainable development of humankind.

The deployment and operation of 6G networks should be realized in a way that does not create additional health and well-being concerns for humans and other living creatures. It is therefore necessary to investigate potential health risks created by e.g., denser base station networks or the deployment of repeater stations for NTN uplink connections.

Many of the enabling technologies discussed above are already under investigation at European level, for instance, the European Smart Networks and Services Joint Undertaking (SNS JU) has funded 19 phase I projects to foster 6G technology advancement in Europe [7], [8] that cover a wide range of 6G enabling technologies. The phase II project proposals are under review, which would be expected to be launched in the early part of 2024.

3.2.1.2 *Affinity with ETSI Work*

The affinity of ETSI work with 6G may be seen from different perspectives:

- Many ongoing ETSI ISGs are highly relevant to 6G discussion. For instance, ETSI THz ISG, RIS ISG, PDL ISG all have relevant technical work related to both 5G and the evolution towards 6G, which may further impact the 6G activities to be launched by 3GPP.
- ETSI has also established an extensive network of partnerships in 6G-related areas, including other SDOs, industry fora, research projects / platforms and academia.

3.2.1.3 *Time Frame*

The 3GPP 6G work plan is expected to begin at the end of 2025 (e.g. Release 20). Therefore, it is essential for ETSI to accumulate sufficient knowledge in order to generate impact and shape the standardization work in 3GPP in the next 3 to 5 years in mid-term and 5-10 years in long-term.

3.2.1.4 *Recommendations*

6G shall become an essential pillar in ETSI activities. Therefore the recommendation is to ***Investigate, Promote*** **and** ***Adopt***. In this area, the most appropriate recipient for ETSI work strongly remains 3GPP.

ETSI could act as the bridge between (pre-standardization) research and standardization activities. The existing 6G-related ISGs established in ETSI are expected to work on such pre-standardization related activities as well as aggregate the technical output especially from EC funded or national funded 6G projects. Moreover, ETSI should actively collaborate with relevant 6G related industry platforms, organizations and associations, and help to promote technical consensus and one global 6G standard in the near future.

3.2.2 Artificial Intelligence

3.2.2.1 Description

This document considers AI to be a means to derive insights automatically from data, based on an evolving set of statistical learning methods. Learning is the method used by the AI system to extract knowledge from the training data. An AI system that is trained and has learning in a particular task (such as image recognition, eHealth, networking, and resource management, IoT, robotics, etc.) may continue to adapt with further online learning. It may also be given offline learning to refresh its awareness (re-training) of the situation. Recent progress in Large Language Models and Foundational AI Models, often available as open source software has greatly expanded applications. The resultant activity is only as good as the quality of the data used to train the AI system.

The EU is investing heavily in AI research and development as shown in the EU coordinated plan of December 2018 [9], the EC review in 2021 of that plan and the European investment recommendations on Artificial Intelligence [10], including billions of Euros allocated in the Digital Europe Programme [11]. This is due to protecting citizen safety, e.g. issue of liability, see [12] and [13] as well as potential economic gains, e.g. see OECD reports on AI investments [14] and on AI patents [15]). A JRC report estimated that the EU invested around 13-16 billion Euro in AI during 2020 and every budget brings additions[2].

3.2.2.2 Affinity with ETSI Work

Many areas related to networks can benefit from AI, such as in the emerging paradigm of Autonomic Networks (also known as Self-Adaptive Networks or Smart Networks or Autonomous Networks in the literature) that is discussed in clause 3.2.3. The ETSI community has a strong interest in AI as a “tool”: in architectural models, to enhance information/data models, to redesign operational processes, to increase solution interoperability, and for data management for new ICT standards (see clause 3.2.1). At the same time, the ethical and security issues of AI are being considered in ISG SAI (now TC SAI) and TC eHEALTH. The advances in AI Large Language Models (LLM) have a particularly broad impact on health technologies.

In 3GPP 5G specifications, AI is broadly referenced in the two main areas of Core Network capabilities (5G NG Core) and Radio Access Network (5G RAN). In both areas, AI plays the role of an ancillary layer that can increase 5G network automation and effective management and orchestration. AI has become an additional function in the management of RAN and the evolution towards the model of a Self Organizing Network (SON). To deliver their full potential, AI-powered mechanisms rely on fast access to data, abstraction of contextual information from events and rule-based systems, supervision, streamlined workflows and lifecycle management.

ISG Zero-touch network and Service Management (ZSM), was formed with the goal to introduce a new end-to-end architecture and related solutions that will enable automation at scale and at the required minimal Total Cost of Ownership (TCO), as well as to foster a larger utilization of AI technologies. Recent specifications apply to Intent-Driven Autonomous Networks and AI Enablers.

[2] See https://digital-strategy.ec.europa.eu/en/activities/digital-technologies-and-research for news in 2023

In related work, ISG Experiential Networked Intelligence (ENI) designs data collection and processing using closed loop decision-making.

The ENI requirements document ETSI GR ENI 007 [16] on network classification of AI details the use of AI in a network into six stages, from "No AI" to "full AI" deployment. The specification ETSI GS ENI 019 [17] defines a model for representing, inferring, and proving knowledge in autonomous networks. The group TC INT testing specifications consider events that can trigger a network to dynamically change network properties, depending on the specific AI systems deployed in the network and the level where they operate, external or internal to the network.

ISG F5G addresses the application of AI in several of its Use Cases (all available in ETSI GR F5G 008 [52]), and in the Architecture documents for OAM solutions, for which ZSM framework is a reference (e.g. ETSI GS ZSM 002). In particular, it is considered by ISG F5G very important to exploit AI features for managing the resources in the Access Network, including to allow the optimisation of their use based on the customer’s request and the SLA profiles. AI has been applied in some F5G PoCs. Alignment with ISG ENI and TC SAI work is also fundamental.

A Generic Test Framework for testing AI models/systems during their lifecycles (see ETSI EG 203 341 [18]) has been developed in ETSI TC INT to identify different types of test systems that could be employed to the problem space of testing AI Models: from those applied in phased testing starting at design time, up to those at the point when a network consisting of trusted and certified AI Models is tested as a whole (for integration and user acceptance testing).

Applications running on top of networks, collecting data and controlling real-world things, are at the heart of AI use cases for consumers and businesses. These aspects – handled by groups such as SmartM2M, ISG CIM, and oneM2M – are described in the clause on Dynamic Data.

Many other groups are considering or working on AI topics, as indicated in Table 1 below from the ETSI White Paper No. 34 [3].

Table 1: Mapping of AI Standardization Activities within ETSI (Ref White Paper No. 34 [3])

◔ = considering ◑ = started ◕ = strong	3GPP	EP eHEALTH	ISG ARF	ISG CIM	ISG ENI	ISG MEC	ISG NFV	ISG / TC SAI	ISG ZSM	oneM2M	SC EMTEL	TC CYBER	TC INT AFI WG	TC SmartM2M	TC MTS	ISG F5G
Terminology					strong			strong	strong	considering			strong	considering	strong	
Use cases	considering	considering		considering	strong	started	started	started	strong	considering	considering		strong	considering	strong	started
Impact of EU ethics guidelines		strong						started		considering				considering	considering	
Trustworthiness & Explainability		started						started	considering	considering				started	considering	
Security/privacy		strong		considering	considering			started	strong	considering		strong	considering	considering	considering	started
Architectures and RPs			considering		strong	started	started	started	strong	considering			strong	strong	considering	started
Management of AIs					considering			started	strong	considering			strong	started		
Dataset requirements and quality		strong		started	strong		started	started	considering	considering			started	started	considering	considering
Interoperability		started			strong		started	started	strong	considering			strong	started	strong	started
Test methodology and systems					considering		strong	started					strong		strong	
KPIs and conformance					considering						considering		considering		considering	
System maturity assessment			considering		considering								considering		strong	

A key issue for ETSI is the consideration of ethics for AI: the EC High Level Expert Group Guidelines for a trustworthy AI [19] and related guidelines, are by nature difficult to encode in specifications, implement in solutions or verify in practice. This could become a financial burden for society and ETSI members, especially for SMEs, and especially when compliance to those criteria becomes part of the requirements in public/private procurement. Such work in ETSI is ongoing mainly within the scope of EP eHealth and ISG (now TC) Securing Artificial Intelligence (SAI). The draft EU AI ACT will mandate a large body of standardization, with the initial resulting EC Standardization Request for targeted specifications being handled by CEN/CENELEC JTC21 with consultation from ETSI.

3.2.2.3 Time Frame

From the example of many different aspects of AI being considered in ETSI, it is clear that this technical trend is already strongly impacting ETSI's work. The use cases are so broad, and the consequences for security and for reliability are so deep, that the work is expected to continue for about two more years in the initial phase, i.e. for the obvious elements. The consideration of the *consequences* of introducing AI so broadly throughout so many ICT systems will require longer consideration.

3.2.2.4 Recommendations

Artificial Intelligence is a game changer that brings several challenges both to the ICT industry and to society in general. The use of AI as a tool needs to deal with interoperability issues, new concepts for testing and validation, and ensuring that ethical guidelines are embedded in order to guarantee a trustworthy Artificial Intelligence that "first, does no harm".

In order to understand the standardization requirements, and create appropriate and relevant standards, ETSI needs to develop:

- a complete mapping in ETSI of "AI as a tool"
- a co-ordinated approach to AI, including collaboration with CEN/CENELEC and ISO/IEC
- an evaluation of the technical impact of the EU ethical guidelines on ETSI standardization
- AI Interoperability and Interchangeability standards (models, trained neural networks, etc.)
- guidelines for AI Testing and Validation
- dataset and quality requirements for Artificial Intelligence (training and real-time)

All of these steps can only be done through cooperation and collaboration both inside ETSI's technical groups and also with several external bodies and SDOs.

3.2.3 Autonomous Networks

3.2.3.1 Description

Technology acceleration and evolution has now reached a point where a revolutionary approach is required in the way networks and services are provisioned and managed, leading to the introduction of a new level of automation and intelligence.

Existing networks are made up of a complex set of heterogeneous devices that must be integrated to provide seamless end-to-end services. Until very recently, the planning, implementation and management of this mix of services have been a largely manual activity with some automated assistance. It must be recognized that these services can no longer be managed using such legacy approaches. The new requirements need a transformation supported by the integration of new technologies, such as virtualization, future cellular technologies, digital twin and Artificial Intelligence that together provide scalable mechanisms for managing ever increasing complexity. Digital Twin technology enables the creation of a network model, important for the automation of the whole lifecycle of the infrastructure and of the service creation. AI allows to reduce the number of protocols levels within multiple scenarios. In Data Centre Networks, Internet Protocol (IP) is the only sensible choice to connect data storage and applications. This enables cost and power saving in both realization and operation, as well as the increase of the automation capabilities.

New business models and value creation opportunities enabled by technology breakthroughs such as Network Slicing impose unprecedented operational agility and higher cooperation across network domains. Currently there are multiple inconsistent management frameworks in the industry, many silos, a lack of alignment and a lack of interoperability. It is essential to move to an environment that leverages synergies and achieves alignment through convergence on a single end-to-end network and service management architecture.

Autonomous Networks are considered one of the most important evolutions in order to enable the Digital Transformation of the Industry where ICT and Artificial Intelligence play a major role across several Vertical applications, offering new service opportunities and significant cost saving in network operation.

An **Autonomous Network** is a network that self operates according to the business goals with no human intervention beyond the initial supply of input (e.g., intent, goals, policies, certain configuration data) by human operators. It is capable of self-management operations (e.g., self-configuration, self-diagnosis, self-repair, self-healing, self-optimization, self-protection) of its resources, functions/applications and services. Its self-management operations are enabled by, among other things, a capability to auto-discover operational information and act on it.

An autonomous network can be considered as a network exhibiting the following properties:

- Automatic – the ability to self-control the internal resources and operations, as well as to bootstrap and operate without manual intervention.
- Aware – the ability to monitor its operational context, performance and internal states to assess if its current operation serves defined and agreed goals.
- Adaptive – the ability to change its operations to cope with temporal and spatial changes in operational context on short and long terms. In other words, the ability to adapt its behaviour by changing its decisions in order to maintain agreed operational delivery values.

The level of autonomy may vary, ranging from some low levels of automation capabilities to fully matured autonomous capabilities. The objective of Autonomous Networks is to provide a wide variety of autonomous services, infrastructure and capabilities with “Zero-X” (zero wait, zero touch, zero trouble) experience based on fully automated lifecycle operations of “Self-X” (self-serving, self-fulfilling, self-assuring) to dynamically accommodate and adapt to customer needs and available resources.

An autonomous network may be recursively composed of other autonomous networks, and it is responsible for the necessary interaction with and between them.

There are various models in the industry of Autonomous Networks. Figure 6 provides an example of a high-level illustration of the capabilities provided by an Autonomous Network connected with external entities via dedicated interfaces and the related common enablers (from ETSI White paper No. 56 [20]).

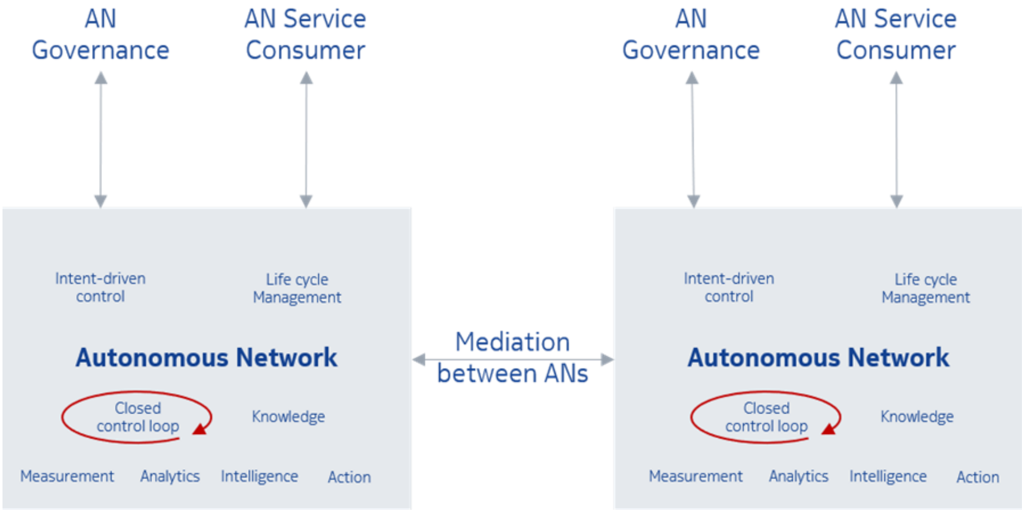

Figure 6: High-level illustration of Autonomous Network enablers and external interfaces

3.2.3.2 Affinity with ETSI Work

Autonomous Networks are achieving momentum in Standards and ICT Industry. ETSI is already playing a role in AN standardization with many ISGs contributing to AN and plans to increasingly invest in the Autonomous Networks challenge (as documented in ETSI White Paper No. 40 on Autonomous Networks [21] and ETSI White paper No. 56 [20]).

Because Autonomous Networks are an end-to-end solution in ETSI, several ISGs and TCs are contributing to produce architectures, recommendations and case studies, depending on ISG/TC purposes and expertise. In order to facilitate coordination and knowledge-sharing among the ISG/TC contributing to AN and to represent ETSI effort on this strategic trend with other Fora and Alliances, an Operational Co-ordination Group on Autonomous Networks (OCG AN), was created. AN OCG Whitepaper No. 56 [20] was recently delivered to report and present a comprehensive and synthetic view of AN main achievements in ETSI. Table 2 reports ISG/TC focus and progress, categorized by activities and enabling technologies.

Table 2: Autonomous Networks activities in various ETSI technical bodies

	AN topics / ETSI Groups	**TC INT AFI WG**	**ISG ENI**	**ISG ZSM**	**ISG F5G**	**ISG MEC**	**ISG NFV**	**ISG IPE**	**ISG/TC SAI**	**TC MTS**
1	Terms & definitions	●	◕	○			○		○	
2	Use cases & requirements	●	◕	●	◕	○	●	●		
3	Architecture / framework	●	◕	●	◕	◔	◔	◕	◑	●

	AN topics / ETSI Groups	TC INT AFI WG	ISG ENI	ISG ZSM	ISG F5G	ISG MEC	ISG NFV	ISG IPE	ISG/TC SAI	TC MTS
4	Levels of autonomy/autono-micity	●	●	○	◔					
5	Cognition	●	◕	◔			◔			
6	Self-X properties	◕	◔	◔			◔	◑		
7	Governance interface	●	◕	◔	◔		○			
8	Intent-driven management	◕	◔	◔	◔		◔	○		
9	Policy Control Management Framework(s)	●	◕	○			●			
10	AN services, functions and resources Life-cycle management	◑	○		○	◔	◑			
11	Closed control loop automation	●	◕	◑			◔	◑		
12	Analytics and intelligence (including AI topics)	◕	◕	◔	○		◔	◕	◔	
13	Knowledge representation (e.g. information models & Ontologies) & management	◑	◔	○			○			
14	ANs federation and Inter-AN coordination	◕		◑	◔	◔	○	◑	◔	
15	APIs and data models	◑	◑	◔	◔		○			
16	Robustness, trustworthiness, traceability	◑		◔			○		◑	

	AN topics / ETSI Groups	TC INT AFI WG	ISG ENI	ISG ZSM	ISG F5G	ISG MEC	ISG NFV	ISG IPE	ISG/TC SAI	TC MTS
17	Security/privacy	◑	○	◕	○	○	○		●	●
18	Testing framework and methodology	◑	○	○			○		◑	●
19	Metrics and KPIs	◕	◕		○		○			◑
20	PoCs	●	◕	◔	○		○	◔	◔	

Table 2 clearly shows that some ISG/TC are more focused on Autonomous Networks (ISG ZSM, ISG ENI, TC INT/AFI) whereas others are very specific to the Autonomous Network evolution and the domain of network/service investigation (F5G on optical F5G fixed-access, MEC on Multi-access Edge Computing, NFV on Network Management Domain and Virtualized Infrastructure, SAI on Security for AI, MTS on testing, IPE in transmission and IPv6 networks).

ISG Zero-touch network and Service Management (ZSM) is working on the definition of a new, future-proof, horizontal and vertical end-to-end operable framework and solutions to enable agile, efficient and qualitative management and automation of emerging and future networks and services. Horizontal end-to-end refers to cross-domain and cross-technology aspects. Vertical end-to-end refers to cross-layer aspects, from the resource-oriented up to the customer-oriented layers. The goal is to have all operational processes and tasks (e.g., delivery, deployment, configuration, assurance, and optimization) executed automatically, ideally with 100% automation.

ISG Experiential Networked Intelligence (ENI) is defining a cognitive network management architecture to adjust offered services based on user needs, environmental conditions and business goals. Therefore, 5G networks will benefit from automated service provisioning, operation, and assurance. The use of Artificial Intelligence techniques in the network will solve problems of future network deployment and operation.

ENI focuses on improving the operator experience, using closed-loop AI mechanisms and metadata-driven policies to recognize and incorporate new knowledge. This model gives recommendations to decision-making systems.

TC INT AFI WG (Autonomic Management and Control Intelligence for Self-managed Fixed-Mobile Integrated Networks) produced the Generic Autonomic Network Architecture (GANA) framework, scenarios, use cases and requirements for autonomic/self-managing future Internet. Its focuses are the landscape for Autonomic cognitive Management and Control (AMC) – reference model, GANA implementation guide and instantiations reports for various environments/architectures – and testing and trust reports for AN.

3.2.3.3 Time Frame

The technical trend on Autonomous Networks is currently accelerating with the complexity of network and the need for end-to-end solution. Full end-to-end automation of network and service management becomes an urgent necessity.

In terms of industrial exploitation, the time-frame to have fully Autonomous Networks (Level 5) should be around 3-5 year, according to major experts. This means that an SDO should move fast to transform recommendations and scenarios in Standards. A progressive introduction of Autonomy (Level 3-4) is going to start in most advanced Telecom Operators. Many experts consider Autonomous Networks a key issue for 6G.

However, the development toward a domain-wide Autonomous Network is by necessity a long term goal and requires significant effort with step-by-step evolution to push the entire industry to have a common understanding and consensus on:

- Definition of Autonomous Networks concept, framework, Autonomous Networks Levels and key capabilities.
- Development of key mechanisms, interfaces and corresponding metrics to measure the maturity of Autonomous Networks Level.
- Demonstration of valuable use case scenarios and best practices across the industries among CSPs, solution providers and customers.

Autonomous Networks open business opportunities both in terms of launch of new services and cost optimization. Significant innovation opportunities beside the current work include:

- Network Digital Twin (NDT)
- Impact of NDT on AN evolution
- Digital Twin for supporting decision making for service and network provisioning
- 6G & Autonomous Networks
- Marketplace for Autonomous Network APIs, identifying the environment required to make them available and defining the rules for the API development and exchange

3.2.3.4 Recommendations

Significant effort and relevant initiatives are active across the industry ecosystem on Autonomous Networks and in general on Network Automation. This outlines the business interest and technological value of Autonomous Networks across the industry. Major standard and industry fora (e.g. ETSI, IETF, ITU, TMForum, GSMA, NGMN, etc.), Multi-partnership project for interoperable standards (3GPP) and open-source communities (e.g. ONAP, etc.) are delivering recommendations, preliminary standards, deliverables and APIs.

Industry cooperation and coordination are essential for harmonization, widespread interoperability, and consistent behaviour, across a multi-vendor ecosystem. This cooperation softly started with the M-SDO Autonomous Networks (AN) Table, supported by TMForum. This AN M-SDO Table that includes the main projects on AN across the mentioned fora and Open Source (ETSI, ITU-T, IETF, GSMA, 3GPP, Linux Foundation, etc.) organized on-line workshops to share results and present ideas, architectures, solutions. Initiatives like this represent a good starting point to improve and launch a stronger coordination, where ETSI can play a significant role. Most of the areas require studies and a coordinated commitment in the industry.

The massive activities and deliverables around Autonomous Networks clearly indicate the hype role of AN in Digital Transformation in the extended ecosystem. This means that Autonomous Networks has reached momentum in terms of business interest. There is unfortunately a potential risk of fragmentation in the related recommendations and standards that could lead to a lack of convergence and potential wasted resource. In order to avoid these risks it is essential to find coordination inside ETSI TC/ISGs and to extend collaboration and knowledge exchange among leading SDOs/Fora.

Within ETSI, further cooperation between individual groups should be sought, as it has been done in the past, for example, for the joint development of standardization documents. Cooperation enables a reaction to new and changed requirements for own products and services during their production or design. In addition, from the point of view of the actors involved, requirements for products and innovations for conformity assessment processes, especially tests, can be influenced in their own favour in the course of joint cooperation. OCG AN can play a role to facilitate cooperation inside ETSI TC/ISG and can progress with workshops on dedicated items and coordinated meetings.

In general, cooperation among different organizations should be envisaged and encouraged. This information sharing and knowledge exchange started thanks to the mentioned AN M-SDO Table, promoted by TMForum and the first bilateral meetings between working groups from different SDOs.

It is recommended that ETSI continues in its leading technical role on AN standardization with particular attention to the new AN enablers (AI/ML, Network Digital Twin, API evolution, etc.), contributes and leads co-operation initiatives to facilitate the adoption of common standards and avoid market fragmentation.

Being proactive in these initiatives is a way to promote ETSI results on AN, to contribute to the success of Autonomous Networks and to facilitate recommendations and standards convergence in the European Union and worldwide.

3.2.4 Cybersecurity, Privacy and Trust

3.2.4.1 Description

Strong cybersecurity, privacy and trust are key features of communications technologies, services, and architectures. While new technologies and new use cases for established technologies contribute to an ever-increasing security threat landscape, the fundamental need for strong cybersecurity and underlying requirements remains broadly unchanged. Innovative approaches and solutions that address new and emerging threats need to be combined with more traditional solutions to provide fully integrated vertical security across all layers of virtualized networks and services.

Due to the development of the Internet of Things (IoT) and the rise of Artificial Intelligence (AI), the world has never been more connected or data-driven than it is today. These developments and the corresponding dependency on very large amounts of quality data and reliable connectivity have become critical to our everyday lives, for businesses and individuals. Other related topics such as the need for security, privacy, and trust have also been recognized as being absolutely essential for the safe and trustworthy deployment of digitized networks and services. Our growing dependence on networked digital systems and software brings an increase in the variety and scale of threats and cyber-attacks.

Cyber security, privacy and trust are large encompassing topics that are advancing and evolving in five main directions:

1) **More:** The trend continues towards more of everything. 5G, increasing broadband speeds and cheap scalable compute power, fuel the creation of new services especially around private 5G and edge computing. This development and the increasing use of AI technologies further drives the volumes of privacy and security sensitive data being generated. Combined with an increasing reliance of Critical National Infrastructure (CNI) on communications networks and services, this provides attackers with an ever-increasing range of attractive targets. Defenders (and as a consequence underlying security standards) need to adapt to address these challenges, with an increased focus on detection and security agility. This need for agility and strong cybersecurity continues to drive approaches such as Zero Trust.

2) **Fewer:** Another continuing trend is the shift to fewer, more powerful entities in the technology space. Purposefully driving centralization certainly ensures that solutions can be deployed but may shut out competitors, leading to a more fragile and potentially anti-competitive ecosystem This is also ultimately bad for security, privacy, and trust:

    - worse resilience and over-reliance on a few entities,
    - data concentrated in the same companies,
    - more attractive targets for potential attackers,
    - little to no choice for users, resulting in worse trust.

    This is both a market and a technical concern. Necessary IPRs owned by a few powerful entities may be used as barriers against new market entrants. Additionally, closed non-transparent eco-systems do not benefit from review by independent security researchers who would otherwise expose potential security vulnerabilities at an earlier stage leading to stronger cybersecurity across the industry.

3) **Shifts:** A move to the edge, leveraging of AI or automation and replacement of closed private networks with public communications technologies (e.g., Private 5G), continue to be significant disruptors from a security perspective. While a move to the edge does not automatically lead to significantly increased threats, the distributed and localised nature of edge technologies increases the risk of compromise due to an increase in assets to be secured and in the number of points of access. The use of private 5G by critical industries and connection of legacy industrial systems (especially those based on legacy niche proprietary protocols) that were not originally designed for use on modern communications networks, require an increased focus on isolation and trust establishment.

    Network and Service automation through AI continues to be a double-edged sword from a security perspective. While security of AI systems or processes introduces new threats and attacks, these can be managed if techniques such as Threat Vulnerability Risk Analysis (TVRA) are adequately applied. However, the use of AI technologies for both cybersecurity and attack and defence purposes is an increasing challenge.

4) **Regulation and Certification:** Privacy and cybersecurity regulations are increasing. In EU, GDPR underpinning fundamental rights to data protection is being supplemented by cybersecurity specific regulations such as EU Cybersecurity Act (CSA) and pending EU Cyber Resilience Act (CRA). While there are common cybersecurity objectives in many regional or national cybersecurity regulations, there is increasing fragmentation and lack of cross jurisdiction recognition which increases cost and reduces agility, especially where regulations require localised certification of products for specific markets. In addition, many regulations result in contradicting security requirements (e.g., user rights vs mandatory security patching), with industry and standards bodies left to interpret a balance on a case-by-case basis.

   Additionally, speed of technology change and innovation continues to outstrip regulation. SDOs and industry are therefore increasingly required to estimate the likely impact of subsequent regulation applied to technologies that are already in the field. It is critical that SDOs and industry leverage standards to ensure that a human rights-driven "opt in” rather than “opt out” approach to data collection and processing is applied to new technologies.

5) **Co-ordinated security:** The increasing use of open source, increasing complexity of system and services, along with increased availability of low-cost attack tools means that co-ordinated collaboration between service providers, researchers and manufacturers is critical. Real-time standardized sharing of knowledge about threats through Information Sharing Analysis Centres (ISACs) and co-ordinated management of vulnerabilities through Co-ordinated Vulnerability Disclosure (CVD) schemes are key components in reducing the spread of attacks and handling zero-day vulnerabilities as they are identified. All technology eco-system entities need a CVD scheme.

   While high profile narrow focus attacks on government or industry systems often grab headlines, basic expanding volumetric fraud, phishing and ransomware continue to demonstrate the human element in security. Usability, operational resilience and security of products are always a trade-off and attackers are increasingly innovative in tricking users to expose themselves to fraud. Therefore, industry needs to place an increased focus on combined fraud prevention and cybersecurity approaches.

Standards have a key role to play in improving cybersecurity across a range of use cases.

3.2.4.2 Affinity with ETSI Work

ETSI has many groups that support work on these topics. TC CYBER focuses on breadth: creating security, privacy and trust standards that impact a wide range of use cases. For example, it has produced world leading standards on IoT security (such as ETSI EN 303 645), data protection and privacy, network security, mobile device security, attribute/identity-based cryptography and quantum-safe cryptography; each of these standards apply to a variety of sectors, products, use cases and user groups.

Other ETSI groups focus on:

- Securing specific technologies and systems such as mobile / wireless systems (5G, TETRA, DECT, RRS, RFID), IoT systems, network functions virtualization, intelligent transports, e-health, mobile edge, artificial intelligence; or
- Specific security tools and techniques such as lawful interception & retained data, digital signatures & trust services, permissioned distributed ledgers, smart cards / secure elements and certification.

The numerous ETSI groups dealing with cybersecurity, privacy and trust continuously adapt their work programme to address the new challenges brought up by the all connected, data-driven digital society.

ETSI through its historical creation of GSM standards, is also the largest SDO by membership to 3GPP which is responsible for creation and management of mobile network standards (5G and future 6G). ETSI also works closely with GSMA working groups on topics enabling the deployment of operational mobile networks.

Through ETSI's annual Security Conference (currently held in October each year), ETSI brings together research, operators, manufacturers, regulators, and user groups to ensure that ETSI and European standards continue to innovate and remain world leading.

3.2.4.3 Time Frame

The technical trends above are happening currently and accelerating – meaning work spanning security, privacy and trust needs to continue and also adapt to these ongoing trends. Additionally, with the increasing move to cloud centric technology, encryption and privacy, security is not a feature that can be readily added as an afterthought. Products and system must be Secure by Design with due diligence given to how that security is maintained throughout the entire product lifecycle.

Security, privacy, and trust will continue to be critical for new technological innovations. Ground-breaking technology has the potential to revolutionize our interactions, improve our quality of life and enrich security – but without first-class technical standards and good practices, misuse and fraud will prevent such innovations achieving their market potential.

3.2.4.4 Recommendations

Without excellent industry led technical standards, well-considered threat models, and security best practices, the security of communications technologies and services will not keep pace with real world attacks and fraud– and that is where ETSI can help.

Recommendation #1: TC CYBER (with QSC) and TC SAI each have individual roadmaps to look ahead for their future sector challenges. All groups within ETSI focused on security, privacy and trust should have their own roadmaps to navigate the near term and longer future challenge space, and this roadmap should be reviewed by the groups regularly.

Recommendation #2: ETSI needs to be able to begin Work Items (WIs), scope groups, host workshops or send expert liaison statements to relevant SDOs/EC stakeholders on topics as needed to adapt to these future trends. Over the next 1-2 years, such topics would include:

- **Centralization and consolidation (Fewer):** Standards need to be an enabler for rapidly changing technologies and implementing new use cases and not a non-agile barrier to innovation or market entry. Aggressive moves by individual market participants towards consolidation and technology centralization based on their technology or IPR must be counter-acted. ETSI's security and trust work creates an open, balanced, and diverse market that works best for citizens, governments and industry. ETSI working groups need to ensure that standards are produced with input from diverse global contributors and ensure that SMEs and smaller stakeholders views are taken into account.
- **Automated data exchange (More):** As IoT and AI expand, machines exchange data at a new, large scale that is only possible through automation. The challenges around protecting user privacy and

ownership of data require new standards to ensure consistent, interoperable, and high levels of expectation about how the same data is protected across a range of technologies and domains.

- **Advanced cryptography for nuanced use cases (More):** Cryptography methods such as identity-based encryption, attribute-based encryption and fully homomorphic encryption need defining, and implementation guidance, through high-quality technical standards.
- **Virtualization (Shifts):** Moving to network architectures of the future, virtualization is a key aspect. Work is ongoing in ETSI (ISG NFV) to address how virtual networks are created as and when needed to manage traffic volumes or specific use cases. Ensuring this environment remains secure, with consistent security baselines, and utilising security monitoring to provision real-time autonomous healing, requires new security standards.
- **Zero Trust (More):** The decoupling of services from transport networks and the move to dynamic substrate agnostic service communications paths (combining mobile, fixed and satellite) creates an increased need to focus on risk based Zero Trust security standards.
- **6G (Shifts):** Although 5G is a 2020s deployment technology, core 5G security standards and principles (including virtualization) were largely developed between 2012 and 2017. Similarly, while 6G will not be deployed until the 2030s, during the period 2024 to 2027, the core principles of 6G will be laid down in 3GPP and ETSI. Potential changes will include more cloud native support of micro services, native support for edge compute open RAN and a potential decoupling of the legacy authentication architecture which exposes 5G to 2G/3G security weaknesses. Therefore, ETSI security working groups need to develop and share their global interoperable vision for 6G, focusing on open interoperable standards across all network and service layers.

Recommendation #3: As a world leading SDO in the security, privacy, and trust area, with cross-industry engagement and expertise, ETSI should continue to take steps to actively share its work and the topics it addresses with key stakeholders. Although ETSI and 3GPP standards are often the established industry standards for communication and ICT eco-systems, ETSI standards are frequently under-represented in European regional activities which leads to fragmentation, reduction in security agility and increased industry cost. Therefore, ETSI should actively work further on its presence with key stakeholders and European bodies via communications and formal efforts in the organization to build relationships.

This presence would allow ETSI along with standardization partners to better ensure that established communications industry standards which are freely available to all market participants form the basis of regulatory compliance approaches.

3.2.5 Distributed Ledgers (Blockchain)

3.2.5.1 Description

Blockchains, which is the common term used to refer to what more generally should be termed Distributed Ledger Technologies (DLTs), are promising technologies increasingly used to store and share data and manage transactions, in a secured and trusted manner, in a fully distributed environment. Initially conceived to operate in the Fintech field underpinning the rise of cryptocurrencies such as Bitcoin, Ethereum and others, they are of growing interest in many others areas, such as Digital Networking, logistics, e-government, identity management, e-health, energy, to name a but few. In ICT, the current trends towards distributed and flexible networks, trustworthy networks and devices, connected and native intelligence, the convergence of communication and computing, edge computing, network automation and massive machine type communication introduce new technology challenges that can benefit from the use of DLTs, e.g., to improve trustworthiness, resilience, security, and privacy of the ICT system, to improve ICT system operation and management efficiency, to accelerate processes involving multiple entities and jurisdictions. Additional use cases are described herewith. More than just a technology, in these sectors DLTs lead to innovation through redefining the way transactions, network access, network resource sharing, collaborative devices, information access and data sharing are operated among the stakeholders and how they participate in the process.

Some of the main characteristics of recent DLTs are Throughput (measured by TPM = Transactions Per Minute), Scalability (the ability to handle growth in number of nodes) and Cost (the amount of computational resources required to complete a transaction.

An additional key feature of DLTs is their tamper resistance. DLTs are designed in a manner that makes it very difficult to modify data once it is stored therein. This is achieved by both the cryptographic characteristics (any change would require recalculation of all subsequent transactions/blocks) and the distributed nature of the DLT (the change will have to be performed on all DLT nodes).

DLTs comprise a wide range of participation schemes, ranging from fully non-permissioned approaches, adopted from the Fintech areas, where each entity is anonymous and has full access to all features, to various forms of permissioned DLTs, where certain levels of governance permit access and features based on proven identity. They mainly differ in the trust scheme defining who can register transactions in the DLT. Non-permissioned approaches allow any participant into the ledger, as long as it can bring a proof of its commitment. The typical throughput of non-permissioned DLTs is low and the costs are high, which in certain cases serves as proof by participants to their commitment, and as a barrier against malicious acts. There are different kinds of such proof, being the most usual proof-of-work, associated with dedicating resources to compute-intensive tasks, a process commonly known as mining. In permissioned DLTs, nodes participating in the consensus are co-opted by the rest of participants according to the DLT governance rules. They typically offer higher throughput and lower costs which makes them more suitable to most, if not all, mission critical environments. Moreover, permissioned DLTs can provide further control on whom, specifically, can create smart contracts (applications) on top of the ledger, which makes it more suitable for a consortium of multiple organizations (e.g., multiple providers of a continuum consisting of device edges, radio access networks, edge infrastructure, and/or core networks).

Additionally, further ledger structure technologies are under study, for example the use of graphs instead of blockchains: the main benefit of graph-based DLTs (no matter whether permissioned or not) is that transactions (or blocks) are registered based on previous transaction (or block) history, so no trust has to be assigned to a concrete node to record them, and thus graphs can offer even higher throughput and lower costs than traditional blockchains. In addition, redactable distributed ledgers now make it possible to edit or remove inappropriate or incorrect data stored in DLTs. This is done in a manner that maintains the tamper-resistance characteristics of the DLT.

The potential for DLTs in ICT is high and many use cases are expected to emerge in the next years, leading to new standardization opportunities. Examples include:

- **Trustworthy ICT**: In environments where devices, networks, services, users and applications need to be trustworthy, DLT can establish distributed trust among those parties and coordinate their interactions securely and automatically, without relying on a central party or an intermediator.
- **A new security paradigm** that overcomes the limitation of current parametric security technologies which may not be able to scale to handle billions of IoT devices. With DLT, trusted

IoT devices can be configured and can operate in a trusted way without the supervision of a central server.

- **New ways to train AI edge intelligence**: along with data processing at the edge, DLT and federated learning schemes can reduce the computational effort to validate new knowledge schemes.
- **A log scheme for tracking the lifetime** of edge computing equipment, sensors and IoT devices (and in future even drones, aircrafts components, robotics or satellites) from manufacturing to installation and operation, and finally decommissioning, following a path of certified transactions.
- **Network automation booster**: DLTs can help improve the management of network resources, such as capacity sharing in distributed networks, spectrum, roaming, infrastructure management and sharing, energy trading, service federation in virtualized networks.
- **Service Lifecycle Management**: DLTs can play a central role in management of services that span across a multi-domain supply chain. Including full lifecycle management, from inception, through Configure, Price, Quote (CPQ) to ordering, fulfilment, service quality assurance, usage management, change management and financial settlement.

To fully active this potential, however, a number of challenges are still open, such as:

- Interoperability issues between the various private/public chain/graph variants of DLT currently in existence.
- DLT throughput, scalability and energy consumption as required by IoT applications.
- Compliance with regulatory requirements of business/industrial IoT applications when moving from a centralized to decentralized transaction model.
- Efficient integration of DLT with ICT (e.g., DLT services as an integral part of the ICT system).

3.2.5.2 Affinity with ETSI Work

ETSI is already engaged in pre-standardization activities in the area of Permissioned DLTs, as the kind of DLTs best qualified to address most of the use cases of interest to the industry and governmental institutions (e.g., e-health). In particular, following its Terms of Reference:

"The "Industry Specification Group Permissioned Distributed Ledgers" (ISG PDL) will analyse and provide the foundations for the operation of permissioned distributed ledgers, with the ultimate purpose of creating an open ecosystem of industrial solutions to be deployed by different sectors, fostering the application of these technologies, and therefore contributing to consolidate the trust and dependability on information technologies supported by global, open telecommunications networks."

3.2.5.3 Time Frame

DLT is becoming a consolidated reality in industry and society. It is expected to continue its growth in coming years, provided an appropriate resolution of the key challenges mentioned above. A great boost of the technology could come from widespread adoption of DLT in public administration and ICT, as already planned by several governments and the EC (see the launch of the European Blockchain Partnership, the EU Blockchain Service Infrastructure, the International Association of Trusted Blockchain Application).

3.2.5.4 Recommendations

- **Build** on the work carried out in ETSI ISG PDL and position ETSI as *the* leader in Permissioned DLTs for the ICT Industry and, hopefully, mission critical vertical markets.
- **Coordinate** potential opportunities of DLTs in various ETSI Technical Committees (e.g. TC SES, TC eHealth, TC SmartM2M) through ad-hoc OCG teams if required and agreed, and better synergies with the most active EU research institutions.
- **Liaise** with the key international bodies in the DLTs space, such as (list not exhaustive) OASIS, ITU-T, IETF/IRTF, W3C, IEEE, ISO TC 307, CEN-CLC/JTC 19, mainly on identity management, and vertical markets (e.g. precision agriculture, healthcare, energy, and connected and autonomous vehicles).
- **Seek alignment** between different entities developing DLT specifications through the use of common terminology and common reference architecture.

3.2.6 Dynamic Data

3.2.6.1 Description

Whether it is called Big Data, Analytics or Dynamic Data, online data acquisition and management has become central to many businesses and social infrastructures. Although many industry "verticals" have individually developed extensive sets of (de facto) standards and agreed workflows, the operating costs of collecting, cleaning and reliably re-using (real-time) data remains very high in each domain and indeed accelerates in so-called Volume and Velocity. The pandemic outbreak of Covid-19 in 2020 unfortunately made very visible the need for cross-domain interoperability of data processing standards.

The important shift that is occurring is that dynamic data is being *embedded* in wide-area and global control-loops, to optimize production, product lifecycles, logistic chains and production planning, as well as in more loosely coupled systems such as international energy grids, city and national transportation networks, financial markets, international health research and international public health. The old-style "five-year plans" or "annual plans" implemented by human administrators are being replaced by embedded policies that react to dynamic data. If the data is "wrong" or simply misinterpreted, then the control-loops can be (severely) disrupted. Dynamic data may include data from IoT sources but is much broader in scope, including for example satellite images, detection of WLAN signals from individual's mobile phones, trending topics in social media, Digital Product Passports, hospitalization and diagnostic records, electronic marketplace transactions, etc.

The above remarks apply also in combination with the topics of AI and of Robotics addressed in this document. AI systems can be "poisoned" by incorrect data or "deep fakes" (a topic currently under investigation in ETSI SAI) and autonomous robotic systems can cause or experience significant destruction if their real-world data is inaccurate or not timely. The nascent trend of defining Digital Twins – where dynamic data, AI and robotics are all combined to enable autonomous real-world systems and also simultaneous virtual-world emulations – is fully dependent on accurate and timely dynamic data.

3.2.6.2 Affinity with ETSI Work

ETSI has historically two broad areas related to collecting and using dynamic data: network operations and IoT. Both topics are considered in separate clauses (see clause 3.2.3 Autonomous Networks and clause 3.2.8 Internet of Things) of this document. This clause considers additional cross-domain and higher-layer aspects.

TC SmartM2M has work on the use of IoT systems as an "information feed" for analytics and AI. To enable "bits and bytes" to be interpreted as real-world information by AI systems, semantic interoperability is being developed, including alignment of ontologies and semantics meanings (e.g. see SAREF [22]). The SmartM2M activity evolves specifications for use in oneM2M and the work aims to harmonize (in collaboration with stake holders) data definitions across large market segments such as energy, smart cities and smart manufacturing.

The TC Smart Body Area Network (SmartBAN) reference architecture is managing semantic interoperability through an Everything-as-a-Service (XaaS) mechanism and a Web of Things (WoT) strategy, to link local (body-area) systems to the Cloud and provide (secure) dynamic data with embedded semantic analytics (device/edge/fog levels), automated alarm management, distributed monitoring or control operations.

ISG Augmented Reality Framework (ARF) is defining an interoperability framework for augmented reality after thoroughly studying the existing SDO landscape in the report ETSI GR ARF 001 [23]. The AR Framework provides reference points for Interactive Contents and World Knowledge, which would allow external systems to inject information/objects/actions into the augmented reality view. In such a case, the ARF platform would become a visualization tool for dynamic data.

The above examples of dynamic data in ETSI standards are usually use-case driven. In the group ISG cross-cutting Context Information Management (CIM) federated exchange of data and metadata using a generic information model across *diverse* systems is the central mission. ISG CIM so far considers provisioning of provenance, licensing information, data quality metadata, etc. as part of its NGSI-LD protocol (see ETSI GS CIM 009 [24]). NGSI-LD API uses linked open data and property graphs to reference basically any data and definitions (ontologies), e.g. those in SAREF that are specified in SmartM2M.

3.2.6.3 Time Frame

There is no "big bang" for enabling of dynamic data. The gradual increase in the efficiency of data processing and the availability of such data through digitalisation are simply rising like the tide. However, there is a strong probability that the use of such data will be suddenly restricted at some point in the next few years due to public outrage at a perceived link with some real-world or data-driven catastrophe: scenarios might include collapse of financial markets due to hyper-fast trading, exposure of sensitive health records of millions of people, lock-down of national electricity grids for weeks after data-audits become badly synchronized, etc. Standards are needed to help detect and prevent such misfortunes and reassure commercial and public interests that risks are both known and monitored.

In the longer term, the standards for data exchange, provenance and quality need to ensure minimal cost of transactions and *efficient* monitoring of compliance to regulations (for liability, GDPR, AI ACT, licensing, etc.). Even "free open data" has very significant production and import costs today (see reference [25]) so the promise of open data is sharply constrained by the inefficiencies. Standardization can dramatically reduce those costs, improve reliability, increase transparency and facilitate compliance.

3.2.6.4 Recommendations

ETSI is at the heart of telecommunications, but it is not at the heart of the *data* that is carried by those telecommunication networks. No single SDO can make that claim; data is too diverse. Therefore the key recommendation for ETSI is to collaborate with other organizations and SDOs to make the collection, discovery, transmission, assessment and monitoring of dynamic data as efficient and universally interoperable as possible.

Such forming of partnerships and collaboration may need more flexibility and speed than in past decades and ETSI processes will need to adapt:

- promote joint or complementary technical work, organizing common events, or consider specific work for collaboration using the PAS scheme
- investigate means to assess the "quality" of datasets needed to train and also to test the AI capabilities referenced by new standards, expanding the work initiated by ISG SAI
- collaborate on quality metrics in the areas of AI human-machine and machine-machine interfaces for information viewing/exchange
- investigate means to apply General Data Protection Regulation (GDPR) principles to dynamic data streams

3.2.7 eXtended Reality (XR)

3.2.7.1 Description

eXtended Reality (XR) is the umbrella term used for Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), as well as for future immersive technologies yet to be developed. XR covers the full spectrum of real and virtual environments. Figure 7 illustrates how the different "realities" relate to each other; it is based on the Reality-Virtuality Continuum defined by Paul Milgram in 1994 [26].

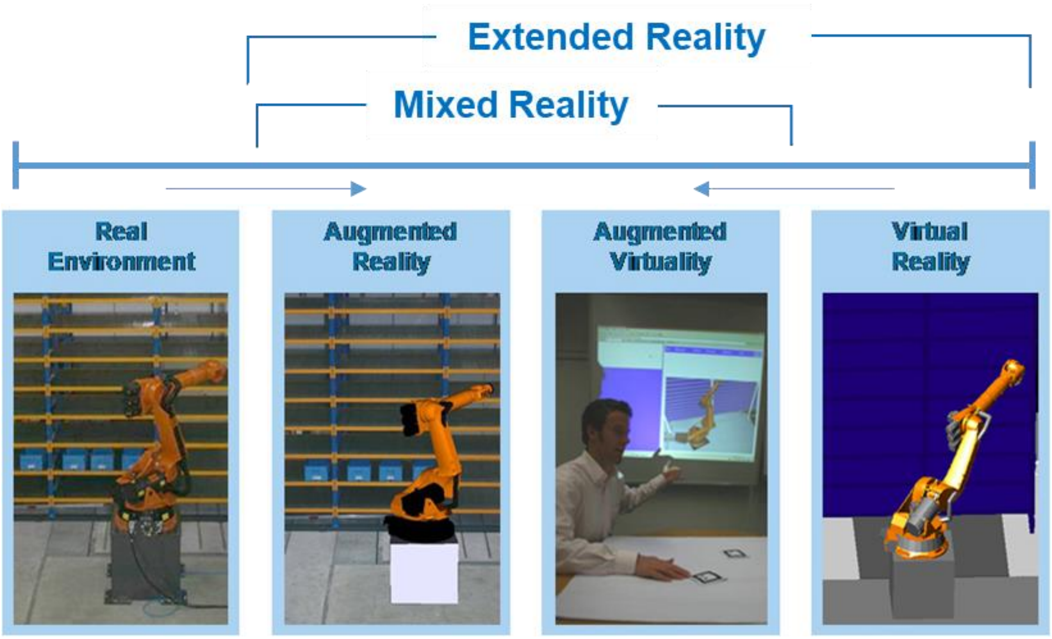

Figure 7: The eXtended Reality Landscape

Mixed Reality (MR) allows to augment the user perception of the real world with additional digital content. Recently, the term "Metaverse" has also been popularized: a digital space in real time, persistent and immersive, inhabited by the representation of people and things [27]. As there is one “Internet”, there could be a single, unique and interoperable Metaverse accessible through XR devices by a very large number of users.

When most people think of VR and AR today the most obvious examples are likely to include gaming and entertainment. Virtually enhanced games often involving popular game-based characters and fully immersive devices that enable users to be able to interact with virtual environments have gained much popularity over recent years.

However that is rapidly changing and the deployment of applications shows that the development of enterprise-level XR devices, solutions and services is now overtaking the pure-consumer applications.

Through the use of Extended Reality (XR) technologies, the industrial sector is realising the potential to boost productivity and quality whilst ensuring the safety of workers in potentially hazardous environments.

Examples include the use of VR for training or optimization purposes to simulate dangerous working environments and/or working with expensive, easily damaged equipment, without the potential risks to the materials or to the user. In this environment the concept of a digital twin is becoming more and more popular as the digital representation of a physical or immaterial object of the real world inside the digital world.

AR can be used to provide essential information about the equipment that is being manipulated directly to the user, hence reducing the time and effort spent by engineers, technicians, or maintenance staff referring to online manuals while performing complex operations. A report developed by ETSI ISG ARF 002 [28] identifies the top four types of use cases for enterprise AR; these are inspection/quality assurance, maintenance, training and manufacturing.

In addition to Industrial applications, the healthcare domain is one that clearly benefits from the application of XR technologies. From the use of VR to help treat patients with phobias and anxieties, to the use of AR by surgeons both in training as well as in the operating theatre.

In the domain of consumer products, these technologies can increase consumer engagement, attract more customers, and provide an extended shopping experience.

Other domains that are also prime candidates for the use of Extended Reality include (but not limited to):

- Events and live/immersive experiences (sporting / musical / cultural)
- Social Networks
- Video entertainment
- Tourism / navigation
- Construction
- Military
- Education
- And many more

All of these applications require ultra-reliable and ultra-fast connectivity, which means their area of implementation will certainly be greatly increased as 5G networks are deployed across the globe.

Adding Artificial Intelligence to the 5G connectivity and the application of extended reality technologies, will provide some of the most influential technology trends of the coming years.

3.2.7.2 Affinity with ETSI Work

ETSI recognizes the importance of Extended Reality technologies and has established a dedicated technical group, ISG Augmented Reality Framework (ISG ARF) that defines a framework for the interoperability of Augmented Reality (AR) components, systems and services in order to create a healthy ecosystem and enable a diverse range of providers to offer components of complete AR solutions.

The main objectives of ISG ARF are:

- to define a framework for the interoperability of AR components, systems and services, in order to reduce market fragmentation and enable providers to offer components of complete AR solutions;
- to encourage the development of high-performance Augmented Reality components which are portable between different hardware vendors, different providers of software solutions and platforms;
- to achieve co-existence of legacy and proprietary platforms whilst enabling an efficient migration path to fully interoperable platforms.

ISG Augmented Reality Framework (ARF) has defined a functional reference architecture for augmented reality solutions (ETSI GS ARF 003 [29]). The group specification introduces the characteristics of an AR system, defines a functional reference architecture and describes the functional building blocks and the relationships between these blocks. The generic nature of the architecture was validated by mapping the workflow of several use cases to the components of this framework architecture. The group started with the description of requirements at the interfaces between several blocks of the reference architecture (ETSI GS ARF 004-1 up to ETSI GS ARF 004-5). For two of these interfaces, the definition of an open API was successfully finalized, and its usage was shown for a selected use case. The API specification is described in GS ARF 005 that also includes links to the software repository on ETSI Forge. The scope of the ISG is AR but the AR interoperability framework should overall be applicable to XR components and systems.

ETSI work is underpinning the ongoing activities in 3GPP SA4 on XR and 5G. Due to the wide range of services and use cases enabled by XR, standards are necessary to define a client/server XR reference architecture powered by 5G connectivity, low latency, high throughput, and distributed computing. The main directions of 3GPP work in the area refer to the main technical enablers:

- Quality of Experience technical requirements (latency, Bandwidth) in the various XR application areas
- Immersive Multimedia enablement (Voice/Audio, Conferencing, Telepresence)
- Evolution of Media streaming architecture

3.2.7.3 Time Frame

Extended reality technologies are currently being deployed in many domains, but much of that is based on proprietary specifications from a number of "large companies", which certainly ensures solutions can be deployed, but does not ensure interoperability between devices, data and services, and slows down large-scale adoption.

As the market expands into multiple sectors over the coming 2-3 years, it is expected that the need for interoperable products and services will increase, particularly when AR/VR/XR is used for business / safety critical applications.

Some projections (e.g. GSMA – Cloud AR/VR WP, Apr 2019) [30]) indicate the number of XR consumer devices could double from 2018 to 2022, to target around 70 million devices. This is a substantial growth prediction but still limited by device cost, visual quality in mobility, and computational capabilities. This suggests the need for standards and architectures where the XR service is distributed among different interoperable components, in the cloud and at the edge, easing the deployment to the market of XR apps and fostering the development of a new ecosystem based on XR components, XR Platform aggregators, Cloud and connectivity providers.

3.2.7.4 Recommendations

As with other technologies, there is no single SDO that is working alone on producing the numerous standards that are necessary for VR/AR/XR evolution and deployment across multiple domains.

Therefore the key recommendations for ETSI are related to the opportunity to develop synergies and enablers. In particular:

- ***Collaborate*** with other organizations and SDOs, particularly with the representative groups of the users that will be applying XR technologies to their business processed.
- ***Promote*** the current activities carried out by ISG ARF on XR enablers, with particular focus on architectural frameworks, component interoperability, cloudification and edgification.
- ***Coordinate*** potential opportunities of XR for various use cases in various ETSI Technical Committees (e.g. TC eHealth, TC SmartM2M, ISG MEC) through ad-hoc OCG teams if required and agreed, and better synergies with the most active EU research institutions.

ETSI has signed Memorandum of Understandings (MoUs) with the following organizations:

- The VR/AR Association (VRARA), an international organization designed to foster collaboration between innovative companies and brands in the VR and AR ecosystem that accelerates growth, fosters research and education, helps develop industry standards, connects member organizations and promotes the services of member companies.
- The Augmented Reality for Enterprise Alliance (AREA), a global non-profit, member-based organization dedicated to widespread adoption of interoperable AR-enabled enterprise systems.
- The Khronos Group, an open industry consortium of over 150 leading hardware and software companies creating advanced, royalty-free, acceleration specifications for 3D graphics, Augmented and Virtual Reality, vision and machine learning.

- The Open AR Cloud Association, whose mission is to drive the development of open and interoperable spatial computing technology, data and standards to connect the physical and digital worlds for the benefit of all.

Some members of the ETSI ARF group are also contributing to the Metaverse Standards Forum (MSF) in different working groups (Network requirements, Real/Virtual World integration, etc.). The work performed within ETSI ARF will also be listed in the standards register of the MSF. This offers opportunities to collaborate with XR industry leaders, promote and develop the work of ETSI ARF.

ETSI is uniquely placed to address the challenges of XR, and in particular those relating to geographic positioning using 5G capabilities.

3.2.8 Internet of Things

3.2.8.1 Description

The Internet of Things has been predicted, hyped, defined, standardized, implemented, promoted and analysed for decades, so it cannot really be categorized as a new trend. However, the IoT creates a fundamental transition for ”man-the-tool-user”. Previously, the tool and the workplace were directly "at hand", as they have been for thousands of years. In a digital environment, direct human senses are substituted by electronic sensors and human actions actuate machines even at thousands of kilometres distance (e.g. remote drones scanning disaster areas). Inaccessible “work places” such as deep-sea submarine cables, or at a smaller scale the targeted delivery of medicines using nanorobots inside the human body, becomes possible.

Back in 2018 we witnessed a tipping point, where the number of IoT connected "things" exceeded the number of connected humans. However, the rate of growth is slower than many expected, principally due to the extreme fragmentation of the market and the diverse methods of management of the millions/billions of devices. This diversity is partly due to the huge range of sensors and actuators required, with varying compromises regarding robustness, power usage, wireless or tethered operation, etc. However, it is also due to a "gold rush" approach by companies, both big and small, seeking to deploy unique (i.e. non-interoperable) systems as quickly as possible in order to take advantage of Metcalfe's Law and play a significant role in transforming the global economy.

Similar factors led to the growth of hundreds of different standardization group activities. Therefore in 2012, ETSI co-founded, together with partner standardization bodies on all continents, the organization oneM2M (see below) to consolidate such work. Particular focus was placed on obtaining a "local-network agnostic" connectivity and a common management layer with build-in security functions. Progress has been steady in the original IoT paradigm of so-called "machine to machine" communication of sensor data and actuation.

Developments continue, however, and the Internet of Things paradigm is now evolving beyond just "remote sensing/actuation" in at least seven different dimensions, towards:

- robust and interoperable labelling of information (semantics) to avoid misinterpretations when sensor data is re-used outside of its original context or its original vertically-integrated use case, e.g. when weather data is coupled with measured pollution data in a climate-modelling emulation
- untethered sensors that are made free of battery or power constraints by using e.g. photovoltaic conversion of ambient lighting for harvesting energy and using pervasive radio networks (see

clause 3.2.1 5G Evolution) for input/output, to enhance and monitor components throughout the complete life-cycle of products e.g. from pre-sales testing, to monitoring of performance, to decommissioning

- semi-autonomous robotic systems that act also upon locally-acquired IoT sensor data (see clause 3.2.10 Robotics and Autonomous Systems) e.g. a "floor-cleaning robot" or a more complex Mars Rover that navigate around obstacles
- providing human operators with enough data and controls, in a virtual environment (see clause 3.2.7 eXtended Reality), such that the human operator can be the "brains" of a remote robot or drone or complex item of equipment, e.g. operation of a remote-surgery system
- massive statistical analytics and emulation systems for complete processes such as supply chains or vehicle traffic on extensive road systems (see clause 3.2.6 Dynamic Data) e.g. using a wealth of mobile network activity to model and predict current estimated times of arrival for travellers
- integration of metamaterials and nanosensors in local networks which (sporadically, so as to conserve energy) federate with wide-area and cloud-based networks, but have local autonomy
- unified and interoperable connection using innovative end to end protocols, optimised to specialised solutions, able to guarantee ultra-low latency and reduced energy consumption in connectivity, e.g. radio.
  Alternatively, unified and interoperable connection using Internet Protocol (IP) for general purpose solutions (e.g. non real-time or energy) in order to guarantee end-to-end connectivity.

These further dimensions for IoT have already provided very practical results for some specific use cases or domains, where stakeholders have united to focus on a selected few specifications and frameworks, for example the Industry 4.0 framework that is targeting Smart Manufacturing. In that usage domain, since the early days of computer-controlled machining, the industry has grown based on dozens or hundreds of proprietary interfaces that manufacturers each designed for *their* tools. Now, repeating the lessons learned over a century ago when hundreds of national and local "standards" for nut and bolt screw-threads transitioned to a single metric system, the efficiency gains arising from usage of a common set of interfaces for all manufacturing equipment will be monumental. ETSI standards groups developing IoT are beginning to work with such proprietary systems in order to integrate various approaches e.g. OPC UA interfaces [31] in oneM2M or MQTT interfaces [32] in ISG CIM.

It is clear that all of the above trends relating to IoT will ensure that connecting objects/things to networks will progressively become more beneficial, provided that appropriate and reliable security/privacy systems are part of the designs and deployments (see clause 3.2.4 Cybersecurity, Privacy and Trust).

3.2.8.2 Affinity with ETSI Work

As indicated above, ETSI has chosen an open and integrative role in promoting Internet of Things. The approach is founded upon providing modular interfaces (e.g. for radio connectivity in 3GPP NB-IoT) and integrative frameworks (e.g. oneM2M) then combining them as needed for particular use cases.

Different ETSI standards groups can play different roles in providing interoperable standards for IoT. Below are some key examples, beginning at the fundamental connectivity layers:

- 3GPP (LTE-M, NB-IoT and EC-GSM-IoT) **provides wide-area connectivity** standards specifically customized to IoT (huge number of devices per base station, options for standby status to save battery power, etc.).
- SmartBAN adds a **local personal-area network to the human body**, to collect and retransmit information from sensors for eHealth, XR and other applications.
- DECT and DECT™ ULE (Ultra Low Energy Digital Cordless Telecommunications) **provide local area radio networks in protected spectrum**, more reliably than WLAN and with longer range. DECT-2020 NR [33] is a 5G new radio interface based on OFDM and MIMO and provides scalable bandwidth, mesh networking, Ultra Reliable Low Latency Communications (URLLC) and massive Machine Type Communications (mMTC).
- SmartM2M incubates new approaches for **IoT and contributes them to oneM2M** e.g. application of IoT to Smart Lifts. SAREF (which is managed within SmartM2M) is our **S**mart **A**pplications **REF**erence ontology that allows connected devices to reference semantic information in many different applications' domains such as energy domain, automotive domain, and others[3].
- oneM2M **provides global standards on requirements, architecture, API specifications, security solutions and interoperability for Machine-to-Machine technologies** for a wide range of technologies so they can work together for Internet of Things. It aims to be network and information-source agnostic for maximum interoperability.
- ETSI ISG CIM specifies a protocol called NGSI-LD running "on top" of IoT platforms and allowing exchange of data together with its context, e.g. what was measured, when, where, by what, the time of validity, ownership, etc. This extends interoperability of applications, helping e.g. Smart Cities to integrate services.

The status of IoT technology in ETSI can be summarized as:

- ETSI has created interfaces and frameworks for the complete range of IoT applications and is developing interworking approaches to integrate the very many proprietary interfaces and eliminate the risk of "lock in".
- ETSI has given cyber security a high priority in its IoT standards, but the market is still very inconsistent in how cyber security is applied.
- ETSI integrative standards have not yet reached the widespread adoption needed in order to break down the barriers between all the many vertical solutions and allow cross-domain IoT to expand along the five "dimensions" explained above.
- ETSI's special role in promoting interoperability and conformance testing has not yet been applied to all the levels of IoT, although oneM2M has partnered in mid-2020 with GCF to offer global conformance testing and ISG CIM has created a developer-friendly test suite for its protocols.
- There is not yet analysis within ETSI on integrating IoT into the complete life cycle of products using devices capable of energy harvesting and embedding them using micro- or additive-manufacturing.

[3] See https://saref.etsi.org/

3.2.8.3 Time Frame

The time frame for IoT is now. Below are a number of recommendations on how ETSI can accelerate acceptance of existing standards and work to fill some gaps. On the other hand, it is probable that at least another five years will be needed to bring some consolidations to the many different vertical markets.

3.2.8.4 Recommendations

The success of IoT is still restrained by insufficient interoperability, so the key recommendations for ETSI are:

- promote existing ETSI standards related to IoT and especially from oneM2M so that the barriers between "verticals" can be broken down, particularly in the key domains of Smart City, Smart Manufacturing and environmental monitoring
- promote ETSI standards for cyber security in IoT and work with European and other important cyber security organizations to ensure that IoT solutions are not fundamentally damaged by cyber-attacks and are not maliciously re-used to contribute to attacks
- promote consensus-driven development of ontologies, especially in relation to SAREF, so that the meaning of collected data is not lost in translation
- promote exchange of (meta)data that re-uses existing consensus ontologies (like SAREF)
- foster examples from industry of "turnkey solutions" that use ETSI specifications, to act as inspirational examples for Smart City, Smart Manufacturing, etc. or other specific use cases
- note where proposed "turnkey solutions" are not viable due to missing standards and subsequently work to fill any important gaps
- collaborate with research projects so that as much of the projects and their proof-of-principle activities (re)use standards where feasible, rather than inadvertently inventing equivalent or less interoperable interfaces
- provide flexible testing and conformance options for ETSI standards, to encourage their interoperable use
- collaborate with European research projects in leading-edge areas such as additive manufacturing or the circular-economy
- promote SMEs use of technologies such as private 5G networks, open source implementations of IoT federated platforms, etc., to encourage entrepreneurship and sustainability

3.2.9 Quantum Computing, Encryption, Networks

3.2.9.1 Description

Quantum mechanics is a well-established theory that is used to predict the behaviour of matter and energy down to the scale of subatomic particles and photons of light. The “science of the very small” is many times counterintuitive and cannot be explained by the rules of classical physics. An understanding of quantum mechanics has supported the development of technologies such as lasers, transistors and magnetic resonance imaging, among others.

Today, not only are we able to understand the effects of quantum mechanics but we also have the ability to actively manipulate individual particles at a quantum level and quantify their states in a single operation. This will enable the development of a new generation of quantum-based applications, namely in the areas of quantum communications, quantum encryption, quantum computing, quantum simulation and quantum sensing and metrology.

A possible base unit of quantum information is the qubit. This is analogous to a binary bit except that a qubit can be in a superposition state of 0 and 1 rather than being known to be either 0 or 1 at a given time as for a binary bit. Concepts such as superposition (objects can exist in multiple states until they are observed), measurement (an object in a superposition state can be changed to a specific state when measured) and entanglement (two qubits can have a common superposition state and, even when sent far apart, an action taken on one of the qubits will influence the detected properties of the other) are central to developing new ways in which quantum information can be processed.

Quantum computers exploit characteristics of quantum mechanics to process information in new ways. They process qubits instead of bits and their computing power will double with each good-quality qubit that is added. It is expected that a Quantum computer can break all existing public key cryptography, optimize data analytics and solve problems in many areas that have extreme complexity.

Future quantum information processing will create the need for a quantum internet that can transfer quantum states and enable them to be processed collaboratively in remote locations. The basic principle that unknown quantum states cannot be measured without disturbing their state can be used today to establish cryptographic keys securely over optical telecommunication links. This is called Quantum Key Distribution (QKD) and since its security does not derive from computational complexity the keys resulting from a QKD protocol are not subject to retrospective attacks enabled by advances in computing power. The prospect of quantum computers offering new ways to solve mathematical problems that public key cryptography used in current networks relies upon is focusing attention on the issues and QKD offers an alternative in this respect. Doing this over large distances presents challenges since the signals cannot be amplified without errors using traditional technologies and quantum repeaters (end-to-end teleportation of quantum states) are not yet mature.

The evolution of quantum networks will have several stages going from pre-quantum networks where end nodes are directly connected and can perform quantum key distribution up to a full quantum network with quantum computers at end nodes, intermediate repeaters and quantum memories, capable of end-to-end delivery of quantum states and execution of distributed quantum applications.

In the area of Quantum simulation we can expect use cases such as ICT infrastructure simulation (e.g., traffic loads), Proteomics, Genomics and drug simulations in Medicine, predictions and risk analysis in Smart cities and transport, climate prediction.

Finally, in Quantum Sensing and Metrology we can expect e.g. improvements in clock synchronization that leads to more accurate sensors with impact throughout many sectors, enabling new applications such as finer slicing and higher bandwidth for time-dependent multiplexing of networks.

Although the practical use of inherently quantum technologies is just starting, it will bring important disruptions to the way we plan, build, operate and use our future networks and computers.

Some foreseen applications are huge advances in secure communications using quantum key distribution as well as secure login into networks, enhanced Global Positioning System (GPS) with more accuracy, more secure applications for voting and digital signatures.

The advent of large-scale quantum computing offers great promise to science and society, but brings with it a significant threat to our global information infrastructure. Public-key cryptography - widely used on the internet today - relies upon mathematical problems that are believed to be difficult to solve given the computational power available now and in the medium term. However, popular cryptographic schemes based on these hard problems – including RSA and Elliptic Curve Cryptography – will be easily broken by a quantum computer, putting confidentiality of real-time and stored information at risk. This will rapidly accelerate the obsolescence of our currently deployed security systems and will have dramatic impacts on any industry where information needs to be kept secure. Major efforts, called quantum-safe cryptography, are taking place to identify algorithms that are resistant to attacks by both classical and quantum computers, to keep information assets secure even after a large-scale quantum computer has been built.

3.2.9.2 Affinity with ETSI Work

Perceived as the basis for a disruptive evolution of computing and networking, quantum technologies will be at the heart of ETSI evolution. In fact, ETSI is already engaged in related standardization activities:

- ISG QKD (Quantum Key Distribution) where quantum cryptography for ICT networks is covered in some critical areas such as implementation security, metrology of components and modules, and interoperability.
- TC CYBER/ Quantum Safe Cryptography and Security (QSC) where assessments and recommendations on the various proposals from industry and academia regarding real-world deployments of quantum-safe cryptography are made, including practical properties such as efficiency, functionality, agility, etc. QSC also covers security properties and appropriateness of certain quantum-safe cryptographic primitives to various application domains (Internet protocols, wireless systems, resource constrained environments, cloud deployments, big data, etc.).

3.2.9.3 Time Frame

The full potential of the application of quantum mechanics to computing and communications is still at an early stage with many developments taking place in academia and research, together with some major industry players. However, proof-of-concept networks are being constructed in a number of locations and the potential of quantum technologies is catching the attention of governments. For example, the EU initiated the “Quantum Technologies Flagship” in 2018 with a 10+ years’ timescale and the European Quantum Communication Infrastructure (EuroQCI) initiative to construct a secure quantum communication infrastructure spanning the whole EU (including its overseas territories) was launched in 2019. The first optical fibre implementation phase of EuroQCI kicked-off in January 2023, with an operational fibre deployment phase to follow largely during this decade, and two satellite deployment phases are also planned this decade and the next. More advanced quantum technologies are likely to be progressively introduced to remove limits and improve scalability through the remainder of the decade and beyond. It is also planned to build 6 state-of-the-art pilot quantum computers, integrated into the EU High Performance Computing Joint Undertaking’s supercomputers (EuroHPC JU). Locations were announced in October 2022 with initial access to the European research community expected to start from 2024. NIST has concluded a competition and selected QSC algorithms for standardization in 2024. Many governments have set dates for adoption between 2025 and 2035. For example, the National Security Agency (NSA) has set a deadline for national security systems to have implemented QSC by 2035 with intermediate targets in 2030 and 2033.

3.2.9.4 Recommendations

- **Progress** the work carried out in ETSI TC Cyber/Quantum Safe Cryptography in order to position ETSI in the leadership of this specific area
- **Monitor** the evolution of Quantum technologies in a continuous mode, identifying challenges and opportunities that may impact ETSI evolution
- **Strengthen** the relation with R&D institutes, NMIs and Academia in this area, reaping the benefits for an early start in Quantum standardization aligned with policy, industry and societal needs

3.2.10 Robotics and Autonomous Systems

3.2.10.1 Description

The presence of an ever-increasing number of **Robotics and Autonomous Systems** (RAS) in modern digitized applications represents a rapidly growing trend in our daily life. Research and development in RAS can be characterized as a “*multidisciplinary scientific and technological domain for implementing complex systems with cognitive capabilities*” (see the EU ICT Standardization Rolling Plan) [34].

For many decades, RAS have been used in a number of business applications such as industrial manufacturing, logistics, maintenance, space exploration. More recently, with significant improvements in sensor technologies, connectivity, computational capability, embedded intelligence and Machine Learning, new application areas have broadened the potential use of RAS, for example in precision farming, autonomous or assisted driving, Unmanned Aerial Systems, surveillance, emergency and rescue, military, Machine to Human social/commercial interactions, health care, assistive living, entertainment, education. RAS deployment brings a strong economic contribution as an industrial and commercial activity on its own and creates new challenges due to its disruptive impact across diverse market sectors worldwide, the emergence of ethics considerations when RAS autonomous decisions apply in the field, the necessity to redefine technical models for architectural design, interoperability, certification and testing. The advent of RAS will also and already has introduced a deep impact on jobs and skills, leading to the eventual replacement of humans in certain sectors or new relations between humans and collaborative RAS (cobots).

Various technologies contribute to enable a new generation of RAS, such as mechatronics devices, power systems, sensors, data communication systems, computer software, multi-agent technologies, signal processing techniques, artificial intelligence, machine learning, communication technologies, from short range communication to 5G and 6G.

RAS can have many physical aspects and different capabilities. Examples of categories of RAS include:

- **Industrial RAS**: "automatically controlled, reprogrammable, multipurpose manipulator, programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications" (ISO)
- **Unmanned Aerial Systems (UAS)**: "a system composed by Unmanned Aerial Vehicle (UAV) and related command and control functionality" (3GPP)
- **Autonomous Vehicles**: "a vehicle that is capable of sensing its environment and moving safely with little or no human input" (Transport Review Journal)
- **Health RAS**: deployment of robots and autonomous systems in areas like surgery, tumour diagnostics, and caretaking of older and disabled persons
- **Cloud-enabled RAS**: "any RAS that utilizes the cloud infrastructure for either data or code for its execution, i.e., a system where all sensing, computation and memory are not integrated into a single standalone system" (J. Kuffner)
- **Collaborative RAS**: any RAS intended to interact with humans in a shared space or to work safely in close proximity. An extreme example of Collaborative RAS is **a chatbot**, software designed to imitate human conversations, locally or remotely

3.2.10.2 Affinity with ETSI Work

As RAS is an integrated result of many digital and ICT technologies in the ETSI domain, the affinity is strong, however, the future direction of robotics and relevance to work in ETSI is constantly evolving:

- Neither robotics, cloud robotics, autonomous systems nor artificial intelligence are in the mainstream of ETSI activities and are not cited in the ETSI Director General progress report 2022 (see [35])
- Standards for Drones and UAV traffic management, are part of ETSI TC ERM WG AERO responsibilities and studied in 3GPP SA6, with increasing focus on KPIs related to UAV 5G capabilities
- Many of Industrial Robotics radio enablers are tackled in TC ERM. Moreover 5G standards developed in 3GPP are a key enablement for RAS systems, and ISG SAI (now TC SAI) is addressing RAS as one use case of Securing AI
- Although Cloud is central in many ETSI activities (Cloud RAN, Cloud Management, Cloud Native), the ETSI focus on Cloud Robotics is currently marginal/non-existent

- Most of the new challenges related to RAS are associated to the adoption of AI capabilities and thereby only indirectly addressed by ETSI in the relevant TBs/ISGs and highlighted in the ETSI OCG AI group

3.2.10.3 Time Frame

The advent of RAS is already a reality in industry and society. All industry analysts agree that RAS represent a fundamental shift in many economic sectors and that trend will continue and accelerate over the years.

3.2.10.4 Recommendations

As highlighted in the 2024 EC Standardization Rolling Plan [34], despite its work in many enabling technologies ETSI is not the core SDO in RAS. ISO (TC299, TC184), IEEE, CEN (TC 310) are more engaged in the subject, although not all the RAS challenges are actually addressed (e.g. safety, protocols, knowledge modelling).

The recommendations for the ETSI Community could therefore be multi-folded:

- ***Follow*** the activities carried out in other SDOs, especially for Industrial RAS. This would avoid overlaps with other SDOs.
- ***Promote*** the current activities carried out by TC/ISG on RAS enablers, with particular focus on wireless communication capabilities, safety and security. This could include, too, to track internal RAS-related activities and evaluate collaborations with other SDOs/fora (e.g. OCEANIS).
- ***Consider*** the opportunity of exploratory work on Cloud-enabled RAS: with the advent of 5G low latency communication, edge computing and new sensors, the area has a growing potential that easily fits with ETSI strengths.

3.2.11 Photonics

3.2.11.1 Description

Photonics is the science and technology of light, identified in ETSI Strategy as a major Technology Trend and an essential contributor to the European and worldwide economy. The global sector is growing twice as fast as the GDP.

The evolving need for higher bandwidth (faster), reduced latency (quicker), increasing number of end-points (wider), enhanced energy efficiency (greener), network-computing integration (smarter) and enhance perception of surrounding environment (more aware) makes out of Photonics a key enabler for the development of advanced digital technologies and services. In the future, many electronic based systems will be replaced by photonics-based solutions, taking advantage of its unique features.

Many diverse application scenarios are enabled by Photonics, including Ultra Broadband communications, Free Space Optics, Quantum networks, THz Communications, Critical infrastructures and Photonic Sensing, among several others. The European Technology Platform Photonics21 unites the majority of the leading photonics industries and relevant R&D stakeholders along the whole economic value chain throughout Europe. The community looks into photonics in a quite broad way including according to the Leaflet:

- Photonics in life sciences and healthcare (Wearable medical sensors, "Clinic on a wrist")

- Photonics for safe, nutritious and affordable food (gas, liquid, matter sensors for agriculture and food monitoring)
- Photonics for autonomous and connected mobility (LIDAR, 5G, IoT)
- Photonics for sustainability and a clean environment (sensors for air and water quality monitoring)
- Photonics in manufacturing and production (Industry 4.0, IIoT, Factories of the future)
- Photonics for smart homes and liveable cities (Smart Cities, LiFi)
- Photonics for a secure and resilient ICT infrastructure (networking)
- Photonics as a driver of the digital knowledge society including novel hyperscale data centre architectures

In the realm of ETSI and near ICT the following topics are for more detailed interest:

- **Optical Networks**, whose development is key to enable the large capacity, energy efficiency, extended reach and low latency to support the new service and traffic requirements of the digital era, an essential resource to build future mobile networks, to ensure inter- and intra-data centre networks and to become widely employed at all levels of networks, from core to access. Many new challenges are expected as the electro-photonic integration needed for a new generation of optical networking, new network architectures with edge clouds close to the end user, flexible capacity scaling, programmability, Optical Network Automation, slicing, E2E management, coherent communication systems, security and many other leveraging the need for future standardization.
- **Optical solutions** can give a huge contribution to sustainability. In access, the optical passive solutions can enable better energy efficient when compared with other largely deployed solutions. These technologies will evolve from current 10, 50 and upcoming 100 GPON to Coherent PON solutions. In transport, reducing the optical-electric conversion by new optical packet switching technologies can leverage photonics technologies for high-performance and sustainable novel network architectures.
- **Critical infrastructures** as the factories of the future, private enterprise networks, and vehicular networks are specific use cases where the benefits of reliability and Electro-Magnetic Interference (EMI) immunity make optical network technologies attractive and specific standards are required.
- **Quantum networking** that enables the development of Quantum communications for the creation of next generation of secure telecommunication networks. Quantum networking for quantum key distribution is still a challenge. The whole ecosystem involves numerous technologies, platforms and application where recommendations on protocols, components and infrastructures requires continuous update.
- **Photonic sensing** that opens new horizons for improved and robust sensing capabilities in factories, healthcare, autonomous driving, agriculture and many other areas that require spatial resolution, 3D sensing or augmented reality. Photonic sensors will have a wide range of applications providing both the sensing and measurement functionalities to leverage the IoT ecosystems in almost every sector. Note that phonics sensing can be based on fibres or in free-space.

- **Optical Wireless Communication,** complementing the continuous need for new spectrum and capacity, being through Free-Space Optical (FSO) point-to-point but also through technologies based on Visible Light Communication (VLC), generally referred as LiFi (Light Fidelity), enabling bi-directional communication, multiuser access and handover. Both wireless as well as photonics oriented aspects are part of such a trend.
- **Terahertz Communications,** enabling Terabit-per-second (Tbps) to become a reality within the next five years. This will require a physical layer efficiency of 100 bit/s/Hz and a photonics approach (e.g. unitravelling carrier photodiodes, photoconductive antennas, optical down-conversion systems, quantum cascade lasers) is one of the most promising paths to achieve it. Terahertz Communications is one of the megatrends identified and further described in this document, where Photonics is a key enabler.

3.2.11.2 Affinity with ETSI Work

Taking into account the major importance of Photonics for the next generation of networks and services, ETSI should be engaged with the Photonics R&D communities and look for an active role in the development of standards that relate with Photonics enhancements.

Currently, ETSI has activities in the area of optical networks (ISG F5G), Quantum (ISG QKD) and THz communications (ISG THz).

ISG Fixed Fifth Generation (F5G)

F5G establishes a structured approach to the fixed network evolution, in an E2E vision based in generations that reflect the evolution of service requirements and optical networks technologies.

F5G has developed his vision based on the definition of fixed networks generations, addressed several use cases and identified specific requirements and standardization gaps that were addressed to the appropriate standardization organizations.

Furthermore, F5G developed its End-to-End reference Architecture, aiming at an all-optical E2E network that allows dynamic and flexible service creation, separation of Underlay Plane and Service Plane allowing them to scale independently, network slicing capabilities, enhanced traffic steering and autonomous management features.

F5G is preparing the evolution to F5G advanced where the latest developments in Photonics will be considered adding new dimensions to the fixed network as enhanced sustainability, optical sensing and deterministic latency.

Sustainability is a major challenge for society and closely relates with the work developed at TC EE for ICT.

Optical sensing will be used for enhanced network management and operation, as well as for services to several verticals as smart cities, industry and health, being an enabler for new developments in areas covered by TC Smart M2M, TC SmartBAN and TC eHealth. Optical sensing can be integrated with optical communication with the purpose to optimize network management (fibre cuts, medium issues), or to re-use fibres already deployed for communication for environmental monitor of any kind. On the other hand, fibres can be deployed with the sole purpose of sensing due to the characteristics to be quite precise.

ISG Quantum Key Distribution (QKD)

ISG QKD addresses quantum cryptography for ICT networks. It basically enables digital keys to be shared privately without relying on computational complexity. The security offered by QKD will not be vulnerable to future advances in algorithms, computational power or the emergence of a quantum computer. It solely relays on photonics and the particular properties of photons.

The ISG addresses standardization issues in quantum cryptography and associated quantum technologies. The work is specifying QKD system interfaces, implementation security requirements and optical characterization of QKD systems and their components.

3.2.11.3 Time Frame

Photonics are in a turning point where its use will increase significantly over the next years.

Some technologies are already in an advanced stage of developments and some are expected to be available in the next 3 to 5 years.

Some others are still being discussed and exploited in the R&D ecosystem and promise important breakthrough for ICT for the next 5 to 10 years.

3.2.11.4 Recommendations

- **Promote** the further involvement of ETSI in the field of Photonics through **Board RISE**, addressing major R&D organizations in this area as **PHOTONICS21** in order to create the links for a smooth and early transition from innovation to standardization.
- **Progress** the work carried in ETSI ISG F5G and ETSI ISG QKD Quantum Safe Cryptography and ISG THz in order to position ETSI in the leadership of these specific areas.
- **Consider** to engage in a transversal initiative among the ETSI technical groups that can benefit from the advances in Photonics (e.g. ISG F5G, ISG QKD, TC Smart M2M, TC SmartBAN and TC eHealth TC EE, TC ATTM) in order to further evaluate possible areas of ETSI involvement.
- **Monitor** the evolution of Photonics technologies in a continuous mode, identifying challenges and opportunities that may impact ETSI evolution. Specifically, the use of photonics technologies in almost all ICT application areas shows the importance of monitoring the developments and engaging in the right activities at the right time.

3.2.12 THz communications

3.2.12.1 Description

The use cases that will emerge in the next decade will require extreme communication performance, as well as functionalities that cannot be provided by current wireless systems. As an example, applications providing users with an immersive and multi-sense experience, such as holographic telepresence, will require data rates in the order of Tbps and sensing information from the surrounding environment. In this regard, THz communications have been widely recognized as one of the technologies that can help bridge the gap. Indeed, communications at THz frequencies open the door to a vast amount of radio resources (between 275 and 450 GHz there are 137 GHz of spectrum allocated for fixed and land mobile services), which can be exploited to deliver extremely high communication performance. Moreover, the peculiar propagation properties of THz signals can be leveraged to enable sensing functionalities able to achieve very high accuracy.

The use cases that can be supported by THz communications can be categorized into:

(i) fixed point-to-point applications,

(ii) applications with mobile nodes, and

(iii) Integrated Sensing and Communications (ISAC).

The first category includes use cases aiming at replacing wired connections with THz wireless links, both between different devices (e.g., to replace the fibre connections between servers in a data-centre, or to realize wireless backhaul and fronthaul links) and within the same device (e.g., to connect different electronic cards in a PC). The second category includes mobile applications with high data rate requirements, such as virtual and augmented reality, applications for in-flight and in-train entertainment, vehicular and satellite communications. The third category includes applications requiring both communication and sensing functionalities, such as holographic telepresence, and interactive and cooperative robotics.

Despite the great potential, communicating at THz frequencies comes with its own challenges. For example, THz signals are subject to high free-space and molecular absorption losses, which limit the propagation range. Moreover, THz devices make use of antenna arrays and beamforming techniques able to focus the transmit power into sharp beams, thus increasing the directionality and achieving a higher channel gain. While this approach can compensate (at least partially) for the high propagation losses, it requires the transmitter and receiver antennas to be perfectly aligned. Given the narrow size of THz beams, a perfect alignment is hard to achieve, especially when the nodes are moving. Finally, THz signals can be easily blocked by walls, humans, and other obstacles, making it difficult to communicate when the direct path between the endpoints is obstructed.

Driven by the advancements in electronic devices, THz communications have gained lots of interests in the last few years. However, up to now, only the first category of use cases mentioned above (fixed point-to-point applications) has been addressed in standardization. Specifically, IEEE has defined 802.15.3d, the first standard for (sub)terahertz communications. This standard covers the frequency range of 252 GHz to 325 GHz and was developed for point-to-point links, thus is applicable to a limited set of use cases with no mobility.

Therefore, further work is needed to support the use cases covered by categories (ii) and (iii), i.e., including mobility and sensing. Similarly, additional work is needed to cover other frequency bands and to enable multipoint transmissions. In order to address the aforementioned challenges and support such advanced use cases, the research community is actively working towards novel solutions. In this context, efficient and high-performing THz systems are expected to become soon a reality. As such, several European and international initiatives promoting 6G research and development activities (e.g., one6G, 6G-FLAGSHIP, and the NEXT-G Alliance) foresee THz communications to be included in the next generation of cellular networks.

3.2.12.2 Affinity with ETSI Work

The research funded by EC through numerous projects (e.g., those listed in Table 3 below) indicates that the electronics required to enable THz communications is maturing and has been validated in labs and relevant industrial environments. For example, the EU project Terranova has demonstrated that 100+ Gbps transmissions are possible over 500+ meters in THz bands. Research outputs from these projects could be channelled into the pre-standardization work at ETSI.

Table 3: Finished and ongoing EC-funded projects on THz communications

Project	URL	Status
Terapod	http://terapod-project.eu/	Finished
Terranova	https://ict-terranova.eu/	Finished
ULTRAWAVE		Finished
WORTECS	https://wortecs.eurestools.eu/	Finished
EPIC	https://epic-h2020.eu/index.php	Finished
DREAM	http://www.h2020-dream.eu/	Finished
Car2tera	https://car2tera.eu/	Ongoing
Teraway	https://ict-teraway.eu/	Ongoing
WiPLASH	www.wiplash.eu	Ongoing
Thor	https://thorproject.eu/	Ongoing
Ariadne	https://ict-ariadne.eu	Ongoing

Furthermore, there is work being done in existing ETSI bodies that is relevant for THz communications. For example, the ISG mWT is already addressing the evaluations of backhaul/fronthaul links in sub-THz bands, while ISG RIS is dealing with metasurfaces, which are expected to play a role at (sub)THz frequencies, where they can ensure virtual line-of-sight transmissions to combat the high path loss induced by blocked line-of-sight. Combined with the promise that THz bands bring to future communication systems (in terms of high data rates, ultra-low latency, accurate sensing, and high reliability), including pre-standardization activities related to THz communications in ETSI seems as a natural progression from the work that is already being done in the above-mentioned projects and at ETSI ISG mWT and RIS.

3.2.12.3 Time Frame

Pre-standardization activities on THz communications for use cases beyond those enabled by point-to-point transmissions have already started. For example, in the ITU-R WP5D #38 meeting, it was agreed to start working on a new report, “The technical feasibility of IMT in bands above 100 GHz”. The workplan is to finish the study in the WP5D #44 meeting, before the World Radiocommunication Conference 2023 (WRC-23) planned for June 2023. The report will study and provide information on the technical feasibility of IMT in bands above 100 GHz, complementing the studies carried in Report ITU-R M-2376. The resulting report will include information on propagation environments and channel models, as well as newly developed technology enablers, such as active and passive electronic components, antenna techniques, deployment architectures, and the results of simulations and performance tests.

As mentioned above, the only standardization effort so far has been IEEE 802.15.3d, which covers point-to-point links only. Therefore, additional standardization efforts will be needed to support more advanced use cases promised by 6G networks. Since 6G standardization work on above 100 GHz bands will start in earnest in a few years' time, the time is right to start the related pre-standardization activities in ETSI, thus laying the groundwork for including THz communications as core part of 6G networks.

3.2.12.4 Recommendations

THz frequency bands will allow for unprecedented data rates (in the range of terabits per second) and new applications (e.g., integrated sensing and communications). To fulfil these promises, baselines for evaluation and modelling of THz communication systems need to be established. The following recommendations address these points.

Recommendation #1: THz communications are moving from lab to the field. To ensure that ETSI is at the centre of the pre-standardization work on THz, ETSI can take the following directions:

i) establishing a close relationship with relevant EC bodies working on the topic (e.g. DG CONNECT) to ensure that future funding opportunities for THz communication systems address topics relevant for the subsequent work at ETSI; and

ii) establishing a close and open forum for exchange with ongoing EC-funded projects and actions (e.g. within COST), so that the outputs of those projects and participants working on them can contribute to further work in ETSI.

Recommendation #2: ETSI has the capability to support the pre-standardization work on THz communications through either an existing technical body or by initiating a new one. Irrespective of the approach, ETSI can support the inclusion of THz communications into the future communications systems by working on:

- defining scenarios (eMBB, factory, D2D/V2X, sensing, etc.) that THz communications can support;
- defining bands of interest in the (sub)THz range (100-220 GHz, 300 GHz, 1 THz+);
- developing channel models for relevant scenarios and frequencies;
- establishing the baseline for THz technology fundamentals: antenna assumptions, simulation assumptions, performance tests, deployment strategies;
- ensuring collaboration with other ETSI bodies dealing with topics relevant for THz communications.

3.2.13 Reconfigurable Intelligent Surfaces (RIS)

3.2.13.1 Description

In WRC-19 a couple of mmWave bands were identified for IMT use on a global scale. The millimetre wave (mmWave) and terahertz (THz) frequencies, with a much shorter wavelength, inevitably suffer from the severe propagation loss over the air, as well as an increased signal processing complexity. In order to exploit the large bandwidth in mmWave and THz bands, active network components and antennas are to be introduced to compensate. In addition, the revolutionary use cases, such as Metaverse, Internet of Everything, Holographic communications, pose several stringent communication requirements in terms of high data rate, reliability, latency, coverage, security, etc., which are expected to be supported by 5G advanced wireless networks. Therefore, academia, research institutes, and the industry have started early stage attempts to standardize RIS.

RIS typically composes of a large number of low-cost nearly-passive reflecting elements that have the capability of shaping the amplitude and shifting the phase of the impinging signal. It is usually implemented by using an associated smart controller, e.g., an FPGA, which communicates with an active BS or user equipment via a separate wireless link for coordinating transmission and exchanging information on channel information and real-time control. By intelligently coordinating the scattering of all the RIS elements by the phase shift matrix, a dense deployment of RIS is able to reconfigure the end-to-end wireless channels, thus to implement the smart and programmable wireless environment. From an implementation perspective, RIS also exhibit competitive advantages in practice. First, since RIS do not need active RF links and only require nearly-passive scattering elements, they have significantly reduced hardware cost and energy consumption as compared to same coverage with 5G technologies based on active antenna arrays. Second, the passive scattering of RIS forms a Full-Duplex (FD) transmission mode that is free of antenna noise amplification and self-interference, which makes it more attractive than traditional active half-duplex relays that suffer from low spectral efficiency or full-duplex relays that require sophisticated techniques to cancel the self-interference. Since RIS are nearly passive, they can be light weight, different shape and even made to be conformal to various objects.

As a result, they can be easily deployed in a wide range of scenarios such as walls, ceilings, billboards, lampposts, and even on the surface of vehicles to support several applications for smart factories, stadiums, shopping centres, airports, etc.

Finally, RIS can be deployed as energy-efficient auxiliary devices that are transparent to the wireless users, without the need of modifying the hardware configuration of the end-user devices. This offers high flexibility and compatibility with legacy wireless systems.

3.2.13.2 Affinity with ETSI work

ETSI is already engaged with in pre-standardization activities in RIS. An Industry Specification Group was established towards the end of 2021. ETSI ISG RIS will provide an opportunity for ETSI members to coordinate their pre-standards research efforts on RIS technology across various EU/UK collaborative projects, extended with relevant global initiatives, towards paving the way for future standardization of the technology. ETSI ISG RIS is concentrating its work on the following aspects: Use Cases, Deployment Scenarios and Recommendations, Technological challenges, architecture and impact on standardization, Communication Models, Channel Models, and Evaluation Methodology.

3.2.13.3 Time Frame

ETSI ISG RIS was created in 2021. A long-term roadmap is provided in Figure 8 below.

Rel#1-Exploration and Gap Analysis	Rel#2-Specifiation Framework	Rel#3-Final Specifications
Year-1 (2022) / Year-2 (2023)	Year-3 (2024) / Year-4 (2025)	Year-5 (2026) / Year-6 (2027)
Exploration • Targets an analysis of the technology potential, validation, maturity timelines and requirements for standardization • Deliverables are mainly GRs, WPs, and PoCs • Collaboration in terms of studies with other relevant ETSI ISG (e.g. THz) • Liaison with research forums for alignment of RIS technology prospects	**Initial specification** • Targets a specification of the functional architecture with reference points between the network, the RIS controller, the RIS, and the terminals • Deliverables are mainly GSs, GRs, WPs, and PoCs • Collaboration in terms of specifications with other relevant ETSI ISG (e.g. THz) • Liaison with SDOs (e.g. 3GPP) for alignment on the technology prospect for specifications	**Final specification** • Targets final specifications • Deliverables are mainly GSs, GRs, WPs, and PoCs • Bridging the results to the SDOs (e.g. 3GPP) where relevant specifications are taking place • End of the ISG

Figure 8: ISG RIS Long-term roadmap

It is foreseen that the ISG RIS will make the best use of its available periods. In the development of the first release, use cases and challenges to the technology are being studied. ISG RIS will also collaborate internally and externally to advance the technologies to be adopted by RIS. In the development of the second release, the architecture of RIS shall be studied. The collaboration with other ISGs and organizations are to be more relevant to use cases and scenarios. The final release is to provide a jumpstart for 3GPP or other SDOs to standardize RIS technology. This will also bring an end to the ISG.

Zooming out to a more comprehensive time frame, WRC-19 identified a few millimetre wave bands for IMT. During the development of this ETR White Paper, a number of Regulators were also consulting the public on the use of THz for wireless communication systems. In addition, the telecom industry is also studying the applications in THz, and a potential WRC-27 agenda item on IMT in THz. It is understood that this time frame will provide firm support to the deployment of 5G and 5G-Advance in mmWave bands, as well as the development of future generations in THz band.

3.2.13.4 Recommendations

RIS provides opportunities to manipulate the propagation channels and enable smart radio environments at a reduced power consumption and cost.

It is recommended, first, that interested parties should take part in the studies of theoretical and technological enhancements which will improve the performance of RIS while reducing the associated implementation and deployment cost.

Second, industry stakeholders should also actively participate in the early-stage standardization efforts, such as ETSI ISG RIS, working towards the realization of truly controllable, programmable, and smart radio environments.

It is also recommended that ISG RIS actively liaises with external research bodies, academia, labs and SDOs in order to create a globally harmonized technical specification.

3.2.14 Optical Wireless Communications

3.2.14.1 Description

To meet the high communication rate and high-precision sensing requirements in ElectroMagnetic Field (EMF)-free scenarios such as healthcare and industry automation, integrated sensing and communications is also possible through the use of optical wireless data transmission and communication (ISAC-OW). The optical frequency band has huge spectrum resources, including ultraviolet, visible, and infrared light, available for communication and sensing see Figure 9 below and reference [36].

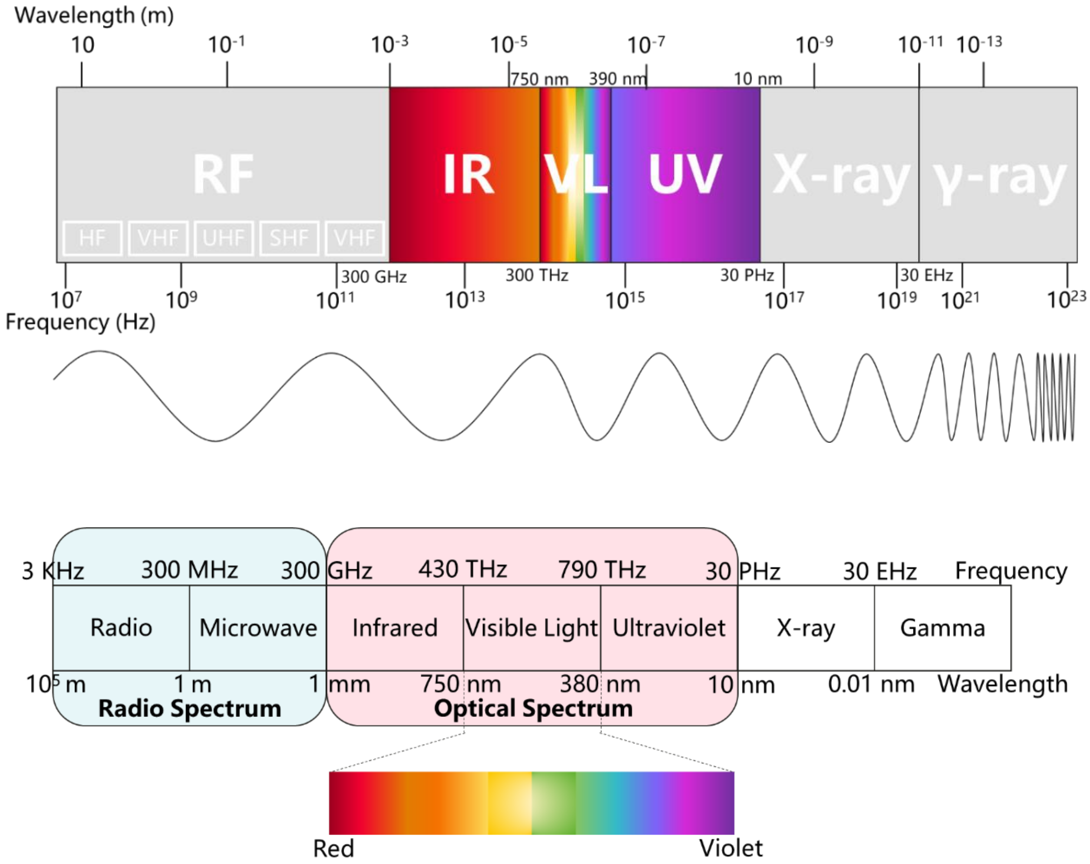

Figure 9: The Electromagnetic spectrum [37]

Therefore, optical spectrum-based communication and sensing technology can meet many future 6G application scenarios by supporting Tera bits per second (Tbps) rates, high-precision positioning, and high-precision sensing that will emerge in the 6G era.

Optical wireless communication systems exhibit many benefits including free, unlicensed spectrum, low cost, low power usage, secured connectivity, etc. when compared to RF-based communications. The main OWC technologies, namely Visible Light Communication (VLC), Light Fidelity (LiFi), Optical Camera Communication (OCC), and Free Space Optics (FSO), are considered to be “direct emission” type. Figure 10 illustrates the general architectures of these technologies [38].

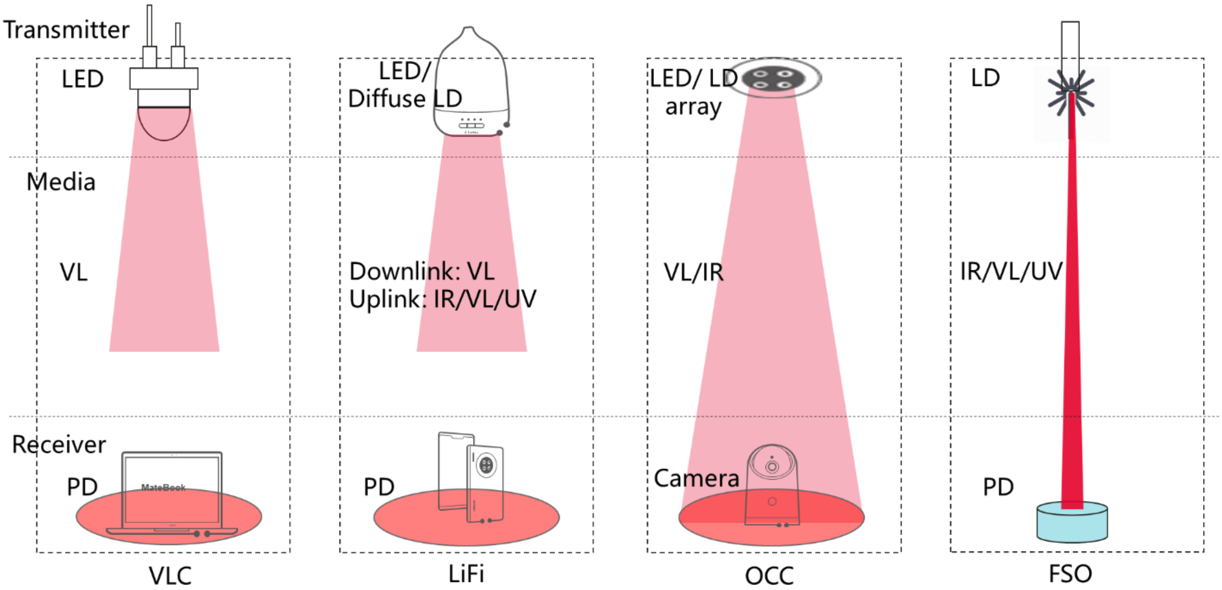

Figure 10: Direct emission type OWC technologies [37]

VLC and LiFi both use visible light spectrum for downlink only, whereas LiFi takes VLC principles further by realizing a fully networked wireless system. This includes bi-directional multiuser communications, and full user mobility. OCC uses camera, or image sensors, to receive the optical signal. If equipped with a LED array and an optical lens to distinguish the images of LEDs in the image sensor, an OCC system follows a massive-MIMO configuration. FSO incorporates very narrow laser beams which decrease the amount of geometrical path loss. In the meantime, Laser Diodes have very wide modulation bandwidth (up to tens of GHz), which makes the FSO a viable solution for high-speed point-to-point wireless communications. However, accurate beam tracking and pointing is required for FSO to maintain the alignment between the transmitter and the receiver. VLC, LiFi, OCC, and FSO are widely applied in the indoor communication scenarios, outdoor communications and satellite communications, etc.

Meanwhile, OWC also face several technical challenges:

- Architecture and operation schemes for VLC networks: in many indoor scenarios, illumination is done deliberately by reflection or refraction and are covered by lamp shades, covers and are turned towards walls or other objects. Thus, there is a need to develop techniques for high-speed communication even when the receiver is not in direct view of the transmitter.
- Handover: the handover techniques are important to support user mobility without information loss. The optimizing algorithm for multi-user downlink and wireless optical backhauling in optical networks are also important.

ISAC-OW technology can be naturally integrated into the existing lighting and light display systems, making every lamp and every screen part of the 6G ISAC-OW system. Given the ultra-high communication bandwidth, ISAC-OW is also a potential candidate to achieve ultra-high throughput. Because of the gap between the optical spectrum and the conventional electromagnetic spectrum, there will be no electromagnetic interference to conventional radio frequency bands. In this sense, ISAC-OW is especially suitable for electromagnetic radiation sensitive environments like smart healthcare and industrial manufacturing.

In addition, the sub-millimeter wavelength of the optical spectrum can achieve high-precision positioning and high-resolution imaging, which, when combined with the response of substances to the characteristics of light waves, will enable more precise and accurate indoor environment and health sensing and monitoring.

Capitalizing upon the advantages of the optical spectrum, which include high bandwidth, no RF interference, and high energy efficiency, the ISAC-OWC system creates additional opportunities and a solid technical foundation for 6G applications. The ISAC-OWC can meet the extreme requirements of communication use cases that the current wireless systems cannot satisfy. The user immersive and multi-sense scenarios, such as holographic telepresence, can be provided by the Tbps and sensing information by the ISAC-OWC system. Therefore, it would be expected that OWC technology could be utilized in many sectors, such as industrial, healthcare, retail, education, residential, office buildings, or hotels, which will continue driving OWC's development and commercialization. ISAC-OWC technology will be widely applied in health monitoring, indoor monitoring, outdoor sensing, environment reconstruction, etc.

3.2.14.2 Affinity with ETSI Work

The High bandwidth oPtical wirEless tRansmission For sEcure CommunicaTion (PERFECT) project, Co-funded by EFRE and the European Regional Development Fund will demonstrate the next generation LiFi system, with new high-speed VCSEL-arrays as transmitters, advanced transmission techniques, sophisticated Software-Defined Networking (SDN) protocols and new features for user localization. 5G-PHOS is a H2020 5GPPP Phase II project focusing on 5G integrated optical Fiber-Wireless networks that leverage existing photonic technologies towards implementing a high-density SDN-programmable network architecture. 5G-PHOS expects to release a seamless, interoperable, RAT-agnostic and SDN-programmable 5G network that supports 64x64 MIMO antennas in the V-band. Five universities, University Leeds, University of Strathclyde, University of Cambridge, University of Edinburgh, and University of Bath, perform joint research on Terabit Bidirectional Multi-user Optical Wireless Systems (TOWS) for 6G. In TOWS, they propose the use of new concepts in cellular optical communications to develop a Terabit Bidirectional Multi-user Optical Wireless System intended for use in an indoor environment. The Light Communication Alliance (LCA) [39] focuses on optical wireless technologies, fostering the development of optical wireless technologies to support communication. The IEEE 802.11bb standard supports LiFi as it has many advantages. VLC's progress in standardization has followed the industry's lead. IEEE forms the VLC technical standard IEEE 802.15.7-2011, which made the specifications of VLC modulation mode, networking architecture, and physical layer design.

As an important enabling technology for the next generation mobile communication system especially in 6G era, OWC is a relevant topic to be investigated by ETSI.

3.2.14.3 Time Frame

Since 2015, NASA's Lunar Laser Communication Demonstration (LLCD) transmitted data from lunar orbit to Earth at a rate of 622 Megabits-per-second (Mbps) by using optical communications. The Laser Communications Relay Demonstration (LCRD) is the follow-on mission scheduled in 2017. In 2016, the Wireless Personal Area Network Standards Working Group of the National Technical Committee for Information Technology Standardization released the White Paper on Visible Light Communications Standardization. In 2018, the GB/T36628 "Telecommunication and Information Exchange Visible Light Communication between Information Technology Systems" series of standards were released. The IMT2030 work group focuses on ISAC-OWC and OWC systems that are capable to demonstrate tens of Gbps data rate. The key optical related components will become more and more mature which enables the feasibility to be integrated into the ISAC-OWC technology to support various types of applications. Based on the 2030 vision of TOWS, the Tbps OWC system prototype might become feasible and it is expected to be implemented employing ISAC-OWC products.

3.2.14.4 Recommendations

Although various industries and standards organizations have made great efforts and contributions, including ITU/IEEE standards [40], as well as academic research institutes and lighting manufacturers, OWC has not been widely adopted due to limited performance (compared to the other mature wireless communication technologies), limited investment, as well as complicated industrial supply chains. For instance, the LED chip has always been dominated by the lighting industry, and communication manufacturers have not been involved. As a result, it is difficult to provide a competitive OWC solution in the short term. However, under the scope of the next-generation communication system, OWC may reach Tbps-level data rates, because the usable spectrum of light can provide higher bandwidth and has a greater potential as a candidate technology to reach extremely high data rates.

In order to realize this vision, a number of research aspects of OWC need to be further investigated, including system architecture, light source component and chipsets, and air interface technology, etc.

3.2.15 Intelligent Distributed Edge

3.2.15.1 Description

Edge Computing technologies have been available in Telco networks for many years. However, it is only with the advent of 5G networks that we are seeing a progressive adoption and deployment of edge computing infrastructure, which is evolving in parallel to the virtualization of the 5G communication infrastructure. Also, the design approach following the cloud-native paradigm is migrating from "monolithic" toward "microservice-based" applications providing further flexibility and dynamic management of computation workloads. From a standardization perspective, the support of edge computing in mobile networks can be considered mature from 3GPP Rel-17 and is further evolved through Rel-18 specifications (5G Advanced). 3GPP Rel-17 and Rel-18 are being aligned respectively with ETSI MEC Phase 2 and Phase 3 specifications. However, the deployment of 5G networks is still ongoing, and similarly the ecosystem of applications today is still partially anchored in the traditional design principles.

The communication and computation transformation process is still ongoing, and still at the early stages of its journey. Looking to the future, from a technology perspective, the rigid system design and decoupling between communication and computing in current mobile systems is expected to add complexity to scaling computing from data centres to the network "edges". In fact, traditionally, mobile systems and cloud computing systems have been designed separately from each other, focusing on providing better communication services with the cloud computing systems operating on top of the mobile communication system. This separate design approach may work well for centralized computing, but as computing becomes more distributed and is moved out towards the far network edge, close coordination between communication and computing is needed to realize the full benefits of distributed computing. Hence, the current separate design approach also introduces barriers to coordination between communication and computing and causes complexity and scalability issues. To prepare for the further evolution from edge computing to ubiquitous computing in 6G, the system bottlenecks and complexity issues need to be resolved. This requires a certain level of coupling or integration across communication and computing domains. Moreover, the pervasive usage of AI technologies will provide the required intelligence to efficiently manage and operate both communication and computing infrastructures.

Examples of some key enablers include:

- the use of AI agents and intelligent algorithms to manage cross-domain converged communication and computing resources, and to optimize edge cloud infrastructure,
- management of virtual resources and LifeCycle Management (LCM),
- application workload placements,
- configuration of the parameters needed for end-to-end network automation,
- network slicing management,
- application scaling,
- security and privacy enforcements,
- data management in cross-domain scenarios,
- QoS monitoring APIs,
- frameworks to help customers (e.g. verticals) in the assessment, optimization and utilization of the overall infrastructure, including from an energy efficiency perspective (in this perspective, sustainability of future systems can only be achieved through a long-term vision and design).

All of these aspects are contributing to the overall vision of ***Intelligent Distributed Edge***, which is considered as a key enabler for the future of communication and computation. ETSI and its members are continuously evaluating the standardization and open-source efforts that are needed to support the evolution towards future systems and offer new services for existing and new customers.

3.2.15.2 *Affinity with ETSI work*

ETSI is already highly active with standardization activities in Multi-access Edge Computing (MEC), which is an Industry Specification Group (ISG) established in 2015. The overall goal of this MEC group (since its creation) is to offer application developers and content providers, cloud-computing capabilities and an IT service environment at the edge of the network. The MEC environment is characterized by ultra-low latency and high bandwidth as well as real-time access to radio network information that can be leveraged by applications. In addition, MEC enables a new ecosystem and value chain. By using MEC, operators have the possibility to open their Radio Access Network (RAN) edge to authorized third-parties, allowing them to flexibly and rapidly deploy innovative applications and services towards mobile subscribers, enterprises and vertical segments. MEC is a natural development in the evolution of mobile base stations and the convergence of IT and telecommunications networking.

Importantly, Multi-access Edge Computing is an access agnostic technology, hence not limited to cellular infrastructure, but supporting also Wi-Fi and fixed access networks. Furthermore, MEC supports a variety of use cases, and will enable new vertical business segments and services for consumers and enterprise customers. MEC Usage scenarios include (but are not limited to):

- V2X;
- video analytics;
- location services;
- Internet of Things (IoT);
- augmented reality;
- optimized local content distribution; and
- data caching.

MEC allows software applications to access locally stored content and real-time information about the local-access network status. By deploying various services and caching content at the network edge, mobile core networks are alleviated of further congestion and can efficiently serve local purposes.

As said, in addition to mobile networks, MEC also addresses both fixed and WLAN accesses. This open approach of MEC industry standards allows a variety of deployment options for MEC systems that will act as enabler for new revenue streams for a diverse ecosystem of stakeholders, ranging from operators, service providers, cloud providers, network vendors, system integrators and software companies. Also, MEC allows the discovery and consumption of API and services produced by other applications, hence opening the market to the universal exposure of APIs not standardized in ETSI MEC (as long as they comply with basic MEC principles for API design).

ETSI ISG MEC is currently working on the "MEC Phase 3" activities that consider a complex heterogeneous cloud ecosystem. The work embraces MEC security enhancements, expanded traditional cloud and NFV Life Cycle Management (LCM) approaches, and mobile or intermittently connected components and consumer-owned cloud resources.

Artificial Intelligence (AI) will play more and more important roles in future mobile communication and computation system. Although ETSI ISG MEC is currently not directly focused on edge AI enablement, in general ETSI has been investigating a reference model for autonomic networking, cognitive networking and self-management of networks and services in Generic Autonomic Networking Architecture (GANA) which also deals with centralized and distributed management and control solutions for networks and services. Furthermore, ETSI ISG Experiential Networked Intelligence (ENI) aims to design an intelligent architecture for network management and operation. It is likely that future activities may need to consider also these directions, and in this case it will be appropriate to interact with these other ETSI groups.

3.2.15.3 Time Frame

ETSI ISG MEC was created in 2015. The MEC long-term roadmap is shown in the following Figure 11 and covers MEC Phase 1, Phase 2 and the current Phase 3 as well as providing some key aspects from the current ISG MEC Terms of Reference #5, providing a first view of the future MEC Phase 4 work (2024-2026 timeframe).

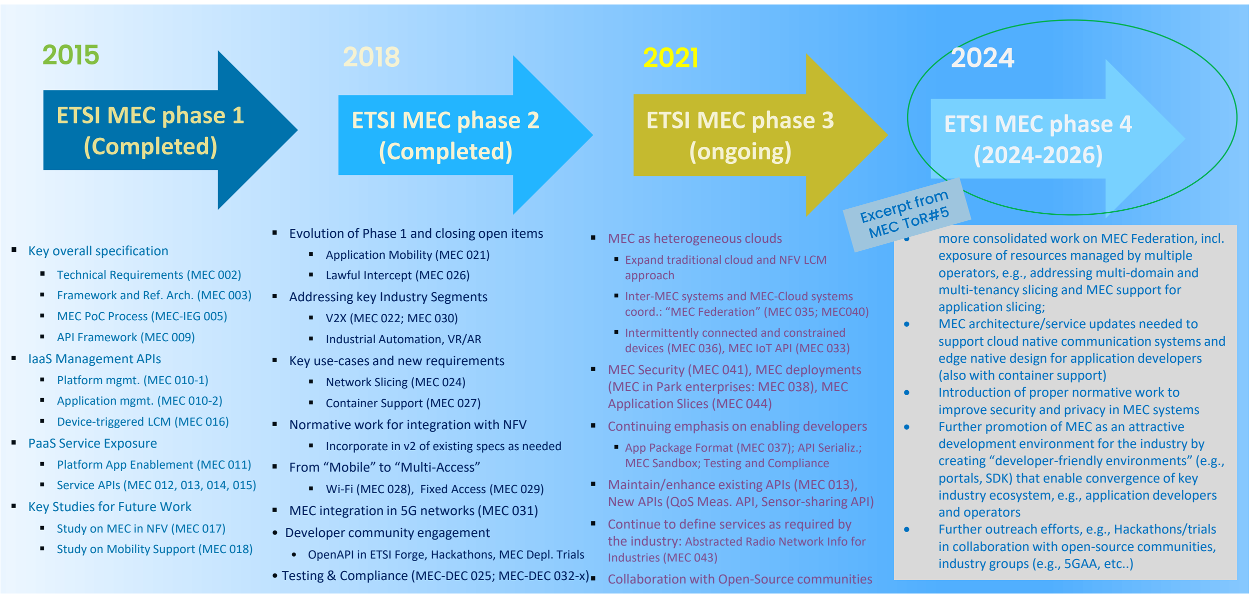

Figure 11: ISG MEC Timeline

The ISG MEC Phase 4 work is expected to include the following key aspects, which are relevant for the enablement of the Intelligent Distributed Edge:

- consolidated work on MEC Federation, including exposure of resources managed by multiple operators, e.g. addressing multi-domain and multi-tenancy slicing and MEC support for application slicing,
- MEC architectural and service updates to support cloud native communication systems and edge native design for application developers along with container support,
- introduction of normative work to improve security and privacy in MEC systems,

- further promotion of MEC as an attractive development environment for the industry by creating "developer-friendly environments" (e.g. portals, SDK) that enable the convergence of key industry ecosystems, e.g. application developers and operators,
- further outreach efforts, e.g. Hackathons/trials in collaboration with open source communities, industry groups (e.g. 5GAA). The collaboration with open-source initiatives is key.

ISG MEC will continue to collaborate both internally in ETSI (e.g. with TeraFlowSDN) and externally (e.g. with Linux Foundation) in order to accelerate the adoption of MEC technologies and further enable more advanced features for application developers.

In general, the paradigm of Intelligent Distributed Edge is quite pivotal for 6G systems. In fact, so far it has been widely explored from a research point of view and at conceptual level, by both academia and industry, while practical implementations going beyond research purposes are missing. This research will eventually pave the way toward future 6G systems, and feed proper standardization led by experience. In the meantime, even without waiting for 6G, both academic and industrial players can already identify the requirements for the introduction of Intelligent Distributed Edge, by considering the presence of a great number of AI use cases already present in the current systems. Corresponding research as well as (pre-)standardization activities related to Intelligent Distributed Edge are thus expected to continue for the next couple of years.

3.2.15.4 Recommendations

The purpose of MEC is to create a standardized, open environment which enables the efficient and seamless integration of applications from vendors, service providers, and third parties across multi-vendor Multi-access Edge Computing platforms. The initiative aims to benefit a number of entities within the value chain, including mobile operators, application developers, Over The Top (OTT) players, Independent Software Vendors (ISVs), telecom equipment vendors, IT platform vendors, system integrators, and technology providers; all of these parties are interested in delivering services based on Multi-access Edge Computing concepts. The work of the MEC initiative aims to unite the Telco and IT-cloud worlds, providing IT and cloud-computing capabilities within the access network. The MEC ISG specifies the elements that are required to enable applications to be hosted in a multi-vendor multi-access edge computing environment.

Recommendation #1: In order to further expand the current MEC work and support the evolution toward future systems, it is recommended that all interested parties should take part in the technological enhancements and normative work in ISG MEC, by actively participating in the ETSI ISG MEC standardization efforts for MEC Phase 4 (2024-2026).

Recommendation #2: In order to enable the creation of a globally harmonized technical specification for MEC, it is recommended that ETSI ISG MEC should actively liaise with:

- the research community, including all relevant projects, research bodies and academia labs;
- all relevant SDOs working in the area of MEC, to avoid duplication of work ,and deliver coherent standards to the edge ecosystem;
- all relevant open source initiatives, such as CAMARA (under Linux Foundation), complementing the standard work in the ISG.

The latter is important for MEC, as CAMARA work is key for the exposure of APIs at the edge that can further enable the adoption of edge-native design principles towards intelligent distributed edge systems.

Recommendation #3: since the Intelligent Distributed Edge will likely be a key enabler for the pervasive introduction of AI in future 6G systems, therefore it could be recommended to:

- deep dive into use cases and requirements for 6G Intelligent Distributed Edge within ETSI;
- consolidate the relevant initiatives within ETSI to discuss and contribute to new 6G paradigms on native AI architecture enabled by Intelligent Distributed Edge.

3.2.16 Environmental sustainability

3.2.16.1 Description

The term environmental sustainability covers the actions and processes aimed at the conservation of our limited natural resources and protection of the ecosystems to support health and wellbeing of the population while ensuring economic growth. The related activities in ETSI on environmental sustainability focus on the sustainable digital transformation by defining processes and requirements for the sustainable use and deployment of Information Communication Technology (ICT) products and networks.

Environmental sustainability aspects linked to ICT include:

- Power saving
- Energy Efficiency
- Reduction of CO2 emissions
- Product/network/services lifecycle management
- Resource management particularly the management of rare raw materials
- Reduction of pollution and waste

The sustainable digital transformation should be supported by guidelines, standards, regulations that help to:

- reduce power consumption at the different stages of ICT equipment operations
- improve the energy efficiency
- improve and reduce the use of raw material (e.g. Lithium for batteries/microchips/screens)
- define tools to determine the environmental impact
- define tools for the sustainable use and deployment of ICT equipment/networks and services
- reduce the waste

3.2.16.2 *Affinity with ETSI Work*

ETSI is widely active in environmental sustainability of the ICT sector and has Technical Bodies, TC EE and TC ATTM, that have been working on related topics for many years. These two TBs are the reference for the environmental sustainability in ETSI, but in some cases other TBs are also involved like TC CABLE, for power consumption, or TC CYBER, for the eco-design requirements associated to firmware/Operating Systems.

TC EE has already produced several deliverables on energy efficiency, circular economy and Life Cycle Assessment. TC ATTM has developed deliverables for global KPIs of environmentally sustainable sites.

Furthermore, TC EE is involved in standardization of eco-design requirements for EU Regulations in the frame of eco-design directive 2009/125/EC on which they have already produced harmonised standards for the “network stand-by” of interconnecting ICT products.

Therefore, ETSI will certainly continue to ensure great support to consumers, industries and regulatory bodies with publication to address environmental sustainability and supporting deliverables of Regulations on environmental sustainability aspects in the ICT sector.

3.2.16.3 *Time Frame*

Environmental sustainability is a topic covered by different standardization organizations, to cite few of them:

- IEC TC111 “Environmental standardization for electrical and electronic products and systems” with European mirror committee CENELEC TC111X
- ISO/IEC JTC1/SC39 “Sustainability, IT and data centres”
- ITU-T SG5 “EMF, environment, climate action, sustainable digitalization, and circular economy”

Therefore, coordination with other standardization organization is a key factor to avoid duplication of work and waste of resources but, assuming that a collaboration plan is put in place with other organizations, ETSI has expertise to increase its role in the environmental sustainability in the ICT sector.

The goal for ETSI would be to complement the present work on environmental sustainability done in other standardization organization with deliverables to fill the gaps in the ICT sector in order to help achieving the goal 13 “Climate action” of UN Sustainable Goals.

3.2.16.4 *Recommendations*

Environmental sustainability is one of the key topics to consider in the design, deployment, use and dispose of ICT products and ETSI is one of the key actors to contribute in this field. Proposed recommendations are the following:

Recommendation #1: Analyse the deliverables on environmental sustainability applicable to ICT and produced by IEC TC111, ISO/IEC JTC1/SC39 and ITU-T SG5, and others identified organizations, to map the gaps and define a work plan to fill the gaps to cover the environmental study in the ICT sector.

Recommendation #2: Cooperate and collaborate with other organizations working on standardization of environmental sustainability for the ICT sector to produce the required deliverables.

Recommendation #3: Maintain updated the published ETSI deliverables on environmental sustainability taking into account the technology evolution.

Recommendation #4: Monitor development of EU Regulations/Directives in the ICT sector and take prime role in the production of standards for the environmental sustainability required for the ICT Regulations/directives.

Recommendation #5: Identify and promote application of ICT in support to the environmental sustainability. This may include the use of AI/ML in support of the environmental sustainability.

Recommendation #6: Promote ETSI work on environmental sustainability with the organization of workshops and press releases.

3.2.17 Integrated Sensing And Communications (ISAC)

3.2.17.1 Description

The Integration of Sensing and Communications together enables the two functions to mutually benefit each other within the same system. On one hand, the communication network as a whole can serve as a sensor. The radio signals transmitted and received by network elements explore the radio wave transmissions, reflections, and scattering to sense and better understand the physical world. The capabilities to obtain range, velocity, and angle information from the radio signals can provide a broad range of new services, such as high accuracy localization, gesture capturing and activity recognition, passive object detection and tracking, as well as imaging and environment reconstruction. This is known as "Network as a Sensor". On the other hand, the capabilities of high-accuracy localization, imaging, and environment reconstruction obtained from sensing can assist and improve the communication performance – for example, more accurate beamforming, faster beam failure recovery, and less overhead to track the Channel State Information (CSI). This is known as "sensing-assisted communication". Moreover, sensing is a "new channel" that observes, samples, and links the physical and biological worlds to the cyber world. Realtime sensing is therefore essential to make the concept of digital twin - a true and real-time replica of the physical world - a reality in the future.

3GPP has initiated some preliminary study on use cases and potential ISAC requirements using the air interface of 5G advanced. 6G ISAC systems will however be further optimized, fully integrated, and will not be constrained by the limitations of the current 5G system. The sensing use cases offered by these future 6G ISAC systems will most likely include ultra-high accuracy localization and tracking, simultaneous imaging, mapping, and localization, augmented human sense, gesture and activity recognition, as illustrated in Figure 12 [41]. We shall elaborate how these use cases would take a role in future vertical applications below.

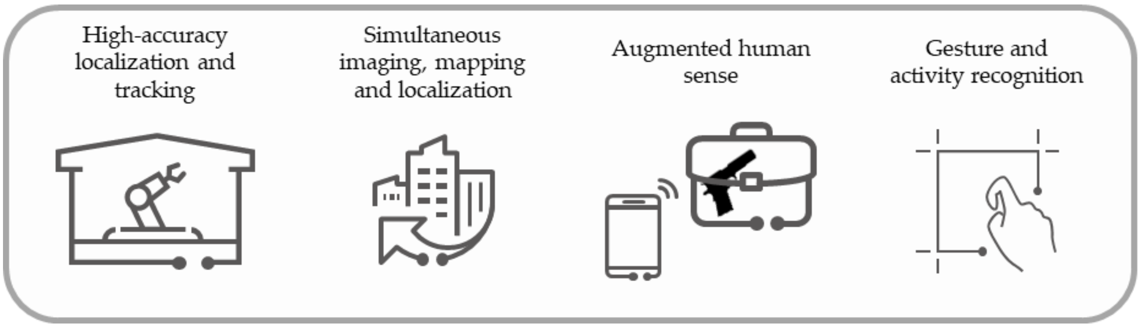

Figure 12: Four categories of typical ISAC use cases in 6G [41]

High-Accuracy Localization and Tracking

For 6G ISAC, the large bandwidths available in and above the current mmWave bands and the use of ultra-massive MIMO technologies will provide superior resolutions and excellent multipath resolving capabilities for high-accuracy localization applications for both device-based (e.g. user equipment connected in the 6G networks) and device-free (environment) objects. In addition, the dense deployment of massive antennas will also enable high precision direction estimation. To exemplify the benefits in a factory environment with such sensing capabilities, collaborative robots in future smart factories will be able to work together in a safer way with humans and also with each other. Some examples of collaboration between moving robots may include a drone landing on a moving carrier vehicle to get charged; a delivery robot refilling liquid or a solid substance to a smart container (bin/tank) when it is detected as empty, etc. In such use cases, centimeter level localization accuracy is required to perform the task.

Simultaneous Imaging, Mapping, and Localization

6G ISAC based sensing capabilities in simultaneous imaging, mapping, and localization enable the mutual performance improvements of these functions which opens up the realm of possibilities in 3D indoor/outdoor non-line-of-sight imaging and mapping. For instance, the sensors on single mobile vehicle usually have restricted view and limited coverage due to the weather, obstacles and sensors' power control. That said, nearby moving vehicles and stationary base stations can jointly provide a greater field of view, longer sensing distance, and a higher resolution with the help of an ISAC system. Thus, the vehicles can use the reconstructed map processed by the base stations to determine their next move to achieve higher levels of autonomy. Furthermore, the sensing resolution and accuracy performance significantly improve due to the fusion of imaging results that are shared globally through the network with cloud-based services. The densely distributed base stations in the urban area and the use of ISAC facilitates environmental reconstruction and 3D localization which in turn can form the virtual urban city. Similar use cases could be applied to indoor factories with many autonomously moving AGVs or robots.

Augmented Human Sense

With the use of much higher frequency bands, the ISAC system can be implemented in portable devices to augment human senses and enable people to "see" beyond the limits of human eyes. Such capabilities can be equipped on portable terminals (sensing devices such as 6G-enabled mobile phones, wearables or medical equipment). This will open the door for numerous applications, such as remote surgery, detection of product defects, detection of particles/molecules in the air, environmental conditions etc., where very high range and cross-range resolutions are required.

6G ISAC capability can also play an important role in the promotion of medical technologies applied to diagnosis, monitoring, and treatments. Chronic diseases (asthma, arrhythmia, hypoglycemia, etc.) need to be constantly monitored. In this case, user equipment with ISAC capabilities can immediately help remote doctors to acquire accurate information of patient's condition.

Touchless Control with Precise Gesture Recognition

Device-free gesture and activity recognition based on the joint capability of sensing and machine learning is another promising aspect of 6G ISAC applications to promote contactless user interfaces and camera-free supervision where privacy can be protected. With high classification accuracy, many functionalities such as gesture recognition, heartbeat detection, fall detection, respiration detection, sneeze sensing, intrusion detection, etc., can be implemented in a smart hospital in the foreseeable future. As a novel usage scenario, the medical rehabilitation system in the smart hospital could enable automatic supervision of patients during their physiotherapy exercises. As such automatic prompt alerts on incorrect movements or gestures could be provided, thus significantly improving the patients' rehabilitation.

3.2.17.2 Affinity with ETSI Work

In the most recent call for the phase 2 of the EC funded 6G research (6G Smart Network and Services (SNS) [7]), the EC has specifically listed the topic of "integrated communications and sensing" in the 2023/2024 SNS work programme [8]. This highlights the importance of this research area for future 6G communications. Four out of the five awarded projects in the stream "Wireless Communication Technologies and Signal Processing" focused on exploring enabling technologies for ISAC. The selected EC funded projects for this call are expected to start at the beginning of 2024, in tandem with the ongoing 6G SNS projects from the phase 1 of 6G SNS, and may last up to 36 months.

Furthermore, ETSI has recently (October 2023) established a new industry specification group for 6G ISAC pre-standardization activities, building on the results of the EC funded 6G SNS projects in both phase 1 and phase 2, and also on the ongoing related ETSI activities, such as the ETSI ISG on RIS dealing with meta-surfaces to provide a reflected link connection when the line of sight connection is blocked and the ISG mWT which deals with Sub-THz band for backhaul/front-haul links.

3.2.17.3 Time Frame

As mentioned above, standardization efforts at 3GPP so far have concentrated only on a study of preliminary use cases and potential ISAC requirements for 5G advanced. More recently, as part of the Release 19 scope planning, 3GPP has agreed to start exploring the implications of ISAC on the 3GPP channel model. ISAC in 3GPP is anticipated to span multiple releases, starting from the exploratory work expected in Release 19. Additionally at IEEE, support of various short range sensing use cases have been considered in both Wi-Fi and UWB standards. Substantial additional standardization effort will be needed to support the more advanced ISAC use cases promised by 6G networks, in line with the scope and timeline of the ETSI ISAC ISG.

3.2.17.4 Recommendations

ETSI has recently launched the ISG ISAC with the mission to establish technical foundation for ISAC development and standardization in 6G. The ISG ISAC has the following scope:

- Definition of a prioritized set of 6G use cases and sensing types with a roadmap for their study and evaluation.

- Development of advanced channel models for the target 6G ISAC use cases and sensing types, and validation through extensive measurement campaigns that can fill the gaps of existing communications-based channel models (e.g. 3GPP, IEEE 802. ITU-R).
- Specification of KPIs and evaluation methodology building upon the channel modelling and measurements, simulations/POCs, and synergies with ETSI ISG RIS and ISG THz.
- Study of a System and RAN architecture framework for 6G ISAC, including end-to-end deployment considerations.
- Study of the privacy and security aspects of sensing data in the ISAC 6G framework.
- Study of impact of widespread deployment of ISAC on UN sustainability goals.

The 3GPP is also expected to start exploring the topic of ISAC in Release 19 as part of 5G-Advanced, with focus on a limited subset of use cases to help gain first insights on the changes required for the 3GPP channel model to support ISAC.

Recommendation #1: Whilst ISAC ISG is more forward looking and targeting at 6G ISAC use cases and scenarios, it is recommended that the ISAC ISG stays coordinated with the 3GPP ISAC activities in Release 19 in order to ensure complementarity and alignment of the ISAC ISG with the 3GPP ISAC roadmap to feed results into future 3GPP releases (R20+).

Recommendation #2: It is recommended that the ISAC ISG stays coordinated with the ITU-R IMT-2030 activities related to ISAC requirements, and evaluation methodologies.

3.2.18 Non-Terrestrial Networks (NTNs)

3.2.18.1 Description

As defined by the 3rd Generation Partnership Project (3GPP), a Non-Terrestrial Network (NTN) refers to a network, or segment of networks using Radio Frequency (RF) resources on board of a satellite or Unmanned Aerial System (UAS) platform. A satellite (or UAS platform) may be implemented either as a relay node or a base station, thus distinguishing transparent and regenerative architectures. NTN plays an essential role in expanding the service coverage of terrestrial networks and providing continuous connectivity for areas not covered by terrestrial networks.

Being different from conventional mobile communication networks, current commercial satellite communication services still require dedicated and expensive user terminals, which may not be easily available and usable for consumer type end users. As indicated by recent technology trend reports and 6G vision papers, NTN is expected to integrate with Terrestrial Network (TN) to form a global 3D integrated communication network covering the earth, including the sea, land, air, and sky as shown in Figure 13. The benefits of integrated TN and NTN are manifold. Firstly, it will change the status quo, because the satellite industry can utilize the ecosystem and the large-scale business of the mobile communication industry, potentially resulting in lower terminal prices and service cost reduction and making TNs more attractive to end users. Secondly, such an approach may significantly improve user experience towards connectivity "anytime and everywhere" – the ever-given promise of the mobile radio industry. Thirdly, by achieving a unified design for TN and NTN, the barriers between the different types of satellite systems could be alleviated, allowing easy-roaming for end users between TN and NTN from different operators.

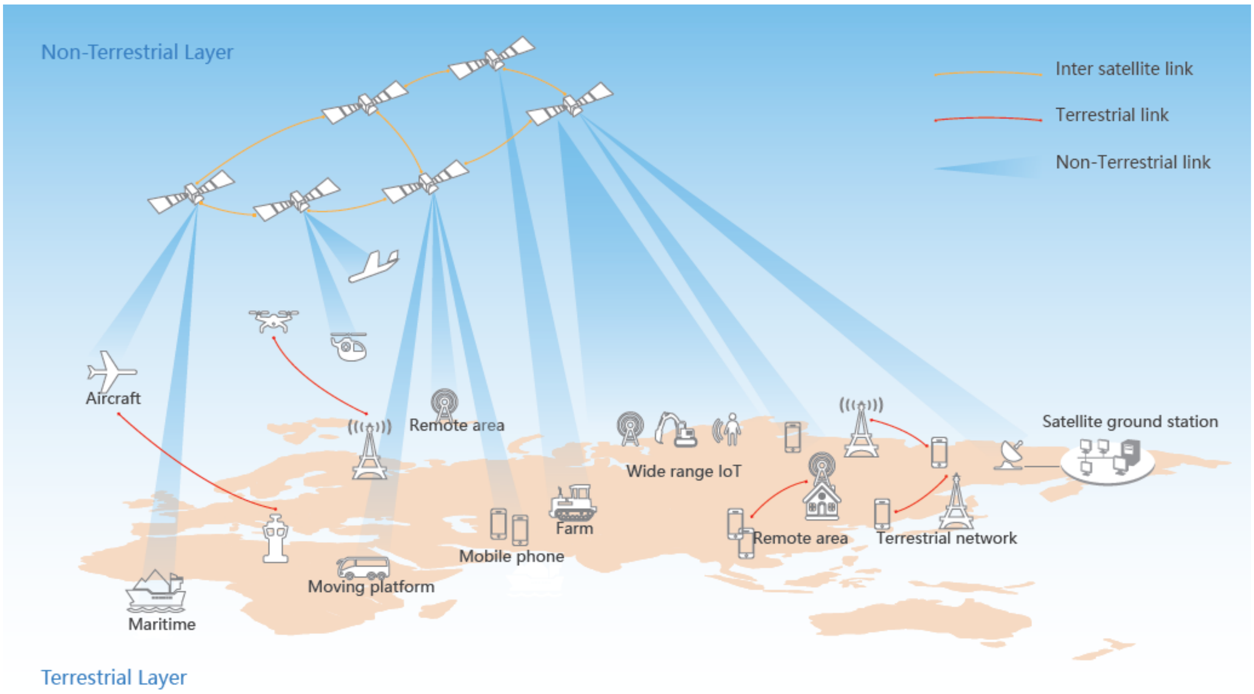

Figure 13: Illustration of integrated NTN and TN to form a global 3D communication network

This capability will not only be useful for supporting existing use cases requiring wide area coverage, but it also enables a variety of future applications.

Extreme coverage

Today, almost half of the world's population lives in rural and remote areas that do not have basic Internet services. NTNs can provide affordable and reliable mobile broadband services for areas where conventional telecom operators cannot afford to build the required infrastructures. NTN nodes (such as satellites, unmanned aerial vehicles, and high-altitude platforms) can be flexibly deployed, connecting people through various devices such as smartphones, laptops, fixed-line phones, and televisions.

Mobile broadband for the unconnected

Current commercial satellite communication systems have low transmission rates which are associated with high costs. In addition, current NTN mobile phones are not aligned with the terminal equipment of the cellular network, and hence people need to use two different types of terminals to access the satellite network and the cellular network, respectively. In the future, mobile phones will be able to directly connect to satellites for mobile broadband services, with data rates similar to those of cellular networks in remote areas. For example, the user data rate should be able to reach 5 Mbit/s for downlink and 500 Kbit/s for uplink.

Broadband connection on the move

People should be able to access the Internet anytime and anywhere, no matter which kind of transportation means they use. Considering air travel for instance, in 2019 over 4 billion passengers travelled by aircraft, which means almost 12 million people fly somewhere every day. Most of them have no Internet connection during the flight at all, or they experience very low speed Internet access. Future mobile communication systems should provide mobile broadband services for all type of passengers - no matter if they are on the ground or in the sky.

Global scale long distance low latency service offering

NTN, especially LEO networks are well positioned to provide low latency services over long distances at global scale.

The fact that radio waves and light travel faster in free space than light in fiber optic cables gives NTN networks a clear advantage over terrestrial fiber optic networks for delivering traffic with low latency requirement over long distances.

Furthermore, NTN does not face the deployment difficulties (over the mountains) or impossibilities (over the oceans) faced by microwave systems that typically provide low latency services.

Considering the first order effects (speed of light, distance, and altitude), the following Figure 14 shows the effective region where LEOs provide better delay performance than optical networks.

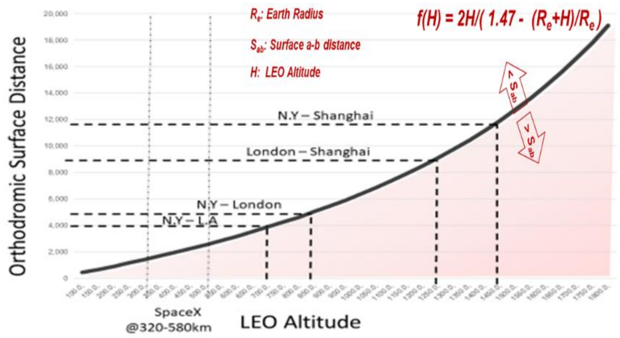

Figure 14: LEO altitude vs performance

Extend IoT services to unconnected/remote areas

Currently, Internet of Things (IoT) communication is mainly based on cellular network coverage, which limits the usage of IoT especially in remote areas. NTN could be a good solution to resolve such a limitation. By extending IoT services to as yet unconnected areas, it is possible to collect various environmental information, such as the status of Antarctic penguins, the living conditions of polar bears, animal and crop monitoring, etc., especially from remote and uninhabited areas.

High precision positioning and navigation

In future, most cars will have the capability to connect to the terrestrial network in order to receive vehicle-to-everything (V2X) services. However, such service provisioning and user experience is highly impacted by the coverage range. NTN can provide enhanced support for high-precision navigation and positioning services and improve the positioning accuracy to centimeter level. On this basis, V2X services could be provided in a much wider range of areas, yielding truly ubiquitous connectivity, which will support adoption of such V2X services by the end users as well as enable further innovations (e.g. support autonomous driving navigation, etc.). Other than V2X, high precision position and navigation services could also be used in other sectors, e.g. high-precision agriculture navigation, mechanical construction navigation, and high-precision user positioning services.

Real-time earth observation and protection

Due to fast deployment of mega constellations[4] and the advancement of remote sensing technology, NTN could be envisioned for remote sensing in real-time and with high resolution. With these two distinct features, NTN could be used for many new use cases from the field of earth observation, such as real-time traffic dispatching, real-time remote sensing maps for consumer type business, high-precision positioning and navigation with high resolution sensing, and enhancing the way in which to respond to natural disasters, in order to provide better protection of our daily life as well as our natural environment.

First responder communication and disaster relief

Terrestrial network infrastructure is vulnerable to natural disasters, such as earthquakes and tsunamis. A continuous and reliable emergency communication system is necessary in disaster scenarios to support disaster prediction, warning, emergency response, and emergency communication, which provides users with services to react to emergencies and natural disasters in a timely manner. NTN is an effective means for responding to and managing emergencies with enhanced high reliability.

3.2.18.2 Affinity with ETSI Work

In the call for European Commission funded 6G research (6G Smart Network and Services (SNS) [8]), the topics of "NTN infrastructures" and "Integrated NTN service provision" are specifically listed in the scope of SNS-2022-Stream-B-01-03 [42]. This highlights the importance of NTN research for future 6G communications. Furthermore, ETSI has highlighted NTN as a key technology trend from the ETR 2022 edition, it would be recommended to develop 6G NTN under ETSI ISG scheme, which could be potential input to ETSI TC SES. It is recognized that the discussions on the technical evolution of NTN and how they integrate with terrestrial networks takes place alongside commercial and political pressures that will shape deployment. Nevertheless, due to the numerous potential benefits that NTN will bring to the future 6G system, it is recommended for ETSI to initiate pre-standardization activities for 6G NTN to enable a smooth transition of the EC funded research projects towards 3GPP in the 6G timeframe.

---

[4] Mega-constellations refer to a new satellite generation of very large constellations in low Earth orbit (LEO) to provide low-latency, high bandwidth (broadband) Internet service.

3.2.18.3 Time Frame

Satellite communication will become an important part of 5G-Advanced and 6G in the global communication ecosystem. 3GPP officially started to elaborate on integrating satellites into 5G New Radio (NR) under the title "Non-Terrestrial Network (NTN)." The Study Item (SI) of NTN (Release 14 to Release 16) identifies NTN scenarios, architectures, basic NTN issues and related solutions, as well as 12 potential use cases by considering the integration of satellite access into the 5G network including roaming, broadcast/multicast, and narrow-band-IoT 0, 0, 0. In Release 17, the first Work Items (WIs) of New Radio Non-Terrestrial Network (NR-NTN) and Internet of Things Non-Terrestrial Network (IoT-NTN) were approved at the end of 2019. NR basic features will be supported by satellites based on transparent architecture in R17~R18, while R19 may be the first release to cover satellites with regenerative architecture. The ITU-R IMT 2030 framework incorporates NTN as a necessary concept and this should encourage further development as we move closer to 6G. 6G NTN will begin from Release 20, and more enhancements and new features will be discussed to support integration of TN and NTN and improve service capabilities compared to 5G and 5G-Advanced NTN. NTN with ultra-dense constellation in the very Low Earth Orbit (vLEO) will become an integral part of the 6G network and play an essential role for ensuring extremely flexible services for communication and access.

3.2.18.4 Recommendations

6G NTN will be able to enhance mobile broadband coverage in unconnected areas, provide universal services worldwide and expand to new application scenarios (mobile phone, vehicle, maritime, aircraft, etc.). Compared to 5G and 5G-Advanced NTN, potential new features of 6G NTN, such as multi-satellite and multi-beam coordination, TN-NTN & NTN-NTN multi-connectivity, dynamic beam and resource management, unified network architecture to enable seamless connectivity via NTN and TN nodes, network service orchestration including the NTN domain, etc. will be technical enablers to realize the 6G NTN vision of global coverage and ubiquitous connectivity. Therefore, we recommend that ETSI initiate discussions and activities towards 6G NTN. The specific recommendations are as follows:

- **Recommendation #1:** ETSI can start to define scenarios and important use cases for 6G that NTN can beneficially support.
- **Recommendation #2:** ETSI can support the pre-standardization work on NTN by initiating a new ISG.
- **Recommendation #3:** ETSI can cooperate and collaborate with other organizations working on standardization of NTN topics.

3.2.19 Integration of High Performance Computing and Communications

3.2.19.1 Description

Go is a game known for requiring a high level of intelligence. In 2016, Google's AlphaGo was the first computer program to defeat a professional human Go player. More recently, ChatGPT has astounded the world with its ability to have human-like conversations, something that would not be possible without supercomputers performing tens of billions of calculations. Indeed, HPC is changing the way we live and work, greatly increasing computing power demands. Consequently, see the trend of users requiring access to massive and ever increasing resources, enabling advanced Compute and Artificial Intelligence applications.

Using mainframe computers such as supercomputers, HPC leverages super-high computing and storage capabilities to solve complex and advanced computation problems at a high speed. Nowadays, there is a set of problems that are difficult to be resolved without recurring to HPC, such as those related to network information security, big data, AI, biopharmaceutical chemistry, financial engineering, smart manufacturing, epidemic prevention and control, simulations and research, where HPC is more and more integrated. In the context of communication systems, we have furthermore identified communication latency as a key bottleneck. Extensive research has been undertaken on how to optimally combine the benefits and drawbacks of central compute approaches (data centres) and local cloud services available at the Edge. There is a clear trend of latency critical applications being locally addressed improving the overall user experience.

Currently, HPC commonly makes use of computing clusters, where a high number of compute nodes are networked together and applying the parallel computing paradigm to archive large processing power. The network or fabric used to connect the nodes plays a very important role in the architecture of the system. HPC tolerates very badly the packet loss in the communication between nodes. The performance of the whole system can drop drastically with just a very low percentage of packet loss that are insignificant in other applications. Still, this classical separation of Compute and Communication will not prevail in the future. Rather, there is a trend for Compute and Artificial Intelligence features being natively integrated into future communication systems as a key differentiator over previous generations. The network will thus be able to manage low-latency distributed compute features and offer its knowledge through AI-as-a-Service type of applications to end users.

In order to make this trend a reality, more switching ports are needed to carry the traffic of the increasing number of applications. Within HPC, the increase in compute power of each single unit is less relevant than the possibility to have an efficient Data Centre and Distributed Compute Network able to properly distribute the workload and prioritize the services needed to support the data centre operations, like storage.

Instead of using ad-hoc switching technologies, such as InfiniBand, which drives up the computing, maintenance and management costs and restricts the scaling of HPC systems, Ethernet is a mature, cost-effective technology and the capacity of the ports is evolving from 10GE to the currently supported 400GE and even 800GE in the near future. As the computing scale expands, many networks need to improve their media bandwidth and port density to better meet the computing needs. This is fuelling the rapid development of Ethernet technology as an alternative to InfiniBand even though it is a more consolidated technology.

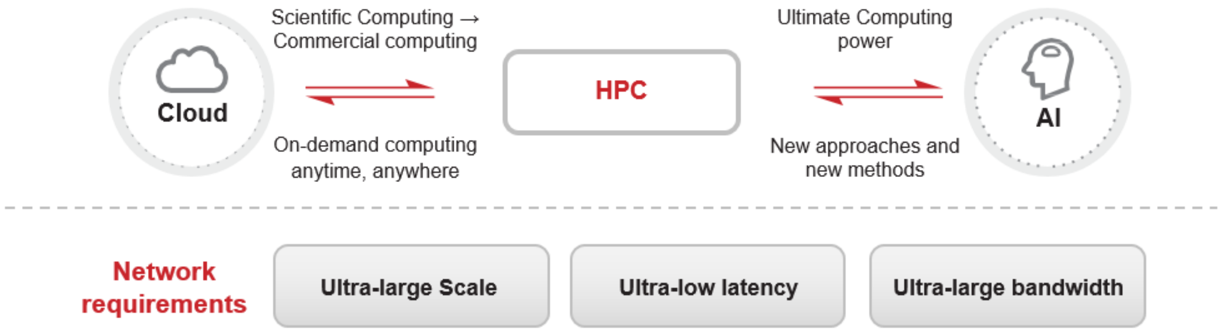

Figure 15: General HPC Overview

In the future the data centre will have to evolve as underlined by the following trend example:

- Ultra-large Scale: HPC data centre will be able to support more than 100,000 server nodes in future.
- Ultra-low latency: The latency could range from 500 to 300 ns in future among the data centre nodes.
- Ultra-large bandwidth: support of 400GE, and future support 800GE in data centre networking in the future.

In the context of an integration of HPC and Communication networks, the ultra-large scale approach is not limited to data centres and server nodes. Rather, it includes any type of processing resources, including Compute and Artificial Intelligence elements, that are managed as distributed resources across the entire network.

3.2.19.2 Affinity with ETSI Work

Considering the major importance of next generation of Telco networks and services for HPC, ETSI should engage with the HPC R&D communities and look for an active role in developing related standards. The objective is to further support the trend and have ICT and HPC communities design a fully integrated Communications and Compute approach, offering natively integrated Distributed Compute and Artificial Intelligence solutions to users. This trend requires increases in compute performance in telecommunications networks to tackle future business scenarios, like Chatbots, Smart Cities and Autonomous driving vehicles, advances in 6G will likely need an increase in demand for HPC for federated learning and also integrate technologies such as the Industrial Internet of Things (IIoT), Artificial Intelligence (AI), and cloud computing. HPC and federated learning are linked and they will drive innovations in 6G systems for many enterprises across multiple verticals. This convergence will not only make the networks smarter and faster, but it will also provide more accurate results and automated management.

ETSI has already ongoing groups taking care of computing platforms, like ISG MEC for the Edge aspects of computing. The evolution of HPC, having multiple features quickly moving from standardization to the implementation phase, has to be considered within ETSI work for the impact on future telecommunications network architecture as well as for the improvement in relevant aspects like autonomous network, green and security.

Possible groups impacted in ETSI are TC INT, TC EE, ISG ENI, ISG/TC SAI. This would enable to fully define the compute/network infrastructure vision of ETSI, providing a clear reference point to the Telecommunication stakeholders as well as to the other SDOs interaction on this industry's fast-evolving technology.

3.2.19.3 Time Frame

The HPC projects are evolving quickly across Europe (EuroHPC Joint Undertaking) and the rest of the world. The creation of a reference point in ETSI would be needed to participate in the definition of the technologies that are quickly evolving towards the market. ETSI has to accelerate existing standards adoption and guide the definition of new ones, using its unique viewpoint on the Telecommunication and Vertical market to define and consequently fill the existing gaps. HPC is accelerating, and ETSI needs to play a role in its evolution in the next 5 to 10 years.

3.2.19.4 Recommendations

ETSI is in need to have a focus on HPC and its networking aspects, in order to:

- **Investigate** existing standards related to HPC so that HPC implementation can tackle the requirements from multiple vertical sectors
- **Integrate** HPC environment (in operator network or from over the top provider) with Telco Networks, in order to grant E2E natively integrated Distributed Compute and Artificial Intelligence service experience and automated overall service lifecycle
- **Collaborate** with research projects (e.g., EuroHPC JU) to identify the need for standards evolution
- **Identify** and create work in ETSI groups

3.2.20 Wireless Area and Private radio Networks Evolution

3.2.20.1 Description

This broad area covers all types of wireless area networks different from the Public Land Mobile Network (PLMN). These networks are designed to allow both ends being owned or operated by the end user and this is the most common operation mode. However, cases of operated networks exist. WLAN (e.g. Wi-Fi), RLAN, BAN, NAN, LPWA, etc., are just particular cases of the category.

An important characteristic is that these devices operate, in most cases, as uncoordinated wireless networks able to share the spectrum with other systems and, in some cases, with systems based on other communication technologies. Today, uncoordinated sharing of spectrum generally requires limitations on transmitter powers. More elaborate solutions such as cognitive radio are seen as a research direction for the future.

The efficiency and robustness of this spectrum sharing feature is a merit figure of the technology and, in many cases, an area for improvement.

Wireless Area Networks typically operate - in most practical cases - with transmission power levels and coverage ranges smaller than the ones used in the PLMN. There is a large number of combinations of coverage ranges and power levels for the several technologies included in the category. The efficiency in the use of energy is another figure of merit of the technologies. Those technologies intended to operate with very low levels of battery power (known as Low Energy or Ultra Low Energy) are a subcategory within the area.

Spectrum use and operation regimen

Many technologies in this field were originally conceived to operate over license exempt spectrum and this is still the most common use case. However, the case of communication systems using licensed, dedicated spectrum also exists. Licensed spectrum can come from a share of the spectrum allocated to a MNO and, therefore, can only be used as part of some business agreements between spectrum licensee and user, which can be a barrier for adoption. Within the CEPT this is sometimes called Licensed Shared Access (LSA). A different case that can be very relevant in the future is licensed spectrum directly allocated to specific vertical industries for their own use under a set of given rules. This regimen is also known as “licensed by rule”. Vertical sector candidates to make use of this regimen are Content Industry (PMSE) and Industry Automation.

This spectrum for verticals can be licensed by localized spectrum licences or licensed by rule.

Localized 5G networks will normally be used to cover a specific geographic area, such as a factory, business park, or construction site. These localized 5G networks will typically be allowed to operate with higher transmitter powers than general licence (e.g. ISM) bands.

On the other hand, “licensed by rule” permits open flexible access to the band for the widest possible group of potential users. Efficient deployment of “licensed by rule” under high connection density scenarios requires specific techniques of spectrum sharing based on cognitive radio.

5G and 6G in private networks

5G in a wide sense means advanced telecommunication technologies able to provide services like enhanced Mobile Broadband (eMBB), massive Machine-Type Communications (mMTC) and Ultra-high Reliability & Low Latency Communications (URLLC). An accepted definition of 5G is the one provided by ITU-R in recommendation M.2150-0 [46] (IMT-2020 radio interfaces).

5G NR is a 5G technology developed by 3GPP for the public mobile service, that can also be used in private networks. DECT-2020 NR is another 5G technology developed by ETSI mostly intended for license exempt or licensed by rule operation.

6G will allow further evolution of all connection performance parameters compared to 5G.

Private 5G Networks

In general, a private network differs from a PLMN in that it does not offer services mainly or wholly to members of the public. These private networks will offer services to a closed user group (say employees of a factory or construction site). The main benefits will be that the owner/operator of the private network can ensure the coverage, capacity, and quality that might be required.

Some of these requirements might be met using network slicing from a PLMN, but in general if the requirements are beyond what a normal PLMN will offer, then dedicated outdoor and indoor base stations will likely be required. Such private 5G networks can be provided by an MNO (using their spectrum) or self-provided using spectrum licensed to the vertical (either general or to cover a particular area).

Many countries have announced bands that can (or will) be used for such self-provided 5G private networks – Germany, France, UK, Sweden, Finland, Norway, China, India [47], Japan. The US also allows such services using its CBRS [48] bands.

The benefit of localized licences is to allow much higher transmission power levels than normally available in licence-exempt bands. Localized licences also allow exclusive use of spectrum at certain locations used by the vertical.

Licensed by rule regimens are also expected for some bands and 5G technologies.

Several bands have been identified by countries for private 5G, at 2 GHz, 4 GHz, and 6 GHz. Within Europe 3.4 to 3.8 GHz and 3.8 to 4.2 GHz seem to be gaining traction.

Application Scenarios

User-operated wireless networks are used in nearly all fields of the modern world: Information Technology, Industry automation, smart grid and metering, smart home and building automation, media and content industry, smart cities, and many others.

For market analysis purposes, the area can be split into mid-range systems and short-range systems. Mid-range systems are dominated by IEEE 802.11 [49] series technologies. The most popular and known by the public are the variants 802.11n, 802.11ac and 802.11ax (Wi-Fi 4, 5 and 6) that dominate the general-purpose data transfer between computers and other devices. There are many other variants of IEEE 802.11 that were created for targeting to specific applications and are less known by the public.

Only a few technologies exploit the coverage niche between Wireless Area Networks and the PLMN. This means that they operate with coverage ranges larger than Wi-Fi [49] but less than the PLMN. One example of this case is DECT-2020 [33].

Regarding ETSI technologies, DECT dominates the cordless market without practical competitors. There are also emerging DECT data applications and low energy variants (ULE) [51] that compete with short range technologies.

DECT-2020 [49], a recent development of ETSI TC DECT is one of the few technologies accepted by ITU-R as an IMT-2020 radio interface and therefore qualifies as a 5G technology. DECT-2020 implements a brand new state-of-the-art radio interface based on OFDM supporting MIMO, scalable bandwidth and mesh networking and is able to provide massive Machine Type Communications (mMTC) and Ultra Reliable Low Latency Communications (URLLC) as defined by ITU-R.

In addition to mid-range systems, there are plenty of short range technologies Bluetooth [50] and Bluetooth LE [51] being the most popular.

Not all verticals and applications are well served with existing technologies. In particular each technology provides a given mixing of the following features: coverage range, bit rate, spectrum efficiency, power consumption, latency, radio networking and reliability. Each application or vertical sector requires a particular mixing of these characteristics.

In particular, opportunities exist for technologies offering combinations of Low Latency, Ultra-high reliability, broad radio coverage and ultra-high density, when technology provides support for user operated networks and operations on license exempt spectrum.

Technical trends and research directions

The following technical trends are identified for future evolution in the area:

- **Cognitive radio and other techniques** for efficient radio spectrum usage and device autonomous operation. These techniques are oriented to enable decentralized, self-organizing, reliable, and spectrum efficient operation in networks where the node densities and deployment scale are beyond current deployments. They include URLLC, mMTC, massive mesh networking, or sensor swarms.
- **Extreme connectivity** refers to an increase in the density of connected radio devices compared to existing implementations. Extreme connectivity is an expected scenario in 5G and 6G private networks. A typical predicted scenario is sensor swarms, expected in industry, appliances, utilities and other environments.
- **Mesh radio networking.** This is the ultimate paradigm for high density and high reliable radio networks. Mesh topology also extends coverage with low transmission power levels. Research topics: scalability, power control, reduction in power consumption, maximizing device densities and throughput, efficient routing, scalability.
- **Enabling radio areas.** Examples: channel modelling, high-frequency bands, space diversity, low energy, chipsets, power optimization, energy harvesting, machine learning, SDR.
- **Radio solutions and integration with critical verticals:** e.g. URLLC and mMTC radio for industry automation, low energy for sensors, smart grid, high bandwidth URLLC for the content industry.

3.2.20.2 Affinity with ETSI Work

ETSI was initially very active in the field (DECT, a founding technology of ETSI, BRAN, etc). Then, there was a relative lack of interest in the area (leading to most developments standardized by IEEE). In very recent times there have been initiatives for repositioning in the field. One of them is DECT-2020 NR [33], a state-of-the art wireless technology targeted to industrial and professional markets and fulfilling the requirements established by ITU-R for IMT-2020 technologies. DECT-2020 NR technology supports autonomous operation over protected license-exempt spectrum directly and without any spectrum planning. These features are very welcomed by the end-users in environments like Industry Automation, smart grid, smart home, PMSE, and many other applications. DECT-2020 NR dynamic channel selection is based on observation of background RSSI from both sides of the communication.

3.2.20.3 Time frame

The sector of wireless area network technology is in continuous evolution on two axes: firstly, existing technologies are in continuous evolution improving performance, reliability, and extending to new application areas. Secondly, new technologies appear targeted to specific markets and applications, typically those not well served by the existing players.

There is no indication that this process will be slowed down in the future.

3.2.20.4 Recommendations

- **Promote** the further involvement of ETSI in the field of Wireless Area Networks and private 5G networks. Work together with selected vertical industries to enhance the understanding of the specific needs to be fulfilled. Work together with research and academic communities. Create links for a smooth and early transition from innovation to standardization. Consider if self-provided private 5G might benefit from specific codes of practice or updating ETR 053 - specifically for localized spectrum licences. This might help promote deployment by industry operators.
- **Progress and support** the work done by TC DECT with DECT-2020 NR in order to re-position ETSI in the area.
- **Target** the technology developments to specific applications, scenarios, capabilities and verticals not well served by existing technologies. Seek for leadership in specific areas.
- **Leverage** on the several European initiatives driven by EC and members states such as Industry 4.0 and circular economy.
- **Consider** engaging in a transversal initiative among the ETSI technical groups that can benefit from the advances in Wireless Area Networks (e.g., .TC Smart M2M, TC SmartBAN and TC eHealth, ISG NIN) in order to further evaluate possible areas of ETSI involvement.
- **Monitor** the evolution of other technologies, identifying challenges and opportunities that may impact the evolution of ETSI technologies.
- **Monitor** the evolution of the needs of vertical sectors.
- **Monitor** new opportunities of spectrum allocation for private networks.

3.2.21 Future User Interfaces and User Experience

3.2.21.1 Description

The interface between users of ICT systems and the ICT systems themselves has been in the focus of R&D since the early 1970s. During the last decade, the design and implementation of user interface has become a focal area for regulatory activities based on, among other developments, the requirements imposed by the UNCPDR (Convention on the Rights of Persons with Disabilities) and the European Accessibility Act.

The interface between users and their systems and/or services can be split into two major areas:

- Presentation of system and device status and information.
- Interaction of user behaviour expressions, and actions with their services and devices.

- While the first aspect is very often considered to be the core of user interface design, the 2nd aspect is covered by what is often called user experience design.
- For many decades, the presentation of information to users has been mainly done through two-dimensional screens, both on computers and (later) on smartphones. But information presentation has also moved to using other human senses, and to three-dimensional presentation of information. Even for pure information presentation it is important to consider the impact of environmental factors (brightness, surrounding noise, identification of available human sensors) when designing UIs.
- Computer and Phone displays used for two-dimensional presentation and (to a limited extent) 3-dimensional Virtual Reality presentations are by now becoming mainstream technologies ready for standardization.
- The use of holographic displays for immersive virtual and augmented reality is one of the areas in which major breakthroughs and developments can be expected. Some of this work is covered in the activities of ETSI ISG ARF.
- The use of computer-generated voice and speech output has very specific applications. Over the last two decades the quality of this communication technology has much improved and has become one of the mainstream UI technologies.
- The use of haptic and/or olfactory information presentation is still very much in an R&D status and very dependent on the availability of related hardware solutions. These presentation technologies will probably remain restricted to specific application scenarios.

For the design of the user experience the availability of sensors to understand users' intentions and actions/commands will be a major driving force in the future.

- In the past the communication of users with ICT systems has been done mainly through switches, keyboards, and pointing devices (mouse, touch screens, etc.).
- With the advent of smart phones with touch screens and movement sensors and reliable camera input the interpretation of gesture input has slowly developed but remains a technology that is difficult for many users to employ.
- In the future UX design based on alternative sensors for biometric input (e.g. retina and eye scans), sensors measurement human body factors (e.g. blood pressure, movement of limbs) and non-intrusive sensors to measure brain activity will evolve, probably with much focus and supporting users with accessibility needs.
- Finally, speech recognition based on sensing users’ spoken interaction (through one or more microphones) has become a mainstream UX technology which still has become an important part of UX design with much potential still to be explored.

The future development of UX technologies may be driven by the availability of a large number of sensors in the environment of the user and the “intelligent“ interpretation of the input received by these sensors to control the user experience.

For the near future major changes in UI and UX design may be expected from deploying AI solutions to support user in their interaction with the system. Examples for such use of AI systems are:

- Development of reliable multi-language UIs, e.g., to ensure access to emergency services for traveling users which may not be able to understand or speak the local language used by emergency services. This will likely have a strong impact on the design of relay services in telecommunication systems.
- Use of generative AI systems as interpreters between users with cognitive deficiencies and their environment. This seems to be an extremely promising approach – the computer/AI system as an interpreter between individual communication behaviour and socially “accepted” communication. Obviously, the protection of the privacy of such users must be a prime objective for these systems.
- Interpretation of user intentions based on a network of sensors in the environment of the users.

3.2.21.2 Affinity with ETSI Work

Standardization of UI and UX technologies has always been a contentious topic, as many UX developments are used by industrial players to ascertain competitive advantages in the markets of devices and services. That said, novel UX technologies have a number of consequences which need to be kept in mind. Many of these consequences are already part of ETSI’s work programme.

- Novel interaction technique will often employ AI technologies (covered by several TCs and OCG AI). Especially when using generative AI systems to support people with (cognitive) accessibility needs, it will become important to protect the user-submitted data and information and to restrict its use to the users employing these technologies
- Novel interaction technologies will create a large amount of data and communication needs which in turn might fuel the consumption of energy, both for communication and user system interaction. This implies that topics like sustainability and power usage for UI purposes must be addressed, in particular when AI technology is being employed in the UI of ICT systems.
- Data protection is of prime importance in the interface between users and ICT system. In particular, the control over data and information communicated to the outside of these ICT systems must remain with the users and accordingly, tools have to be designed and development to ensure such control by users.
- Finally, the protection of privacy remains a major area for research and development.

3.2.21.3 Time Frame

Research on user experience and UI design has been in the focus for many decades, mostly performed by university and industrial research as well as within engineering associations like ACM’s Special Interest Group in HCI SIGCHI. Since the 1990s, ETSI TC HF has been monitoring the developments in HCI technology and tried to develop standards for specific user groups, mainly focused on standards related to accessibility requirement of Humans.

Since (around 2012) UI standardization for accessibility has become a major topic in European standardization and ETSI TC HF has been fortunate to become the major European player in that area of standardization.
Standardization work in this area will likely continue for a period of well over the next decade and beyond.

3.2.21.4 Recommendations

ETSI should reinforce its position on Future UI standardization as the most influential European standardization player.

The recommendations for ETSI Community could therefore be summarized:

Follow the activities carried out in other legislations (US, Canada, Asia) and other SDOs to avoid the development of overlapping or contradictory standards in the area of UI design and accessibility.

Promote the current activities carried out by TC HF and TC EMTEL in the area of UI design for accessibility.

Consider the opportunity of exploratory work on future UX technologies and related standardization options in cooperation with university and industrial research centres.

3.3 Challenges and opportunities

Summarizing the previous clauses, Table 4 below offers a quick guide to key recommendations in each major trend area.

Table 4: Summary of the recommendations related to the selected technical trends

Trend Name	ETSI Affinity	Timescales	Recommendations
Next Gen. Mobile Comms System	Several ETSI ISGs are relevant to 5G -> 6G work.	3GPP 6G work plan is expected to begin at the end of 2025 (e.g. Release 20)	6G shall become an essential pillar in ETSI activities. Therefore the recommendation is to **Investigate, Promote and Adopt** the 6G building block technologies. In this area, the most appropriate recipient for ETSI work strongly remains 3GPP. ETSI may bridge (pre-standardization) research and standardization activities in 3GPP especially from EC funded or national funded 6G projects. ETSI should actively collaborate with relevant 6G related industry platforms, organizations and associations.
Artificial Intelligence	ISG ZSM ISG ENI TC INT SmartM2M ISG CIM oneM2M EP eHealth ISG/TC SAI AI OCG group	AI is already strongly impacting ETSI's work. Work is expected to continue on security and reliability for about two more years in the initial phase	AI has to deal with interoperability issues, new concepts for testing and validation, and ensuring that ethics guidelines are embedded in order to guarantee a trustworthy Artificial Intelligence. Recommendations for ETSI to develop: ▪ a co-ordinated approach to AI ▪ a complete mapping in ETSI of "AI as a tool" ▪ an evaluation of the technical impact of EU ethical guidelines ▪ AI Interoperability and Interchangeability standards ▪ guidelines for AI Testing and Validation ▪ dataset and quality requirements for Artificial Intelligence All of these steps can be done best, or at all, only through cooperation and collaboration with many external bodies and SDOs.

Trend Name	ETSI Affinity	Timescales	Recommendations
Autonomous Networks	ISG ZSM ISG ENI ISG F5G ISG MEC ISG NFV ISG/TC SAI TC INT_AFI	Fully Autonomous Networks is a long-term goal	Within ETSI, further cooperation between individual groups should be sought, as it has been done in the past, for example, for the joint development of standardization documents. OCG AN can play a role to facilitate cooperation inside ETSI. Further cooperation among different organizations working in AN should be envisaged and encouraged. Recommended ETSI continues in its leading technical role on AN standardization with particular attention to the new AN enablers (AI/ML, Network Digital Twin, API evolution)
Cybersecurity, Privacy and Trust	TC CYBER ISG /TC SAI Embedded in several ETSI groups ETSI Security conference	Security, privacy, and trust will continue to be critical for new tech. innovations	Without excellent industry led technical standards, well-considered threat models, and security best practices, the security of communications technologies and services will not keep pace with real world attacks and fraud– and that is where ETSI can help. ▪ All groups within ETSI focused on security, privacy and trust should have their own roadmaps to navigate the near term and longer future challenge. ▪ ETSI needs to be able to begin WIs, scope groups, host workshops or send expert liaison statements to relevant SDOs/EC stakeholders on topics. ▪ ETSI should continue to take steps to actively share its security work with key stakeholders.
Distributed Ledgers (Blockchain)	ISG PDL	DLT is expected to continue its growth in coming years, provided there is an appropriate resolution of the key challenges	▪ Build on the work carried out in ETSI ISG PDL and position ETSI as the leader in Permissioned DLTs for the ICT Industry and, hopefully, mission critical vertical markets. ▪ Coordinate potential opportunities of DLTs in various ETSI Technical Committees (e.g. TC SES, TC eHealth, TC SmartM2M) through ad-hoc OCG teams if required and agreed, and better synergies with the most active EU research institutions. ▪ Liaise with the key international bodies in the DLTs space, such as (list not exhaustive) OASIS, ITU-T, IETF/IRTF, W3C, IEEE, ISO TC 307, CEN-CLC/JTC 19, mainly on identity management, and vertical markets (e.g. precision agriculture, healthcare, energy, and connected and autonomous vehicles). ▪ Seek alignment between different entities developing DLT specifications through the use of common terminology and common reference architecture.

Trend Name	ETSI Affinity	Timescales	Recommendations
Dynamic Data	TC SmartM2M TC SmartBAN ISG ARF ISG CIM	Gradually increasing efficiency of data processing, and the increasing availability of such data through digitalisation	▪ Build relevant partnerships/collaboration rapidly and flexibly. ▪ Promote joint or complementary technical work, organizing common events, or consider specific work for collaboration using the PAS scheme. ▪ Investigate means to assess the “quality” of datasets needed to train and also to test the AI capabilities referenced by new standards, expanding the work initiated by ISG SAI.
eXtended Reality (XR)	ISG ARF	Market to expand into multiple sectors over the coming 2-3 years, increases the need for interoperable products and services	▪ Collaborate with other organizations and SDOs, particularly with the representative groups of the users that will be applying XR technologies to their business processed. ▪ Promote the current activities carried out by ISG ARF on XR enablers, with particular focus on architectural frameworks, component interoperability, cloudification and edgification. ▪ Coordinate potential opportunities of XR for various use cases in various ETSI Technical Committees (e.g. TC eHealth, TC SmartM2M, ISG MEC) through ad-hoc OCG teams if required and agreed, and better synergies with the most active EU research institutions.
Internet of Things	TC SmartM2M TC SmartBAN ISG CIM oneM2M TC DECT	IoT is now. The next 2-4 years are crucial for improving interoperability	▪ Promote existing ETSI IoT standards related to IoT and especially from oneM2M so that the barriers between "verticals" can be broken down ▪ Promote ETSI standards for cyber security in IoT and work with European and other important cyber security organizations ▪ Promote consensus-driven development of ontologies, especially in relation to SAREF ▪ Promote exchange of (meta)data that re-uses existing consensus ontologies (like SAREF) ▪ Foster examples from industry of "turnkey solutions" that use ETSI specifications, to act as inspirational examples ▪ Collaborate with research projects so that as many of the projects and their proof-of-principle activities (re)use standards where feasible ▪ Provide flexible testing and conformance options for ETSI standards, to encourage their interoperable use ▪ Collaborate with European research projects in leading-edge areas such as additive manufacturing or the circular-economy ▪ Promote SMEs use of technologies such as private 5G networks, open source implementations of IoT federated platforms, etc., to encourage entrepreneurship and sustainability

Trend Name	ETSI Affinity	Timescales	Recommendations
Quantum Computing, Encryption, Networks	ISG QKD TC CYBER_QSC	Still at an early stage Results will come progressively primary results in the next 3 years	▪ Progress the work carried out in ETSI TC Cyber / Quantum Safe Cryptography in order to position ETSI in the leadership of this specific area ▪ Monitor the evolution of Quantum technologies in a continuous mode, identifying challenges and opportunities that may impact ETSI evolution ▪ Strengthen the relation with R&D institutes, NMIs and Academia in this area, reaping the benefits for an early start in Quantum standardization aligned with policy, industry and societal needs
Robotics and Autonomous Systems	Not in the mainstream of ETSI activities, but related with ETSI TC ERM WG AERO, TC ERM, ISG/TC SAI, 3GPP 5G	RAS is already a reality in Industry and society to grow in the coming years	ETSI is not the Core SDO in RAS. Recommendation for ETSI Community are: ▪ Follow the activities carried out in other SDOs, especially for Industrial RAS. This would avoid overlaps with other SDOs. ▪ Promote the current activities carried out by TC/ISG on RAS enablers, with particular focus on wireless communication capabilities, safety and security. ▪ Consider the opportunity of exploratory work on Cloud-enabled RAS: with the advent of 5G low latency communication, edge computing and new sensors, the area has a growing potential that easily fits with ETSI strengths.
Photonics	ISG THz ISG F5G ISG QKD	Photonics are in a turning point where its use will increase significantly over the next years	▪ Promote the further involvement of ETSI in the field of Photonics through Board RISE, addressing major R&D organizations in order to create the links for a smooth and early transition from innovation to standardization. ▪ Progress the work carried in ETSI ISG F5G and ETSI ISG QKD Quantum Safe Cryptography and ISG THz in order to position ETSI in the leadership of this specific areas. ▪ Consider to engage in a transversal initiative among the ETSI technical groups that can benefit from the advances in Photonics (e.g. ISG F5G, ISG QKD, TC Smart M2M, TC SmartBAN and TC eHealth TC EE, TC ATTM) in order to further evaluate possible areas of ETSI involvement. ▪ Monitor continuously the evolution of Photonics technologies, identifying challenges and opportunities that may impact ETSI. Specifically, the use of photonics technologies in almost all ICT application areas show the importance to monitor the development and engage in the right activities at the right time.

Trend Name	ETSI Affinity	Timescales	Recommendations
THz Comms.	ISG THz ISG mWT ISG RIS	3GPP work on THz above 100 GHz bands will start in earnest in a few years' time. Now is the right time for related pre-standardization activities in ETSI	▪ Establish close relations with relevant EC bodies working on these topics (e.g. DG CONNECT) to ensure that future funding opportunities for THz communication systems address topics relevant for the subsequent work at ETSI. ▪ Establish a close and open forum for exchange with ongoing EC-funded projects and actions (e.g. within COST). ▪ Further develop the pre-standards required for THz communications in ISG THz and liaise with relevant bodies and projects.
Reconfig. Intelligent Surfaces (RIS)	ISG RIS	RIS workplan for next 4 years. Relevant to be initiated in 3GPP	▪ It is recommended that interested parties should take part in the studies of theoretical and technological enhancements which will improve the performance of RIS while reducing the associated implementation and deployment cost. ▪ Industry stakeholders should also actively participate in the early-stage standardization efforts, such as ETSI ISG RIS, working towards the realization of truly controllable, programmable, and smart radio environments. ▪ ISG RIS to actively liaise with external research bodies, academia, labs and SDOs. In order to create a globally harmonized technical specification.
Optical Wireless Comms. (OWC)	None in existing groups	Early stages of research	▪ a number of research aspects of OWC need to be further investigated, including system architecture, light source component and chipsets, and air interface technology, etc.

Intelligent Distributed EDGE	ISG MEC
	
	ISG ENI
		MEC workplan runs to 2026	▪ Recommended all interested parties should take part in the technological enhancements and normative work in ISG MEC.
			▪ ETSI ISG MEC should actively liaise with:
			  ▪ the research community, including all relevant projects, research bodies and academia labs;
			  ▪ all relevant SDOs working in the area of MEC;
			  ▪ all relevant open source initiatives.
			▪ Deep dive into use cases and requirements for 6G Intelligent Distributed Edge within ETSI.
			▪ Consolidate the relevant initiatives within ETSI to discuss and contribute to new 6G paradigms on native AI architecture enabled by Intelligent Distributed Edge.

Trend Name	ETSI Affinity	Timescales	Recommendations
Environmental Sustainability	TC EE TC ATTM TC CABLE TC CYBER	Sustain is an emerging topic of importance that will grow over coming years	▪ Analyse the deliverables on environmental sustainability applicable to ICT and produced by IEC TC111, ISO/IEC JTC1/SC39 and ITU-T SG5, and others identified organizations, to map the gaps and define a work plan to fill the gaps. ▪ Cooperate and collaborate with other organizations working on standardization of environmental sustainability for the ICT. ▪ Maintain updated the published ETSI deliverables on environmental sustainability. ▪ Monitor development of EU Regulations/Directives in the ICT sector and take prime role in the production of standards for the environmental sustainability for the ICT Regulations/directives. ▪ Identify and promote application of ICT in support of the environmental sustainability. ▪ Promote ETSI work on environmental sustainability with the organization of workshops and press releases.
Integrated Sensing & Comms (ISAC)	ISG ISAC ISG THz ISG RIS ISG mWT	Pre-standards work in ETSI will run over coming 4 years	▪ It is recommended that the ISAC ISG stays coordinated with the 3GPP ISAC activities in Release 19 in order to ensure complementarity and alignment of the ISAC ISG with the 3GPP ISAC roadmap to feed results into future 3GPP releases (R20+). ▪ It is recommended that the ISAC ISG stays coordinated with the ITU-R IMT-2030 activities related to ISAC requirements, and evaluation methodologies. ▪ Ensure ISG ISAC works in collaboration with other ETSI bodies dealing with topics relevant for ISAC.
Non-Terrestrial Networks (NTN)	TC SES	NTN for 6G will become a reality in the coming 2-4 years	▪ ETSI can start to define scenarios and important use cases for 6G that NTN can beneficially support; ▪ ETSI can support the pre-standardization work on NTN by initiating a new ISG or developing work in an existing TC; ▪ ETSI can cooperate and collaborate with other organizations working on standardization of NTN topics.
Integration of HPC & Comms	ISG MEC ISG/TC SAI And others	ETSI may play a role in HPC evolution in the next 5 to 10 years	▪ Investigate existing standards related to HPC so that HPC implementation can tackle the requirements from multiple vertical sectors. ▪ Integrate HPC environment (in operator network or from over the top provider) with Telco Networks, in order to grant E2E natively integrated Distributed Compute and Artificial Intelligence service experience and automated overall service lifecycle. ▪ Collaborate with research projects (e.g., EuroHPC JU) to identify the need for standards evolution. ▪ Identify and create work in ETSI existing / new groups.

Trend Name	ETSI Affinity	Timescales	Recommendations
Wireless Area & Private radio Networks Evolution	TC DECT TC BRAN 3GPP	The area is in continuous evolution in two axes: 1) evolution of existing technologies and 2) new technologies targeted to specific markets and applications. There is no indication that this process will be slowed down in the near future	▪ Promote the further involvement of ETSI in the field of Wireless Area Networks and private 5G networks. ▪ Progress and support the work done by TC DECT with DECT-2020 NR in order to re-position ETSI in the area. ▪ Target the technology developments to specific applications, scenarios, capabilities and verticals not well served by existing technologies. Seek for leadership in specific areas. ▪ Leverage on the several European initiatives driven by EC and members states for such as Industry 4.0 and circular economy. ▪ Consider engaging in a transversal initiative among the ETSI technical groups. ▪ Monitor the evolution of other technologies, identifying challenges and opportunities for ETSI. ▪ Monitor the evolution of the needs of vertical sectors. ▪ Monitor new opportunities of spectrum allocation for private networks.
Future User Interfaces	Multiple groups inc. TC HF	Standardization work in this area will likely continue for a period of well over the next decade and beyond	ETSI should reinforce its position on Future UI standardization as the most influential European standardization player. ▪ Follow the activities carried out in other legislations (US, Canada, Asia) and other SDOs to avoid the development of overlapping or contradictory standards in the area of UI design and accessibility. ▪ Promote the current activities carried out by TC HF and TC EMTEL in the area of UI design for accessibility. ▪ Consider the opportunity of exploratory work on future UX technologies and related standardization options in cooperation with university and industrial research centres.

4 Conclusions

The principal findings from the work performed by the ETR editing team during the building of the ETSI ETR may be summarized as follows.

Non-exhaustive: The technical trends reported in clause 3 are key examples of technology evolutions that are likely to impact both the present and future work of ETSI. They are not an exhaustive list and other technology trends could be considered relevant for the evolution of the ETSI strategy. The ETR editing team revised the work done by many distinguished analysts and collected opinions from key ETSI members, as reported in other documentation.

Interdisciplinary: Many of the technology trends are strongly interleaved and can partially overlap. This brings to the necessity of a stronger coordination between the various ETSI technical teams that, today or tomorrow, could be involved in standardization. ETSI secretariat, the Board, and OCG are in the best position to manage, whenever appropriate, the coordination effort.

Evolution not disruption: Many of those trends are evolutionary technologies, therefore it is natural that many of them are already addressed by the ISG/TBs in ETSI. However the level of maturity is different and could evolve in the next years. Therefore it is not just a matter for ETSI of addressing "the next big thing" at the forefront of innovation, but to find the right strategy to cope with the standard opportunities that could arise from these trends, finding the right balance between innovation, partnerships, ETSI strengths in the industry with respect to other SDOs.

Actions: For each of the considered addressed trends, the document has identified affinities with the ETSI work and suggested specific actions for ETSI. These actions could be reviewed in the ETSI Board, shared with the ETSI OCG and informed actions considered as appropriate.

Future: No matter what technologies may emerge in the future, what is clear is that ETSI is well positioned to play a significant role in the evolving ICT standards landscape in the coming years.

ANNEX A: List of Acronyms and Abbreviations

3D	Three Dimensional
3GPP	3rd Generation Partnership Project
4G	4th Generation mobile wireless communication system
5G	5th Generation mobile wireless communication system
5G NR	5G New Radio
6G	6th Generation mobile wireless communication system
AI	Artificial Intelligence
AN	Autonomous Network
API	Application Programming Interface
AR	Augmented Reality
ARF	Augmented Reality Framework
AS	Autonomous System
CAD	Computer Aided Design
CIM	cross-cutting Context Information Management
CNI	Critical National Infrastructure
CSI	Channel State Information
CVD	Co-ordinated Vulnerability Disclosure
CT	Core and Terminals
DAG	Directed Acyclic Graphs
DECT	Digital Enhanced Cordless Telecommunications
DLT	Distributed Ledger Technology
E2E	End to End
EC	European Commission
EG	ETSI Guide
EMF	Electro Magnetic Field
ENI	Experiential Networked Intelligence
ETR	ETSI Technology Radar
EU	European Union
F5G	5th Generation Fixed network
FSO	Free Space Optics
GA	General Assembly

GANA	Generic Autonomic Networking Architecture
GDPR	General Data Protection Regulation
GEO	Geostationary Earth Orbit
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GR	Croup Report
GS	Group Specification
HAPS	High Altitude Platform Stations
HPC	High Performance Computing
ICT	Information and Communication Technology
IP	Internet Protocol
IPR	Intellectual Property Right
INT	Core Network and Interoperability Testing
IIoT	Industrial Internet of Things
IoT	Internet of Things
ISAC	Integrated Sensing And Communications
ISACS	Information Sharing Analysis Centres
ISG	Industry Specification Group
LEO	Low Earth Orbit
LiFI	Light Fidelity
LLM	Large Language Model
LTE	Long Term Evolution
LTE-M	LTE-Mobile
M2M	Machine to Machine
MBB	Mobile Broadband
MEC	Multi-access Edge Computing
MEO	Medium Earth Orbit
MIMO	Multiple Input Multiple Output
ML	Machine Learning
mMTC	massive Machine Type Communications
mmW	millimeter Wave
MoU	Memorandum of Understanding
MQTT	Message Queuing Telemetry Transport

MR	Mixed Reality
MTC	Machine Type Communications
NB-IoT	Narrowband IoT
NDT	Network Digital Twin
NFV	Network Functions Virtualization
NR	New Radio
NTN	Non-Terrestrial Network
OCC	Optical Camera Communications
OCG	Operational Co-ordination Group
OWC	Optical Wireless Communications
PAS	Publicly Available Specification
PDL	Permissioned Distributed Ledger
PLMN	Public Land Mobile Network
QKD	Quantum Key Distribution
QSC	Quantum Safe Cryptography
RAN	Radio Access Network
RAS	Robotics and Autonomous System
RAT	Radio Access Technology
RFID	Radio Frequency IDentification
RIS	Reconfigurable Intelligent Surfaces
RRS	Reconfigurable Radio System
RSA	Rivest, Shamir, et Adelman
SA	System Architecture
SAI	Securing Artificial Intelligence
SAREF	Smart Applications REFerence
SDN	Software Defined Networking
SDO	Standards Developing Organization
SES	Satellite Earth Stations and Systems
SNS JU	Smart Network and Services Joint Undertaking
SON	Self Organizing Network
SRIA	Strategic Research and Innovation Agenda
STEP	Socio-Techno-Economic-Political
TB	Technical Body

TETRA	Terrestrial Trunked Radio
THz	TeraHertz
TN	Terrestrial Network
TVRA	Threat Vulnerability Risk Analysis
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
UI	User Interface
ULE	Ultra Low Energy
URLLC	Ultra Reliable Low Latency Communications
UX	User Experience
V2X	Vehicle to Everything
VLC	Visible Light Communications
VLEO	Very Low Earth Orbit
VR	Virtual Reality
VRARA	VR/AR Association
W3C	World Wide Web Consortium
WLAN	Wireless Local Area Network
WoT	Web of Things
XaaS	everything-as-a-Service
XR	eXtended Reality
ZSM	Zero-touch network and Service Management

ANNEX B: References

[1] ETSI Strategy. https://www.etsi.org/media-library/brochures-and-guides

[2] ETSI Work Programme. https://www.etsi.org/media-library/work-programme-and-annual-reports

[3] ETSI White Paper No. 34 (2020-06): “Artificial Intelligence and future directions for ETSI”. https://www.etsi.org/newsroom/news/1788-2020-06-etsi-issues-new-white-paper-on-artificial-intelligence

[4] ITU-R, DRAFT NEW RECOMMENDATION, "Framework and overall objectives of the future development of IMT for 2030 and beyond," June 2023.

[5] NGMN: 6G Use Cases and Analysis. https://www.ngmn.org/work-programme/6g-use-cases-and-analysis.html

[6] one6G: 6G Technology Overview. https://one6g.org/download/2699/

[7] 6G SNS: Research for revolutionary technology advancement towards 6G. https://smart-networks.europa.eu/stream-b-research-for-revolutionary-technology-advancement-towards-6g/

[8] Page 21, “SNS-R&I-Work-Programme-2021-2022”, European Commission.

[9] EU coordinated plan of December 2018.

[10] AI HLEG Policy and Investment Recommendations. https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=60343

[11] Digital Europe Programme. https://digital-strategy.ec.europa.eu/en/activities/digital-programme

[12] Bank of Japan. “Legal Liability and AI in finance”. https://www.boj.or.jp/en/research/wps_rev/lab/lab19e01.htm/

[13] "European Commission Report on safety and liability implications of AI, the Internet of Things and Robotics". https://eur-lex.europa.eu/legal-content/EN/TXT/DOC/?uri=CELEX:52020DC0064&from=en

[14] OECD TRANSFORMATIVE TECHNOLOGIES FUTURE JOBS. https://www.oecd.org/innovation/transformative-technologies-and-jobs-of-the-future.pdf

[15] OECD report on AI patents.
https://read.oecd-ilibrary.org/science-and-technology/oecd-science-technology-and-industry-scoreboard-2017/artificial-intelligence-patents-by-top-r-amp-d-companies-by-headquarters-location-2012-14_sti_scoreboard-2017-graph25-en

[16] ETSI GR ENI 007: "Experiential Network Intelligence ENI): ENI Definition of Categories for AI Application to Networks".
https://www.etsi.org/deliver/etsi_gr/ENI/001_099/007/01.01.01_60/gr_ENI007v010101p.pdf

[17] ETSI GR ENI 009: "Experiential Networked Intelligence (ENI); Representing, Inferring, and Proving Knowledge in ENI".
GS ENI 019 - V3.1.1 - Experiential Networked Intelligence (ENI); Representing, Inferring, and Proving Knowledge in ENI (etsi.org)

[18] ETSI EG 203 341: "Core Network and Interoperability Testing (INT); Approaches for Testing Adaptive Networks". ETSI EG 203 341 V1.1.1

[19] EC High Level Expert Group Guidelines for a trustworthy AI.
Ethics guidelines for trustworthy AI | Shaping Europe's digital future (europa.eu)

[20] ETSI White Paper No. 56 (2020-09): "Unlocking Digital Transformation with Autonomous Networks".
ETSI-WP56_Unlocking-Digital-Transformation-with-Autonomous-Networks.pdf

[21] ETSI White Paper No. 40 (2020-09): "Autonomous Networks, supporting tomorrow's ICT business".
https://www.etsi.org/images/files/ETSIWhitePapers/etsi-wp-40-Autonomous-networks.pdf

[22] SAREF Smart Applications Reference Ontology. https://saref.etsi.org

[23] ETSI GR ARF 001 V1.1.1 (2019-04): "Augmented Reality Framework (ARF); AR standards landscape".
https://www.etsi.org/deliver/etsi_gr/ARF/001_099/001/01.01.01_60/gr_ARF001v010101p.pdf

[24] ETSI GS CIM 009 V1.3.1 (2020-08): "Context Information Management (CIM); NGSI-LD API".
https://www.etsi.org/deliver/etsi_gs/CIM/001_099/009/01.03.01_60/gs_CIM009v010301p.pdf

[25] "Economic Impact of Open Data: Opportunities for value creation in Europe", European Data Portal, Published 25th Feb. 2020.
https://www.europeandataportal.eu/sites/default/files/the-economic-impact-of-open-data.pdf

[26] Milgram, Paul, Haruo Takemura, Akira Utsumi, and Fumio Kishino. "Augmented reality: A class of displays on the reality-virtuality continuum." In Telemanipulator and telepresence technologies, vol. 2351, pp. 282-292. International Society for Optics and Photonics, 1995.

[27] Ball, M. (2022). The metaverse: and how it will revolutionize everything. Liveright Publishing.

[28] ETSI GR ARF 002 V1.1.1 (2019-07): “Augmented Reality Framework (ARF); Industrial use cases for AR applications and services”.
https://www.etsi.org/deliver/etsi_gr/ARF/001_099/002/01.01.01_60/gr_ARF002v010101p.pdf

[29] ETSI GS ARF 003 V1.1.1 (2020-03): “Augmented Reality Framework (ARF); AR framework architecture”.
https://www.etsi.org/deliver/etsi_gs/ARF/001_099/003/01.01.01_60/gs_arf003v010101p.pdf

[30] GSMA - Cloud AR/VR Whitepaper (2019-04).
https://www.gsma.com/futurenetworks/wiki/cloud-ar-vr-whitepaper/

[31] OPC Unified Architecture Specification (proprietary).
https://opcfoundation.org/about/opc-technologies/opc-ua/

[32] MQTT v5. OASIS open standard. https://docs.oasis-open.org/mqtt/mqtt/v5.0/mqtt-v5.0.pdf

[33] ETSI TS 103 636 (parts 1 to 5): DECT-2020 New Radio (NR); release 1.

[34] EU ICT Standardization Rolling Plan (2023).
https://webgate.ec.europa.eu/fpfis/wikis/display/RollingPlanICTS/Rolling+Plan+2024

[35] ETSI Progress Report from the ETSI Director General to the GA.
GA(23)81_013r2_Progress_Report_from_the_Director-General.pptx

[36] Wei Jiang; Fa-Long Luo, "Optical and Visible Light Wireless Communications in 6G," in 6G Key Technologies: A Comprehensive Guide, IEEE, 2023, pp.253-294.

[37] O. Alsulami, A. Hussein, M. Alresheedi, J. Elmirghani, “Optical wireless communication systems, a survey” arXiv 2018, arXiv:1812.11544.

[38] Chowdhury, M.Z.; Shahjalal, M.; Hasan, M.K.; Jang, Y.M. The Role of Optical Wireless Communication Technologies in 5G/6G and IoT Solutions: Prospects, Directions, and Challenges. Appl. Sci. 2019, 9, 4367.

[39] LCA: http://lightcommunications.org/

[40] ITU-T G.Sup67, “Application of optical transport network Recommendations to 5G transport”.

[41] https://www.etsi.org/technologies/2065-technology-radar?highlight=WyJpb3QiXQ

[42] R&I Work Programme and Calls for Proposals - The Smart Networks and Services Joint Undertaking, European Commission. https://digital-strategy.ec.europa.eu/en/policies/sns-work-programme

[43] 3GPP TR 38.811, "Study on New Radio (NR) to support non-terrestrial networks (Release 15)".

[44] 3GPP TR 38.821, "Solutions for NR to support non-terrestrial networks (NTN) (Release 16)".

[45] 3GPP TR 22.822, "Study on using Satellite Access in 5G; Stage 1 (Release 16)".

[46] ITU-R Recommendation M.2150-0; International Mobile Telecommunications-2020: Detailed specifications of the radio interfaces of IMT-2020.

[47] https://www.rcrwireless.com/20221220/5g/india-starts-process-identify-bands-5g-private-networks

[48] https://www.fcc.gov/wireless/bureau-divisions/mobility-division/35-ghz-band/35-ghz-band-overview

[49] ETSI EN 300 175 (parts 1 to 8): Digital Enhanced Cordless Telecommunications (DECT); Common Interface (CI).

[50] Bluetooth SIG; Core specification Working Group; Bluetooth Core Specification v5.3.

[51] ETSI TS 102 939 (parts 1 and 2): Digital Enhanced Cordless Telecommunications (DECT) – Ultra Low Energy (ULE) – Machine to Machine Communications.

[52] ETSI GR F5G 008: Fifth Generation Fixed Network (F5G); F5G Use Cases Release #2.

NOTE: While any hyperlinks included in this clause were valid at the time of publication ETSI cannot guarantee their long-term validity.

ETSI
06921 Sophia Antipolis CEDEX, France
Tel +33 4 92 94 42 00
info@etsi.org
www.etsi.org