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ETSI Technology Radar

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Contents

Executive Summary

The principle activity of ETSI is the development of high-quality ICT standards to serve the needs of industry. They 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 digitization activity, ensuring the development of the standards that enable fully interconnected, interoperable, secure, and sustainable solutions.

One of ETSI´s principle Strategy directions is "*to be at the heart of Digital*", expressing the clear intention for ETSI to be one of the leading organizations providing ICT standards, addressing present needs but also 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 ETR has been developed by ETSI Board members, OCG and ETSI secretariat representatives during the year 2020, with the following methodology:

- A thorough trend analysis that has considered 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 key technology trends that could be of most relevance for ETSI today and in the near future. This initial selection does not exclude future revisions or integrations of new technologies in future evolutions of the ETR.

- For each selected technology trend, the identification of affinities or eventual gaps with respect to current ETSI activities as documented in the ETSI Work Programme 2020/21 [1], 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 10 key technology trends reported in figure 1. This selection does not exclude future revisions or integrations, along with further technology evolutions.

Figure 1: Overview of selected technology trends

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 to promote the discussion, verify the requirements, and be ready to be at the frontline of these upcoming technology developments.

The time frame identifies different maturity levels of these trends, with respect to standardization needs, starting from Q4 2020 up to the end of the present decade. This analysis leads to a different set of recommendations for ETSI. The ETR has classified the different recommendations into four main clusters:

- **MONITOR**, when the 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 trend is considered mature for further evaluation and action in ETSI.
- **DEVELOP**, when the 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 trend, and further outreach and promotion could be envisaged.

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

- **Non-exhaustive:** The selected 10 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 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 coming years. Therefore it is not just matter for ETSI to address "the next big thing" that remain at the forefront of innovation, but also ETSI must 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 domains ETSI can play a significant role and define its own space in the forthcoming years.

1 Introduction

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 Strategy directions is "*to be at the heart of Digital*", expressing the clear intention for ETSI to be one of the leading organizations enabling ICT standardization, addressing present needs but also designing tomorrow's world by addressing the ICT needs for future services and applications.

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 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:

- To 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.
- To identify the major technology trends that could be of most concern/interest for ETSI.
- To contribute, for each selected technology trend, to the identification of eventual gaps with respect to current ETSI activities (as documented in ETSI Work Programme 2020/21 [1]) and to promote future more detailed analysis at OCG and/or Board level on the eventual way forward for ETSI to fill the identified gaps.

Throughout the 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)

The ETR document and the ETSI Strategy [2] have been developed in parallel and are intended to be complementary and 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 of 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. GPS and mobile map applications enabled companies such as Uber and many other logistics solutions to flourish. 3D-CAD and computer-controlled machining have allowed a physical separation between design and construction and also from assembly, not just for small simplistic objects such a plastic toys but also for huge and complex items such as ocean liners, space launchers and aircraft. 3D-Printing is further expanding the digital transformation into the domain of customized consumer goods and circular-economy products.

The social impact of ICT is 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 4G video call capabilities to 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 and Machine Learning is an easily underestimated trend, because we have heard of them for so long, and to date the results were so small, meaning a certain level of complacency has set in. 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.

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 take care that the basic digital information is authenticated, accurate and secured, that the ICT systems have sufficient bandwidth and instantaneity and that the AI systems are not disrupted by bias, remaining ethical at all instances.

Carried along with 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. 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 – ironically – the ICT evolution itself makes such oversight possible. The standardization process is fully 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.

How we use that control and oversight is a purely a 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 layers of security? 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 is 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 and targets.

Standards are a part of this policy and legal machinery: the New Legislative Framework (Regulation 1025/2012) and a number of government/industry committees such as the ICT Multi-Stakeholder Platform, 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.

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 to remain "*at the Heart of Digital*", fulfilling its vision of being at the forefront of new Information and Communication Technologies.

The development of the ETSI Technology Radar has been performed 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 trends. The list of reports that have been analysed can be found in clause 5.
- 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. TB/ISG Chairs and Board members have replied to questionnaires prepared by the ETR editing team.

Phase 2: focused on analyzing the information collected during Phase 1 in order 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 an ETSI White Paper 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 OCG (Operation Coordination Group).

Finally, the output of the ETSI Technology Radar was compiled into the present report, providing information on the methodology, the selected technical trends, and the identified gaps, challenges, and opportunities for ETSI.

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.

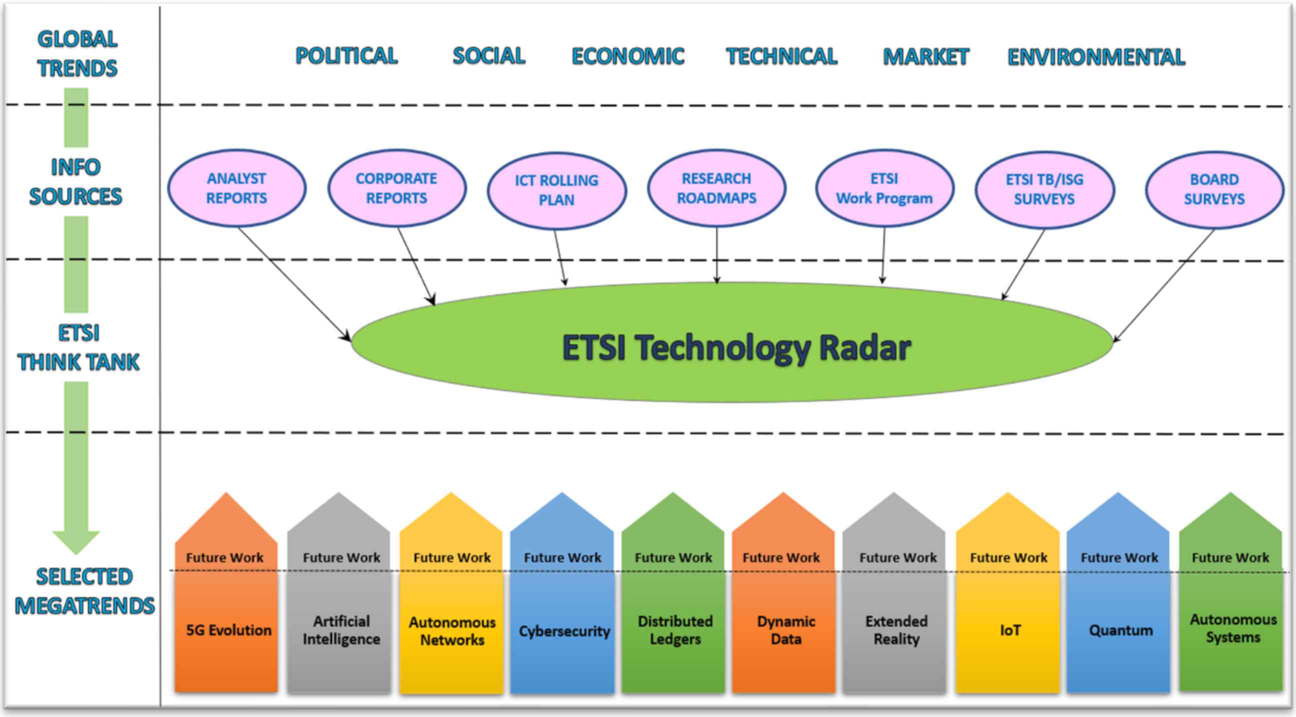

Figure 2: Sources used to build the ETSI ETR

3 Major trends impacting ETSI

3.1 Selected technical trends

The ETR editing team selected 10 technology trends from the wider set of trends identified during the analysis of ETR inputs. Figure 3 provides an overview of the 10 trends that are further described in clause 3.2.

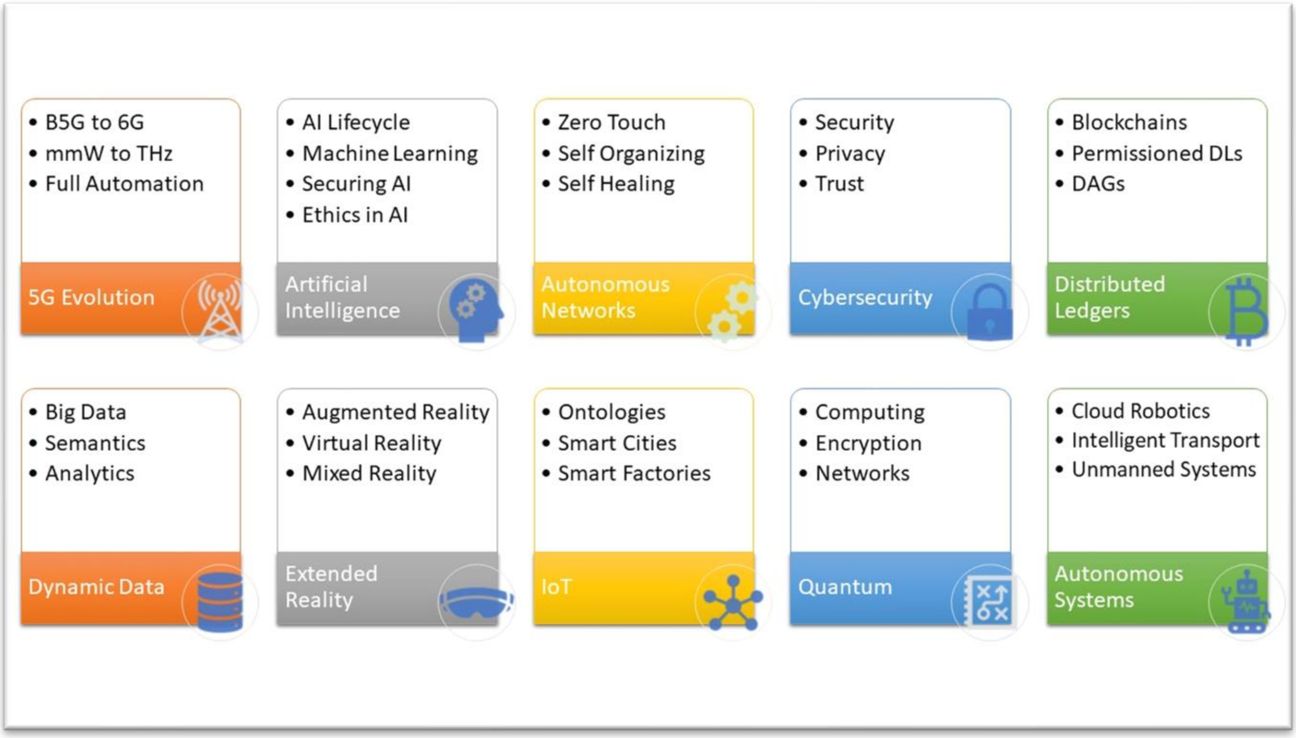

Figure 3: Overview of the ten selected technical trends

3.2 Analysis of technology trends

3.2.1 5G Evolution

3.2.1.1 Description

5G network technology is specified by 3GPP standards releases. Release 15 set the foundation to enable global standards-based 5G NR deployments, while Release 16, finalised in July 2020, targeted enhancements for new radio and core capabilities as well as the 5G expansion into different verticals. Work has started for Release 17, expected to be completed in 2022 and addresses further use cases and functionality.

The innovation funnel ahead of this standardization effort can be globally referred to as "*5G evolution*" as a joint result of academic research, industry developments, and public administrations strategic directions. Although it is not yet clear whether this evolution will be incremental to the current 5G architecture or will provide fundamental pillars to a new wireless standard generation such as "6G", the trend analysis identified some key technology directions that will likely shape the agenda of network evolution beyond the currently planned 5G releases:

- Evolved Network Architecture and Control
  This mainly includes a further evolution of the current NFV/SDN based network models towards full network automation taking benefit of predictive models, AI/ML technologies, IT technologies.
- Evolved Radio Technology and Signal Processing
  The race from mmW towards the use of higher frequencies, such as THz communication, LiFi, Infrared Communication will likely bring a wave of radio technologies, networking models, ultra-massive MTC.
- Evolved Optical Networks
  They will likely bring additional performance to 5G architectures through novel disaggregated multi-layered architectures; integration of x-Hauling with fixed access, SW defined Optical Networks.
- Edge Computing and Meta-data
  The current 5G-enabled edge computing will likely evolve towards fog-computing models and new models for ultra-massive IoT management, benefitting, too, from new distributed authorization and storage models (e.g. distributed ledgers).

These network evolutions will most likely be supported by a set of new technology developments, including:

- a new wave of nanoelectronics, tailored to engineer on-chip antennas.
- metamaterials and intelligent surfaces designed to improve electromagnetic propagation.

These technologies will pave the way to novel approaches such as cell-free radio architectures and quantum radio-optics devices.

Many of the technologies cited above are already under study at European level, as shown in the SRIA (Strategic Research and Innovation Agenda) 2021-27, published by Networld2020 to highlight the potential European Technology Platform evolution [4].

Due to the complexity of the mobile network system, it is apparent that evolution of 5G, rather than a single specific trend, will involve a set of technology trends and topics that may be relevant in the evolution of wireless technologies. The following figure summarizes some of the main drivers that are expected to shape the evolutionary path of 5G during this decade.

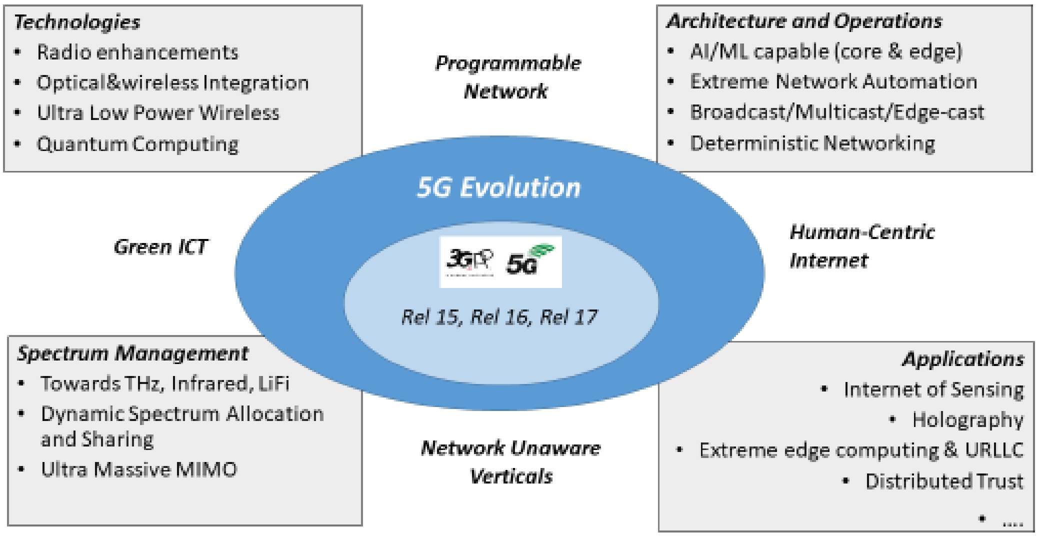

Figure 4: Key drivers for 5G evolution (non-exhaustive)

3.2.1.2 Affinity with ETSI Work

The affinity of ETSI work with 5G evolution may be seen from different perspectives:

- Most, if not all, of the themes of this likely 5G evolution are within the scope of ETSI alone or in partnership with other key international players. As an example, the term "5G" is mentioned almost 300 times in the 2019 ETSI Progress Report from the ETSI Director General to the GA [5] and it is considered a work reference for as many as 30 TB/ISGs, not to mention the key ETSI role in 3GPP that is devoted to 5G standardization.
- In many cases ETSI TB/ISGs are actively contributing to 3GPP work and its continued evolution, in particular with declared liaisons to SA4, SA5 and more generally direct inputs to TSGs SA, RAN, and CT.
- In other cases, ETSI TB/ISGs consider the current 5G architecture as an input to their own work.
- Apparently, reduced effort is currently devoted by ETSI to those 5G evolutionary trends that are marginal/absent in the current 3GPP work plan, e.g. (*indicative, not exhaustive items*) THz communication or SW defined optical networks.
- ETSI has also established an extensive network of partnerships in 5G-related areas, including other SDOs, industry fora, and academia.

3.2.1.3 Time Frame

The current 3GPP 5G work plan is expected to run over the next 3 years. Most 5G evolutions are expected to shape the technical standardization work in the next 3 to 5 years, and get momentum in the second part of the 2020 decade.

3.2.1.4 Recommendations

5G is a key pillar in ETSI activities, as should be 5G evolutionary themes. Therefore the recommendation is to ***Promote*** **and** ***Adopt***. In this area, the most appropriate recipient for ETSI work strongly remains 3GPP. It could be a matter for discussion, for an industry driven, bottom up, organization such as ETSI, whether:

- to monitor the most relevant 5G evolutionary topics by a transversal team, at 5GCOM or OCG level, and promote a high level debate (e.g. workshops, white papers, collaboration with academia);
- to anticipate 3GPP activities in some specific areas that may be relevant in 5G evolution and bring the results, at proper time, to the attention of 3GPP;
- to take no direct actions and simply consider 5G evolution a matter for discussion in 3GPP.

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. 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 [6] and in the European investment recommendations on Artificial Intelligence [7], including billions of Euros allocated in the Digital Europe Programme [8]. This is due to potential economic gains (e.g. see OECD reports on AI investments [9] and on AI patents [10]), as well as economic risks (such as the issue of liability, see [[11], [12]) and to avoid potential loss of European leadership due to failure to act.

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). 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, 5G Evolution). At the same time, the ethical and security issues of AI are being considered.

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 SON (Self Organizing Network). Machine Learning and in general Artificial Intelligence are key enablers for increasing automation. To deliver their full potential, AI-powered mechanisms rely on fast access to data, abstraction of intelligent and contextual information from events and rule-based systems, supervision, streamlined workflows and lifecycle management.

ISG ZSM (Zero-touch Network and Service Management), 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. In related work, ISG ENI designs (Experiential Networked Intelligence) based on data collection and processing using closed loop decision-making. The ENI requirements document GR ENI 007 [13] on network classification of AI details the use of AI in a network into six stages, from "No AI" to "full AI" deployment. 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.

A Generic Test Framework for testing AI models/systems during their lifecycles is under development in ETSI (see ETSI EG 203 341 [14], 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 the table below from the recent ETSI White Paper 34 [3].

Table 1: Initial Mapping of AI Standardization Activities within ETSI (Ref White Paper 34 [3])

considering / started / strong	3GPP	EP eHEALTH	ISG ARF	ISG CIM	ISG ENI	ISG MEC	ISG NFV	ISG SAI	ISG ZSM	oneM2M	SC EMTEL	TC CYBER	TC INT AFI WG	TC SmartM2M	TC MTS
Terminology					strong			strong	strong	considering			strong	considering	strong
Use cases	considering	considering			strong	started	started	started	strong	considering	considering		strong	considering	strong
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
Architectures and RPs			considering		strong	started	started	started	strong	considering			strong	strong	considering
Management of AIs					considering			started	strong	considering			strong	started	
Dataset requirements and quality		strong		started	strong		started	started	considering	considering			started	started	considering
Interoperability		started			strong		started	started	strong	considering			strong	started	strong
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 [15], 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 is ongoing mainly within the scope of EP eHealth and ISG SAI (Securing Artificial Intelligence).

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 three years in the initial phase, i.e. for 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
- an evaluation of the technical impact of the EU ethical guidelines on ETSI standardization
- AI Interoperability and Interchangeability standards
- guidelines for AI Testing and Validation
- dataset and quality requirements for Artificial Intelligence

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

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

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 has been a largely manual activity with some automated assistance. In short, no matter the degree of refinement, it is 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 and Artificial Intelligence that together, as well as a new level of automation and intelligence in the management and provisioning of services and networks, provide scalable mechanisms for managing ever increasing complexity.

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.

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.

The vision and business requirements listed above lead to the need for classification of Autonomous Networks Levels to ensure that digital partners can interact using the same mechanisms in terms of the automation, service intelligence and capabilities (as defined in the TM Forum White Paper on Autonomous Networks [16]).

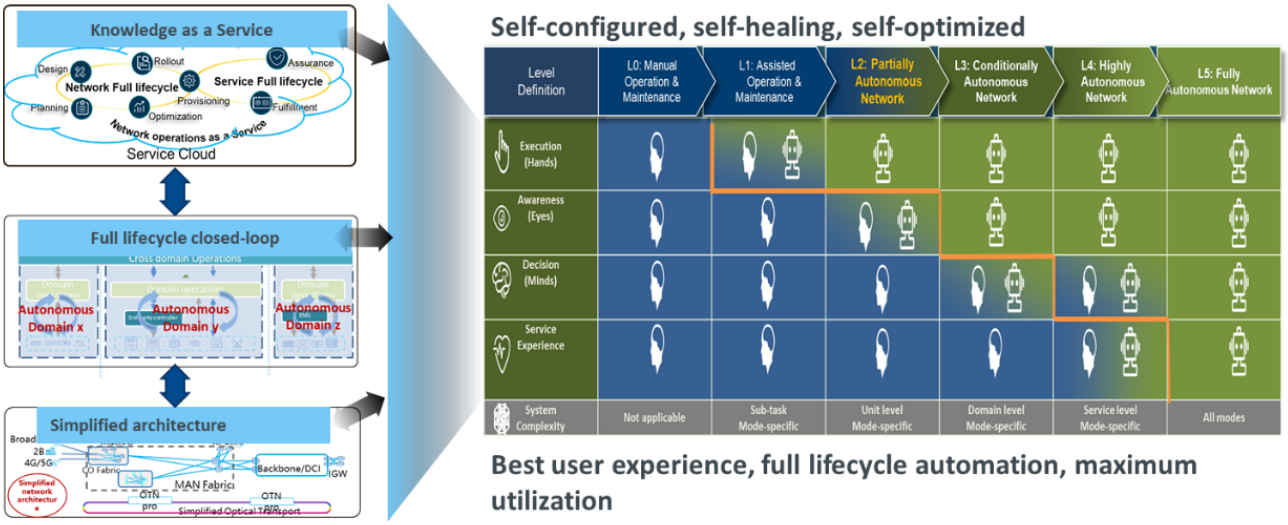

Figure 5: Autonomous Networks Levels

3.2.3.2 Affinity with ETSI Work

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 [17]).

ISG ZSM (Zero-touch Network and Service Management) 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, 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 ENI (Experiential Networked Intelligence) 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.

Other ETSI groups with activities related to Autonomous Networks are: F5G (5th Generation Fixed network), MEC (Multi-access Edge Computing), NFV (Network Functions Virtualization), and SAI (Securing Artificial Intelligence).

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.

However, the development toward a fully Autonomous Networks is also 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.

3.2.3.4 Recommendations

Standardization plays a significant role in terms of interoperability, feasibility and industrial deployment. Some SDOs already launched dedicated projects or produced important deliverables to support the evolution and deployment of Autonomous Networks.

Single SDO's effort is not enough and a collaborative environment among the leading stakeholders in the new extended ecosystem is meant to address, in their respective area of expertise, the Autonomous Networks evolution.

Therefore, we recommend a coordinated effort by leading SDOs, cross industry and vertical organizations, open source alliances and regulatory entities in order to succeed in this digital telecommunication transformation.

Firstly, groups within ETSI focused on Autonomous Networks security should increase coordination and align objectives to allow ETSI to take a leading role in this domain.

Secondly, ETSI should establish coordination with other organizations to share its work and expertise. The main organizations with ongoing activities in Autonomous Networks are TM Forum, GSMA, ITU-T SG13, 3GPP SA5 and CCSA TC7.

It is recommended that ETSI leads the required effort by working together with relevant organizations to facilitate the adoption of common standards and avoid market fragmentation.

3.2.4 Cyber Security, Privacy and Trust

3.2.4.1 Description

Cyber security, privacy and trust are topics that affect the full breadth of technologies, users and architectures – from 5G networks to AI software, from individual citizens to employees, from high-latency global networks to advanced localized endpoints.

From the expansion of the IoT (Internet of Things) to the rise of AI (Artificial Intelligence), the world has never been more connected or data-driven than it is today. These technologies, their data and their connectivity have become critical to our everyday lives, for businesses and individuals, and so too have their security, privacy and trust. 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 three main ways:

1. **More:** The trend continues towards more of everything: both security and privacy, and a heavier reliance on trust. The initial shifts towards "absolute security" and "absolute privacy" are now becoming more nuanced: considering the interplay between security and privacy, acknowledging privacy as a qualified human right, and understanding trust as a multifaceted and iterative process, rather than a single one-off cryptographic signature. This in turn is leading to more technologies addressing the breadth of use cases.
2. **Fewer:** Another continuing trend is the shift to fewer, more powerful entities in the technology space. Purposefully driving centralisation certainly ensures solutions can be deployed but can (by design) shut out competitors, leading to a more fragile and potentially anti-competitive ecosystem. This is ultimately bad for security, privacy, and trust too: worse resilience and over-reliance on a few entities, data concentrated in the same companies, and little to no choice for users resulting in worse trust. This is both a market and technical concern.
3. **Shifts:** The final large trend is the changes seen in architecture, wrought by the introduction of the cloud, edge processing and virtualised networks. Each new architecture brings its own trust and security challenges; when combined with cross-domain considerations, where interactions exist between two networks or organisations of differing security assurances, this poses an even tougher challenge.

A variety in the protective methods used by countries or organizations can make it difficult to ensure consistent, adequate security and privacy; simultaneously, accounting for all security, privacy and trust use cases needed across the vast array of devices, data and services that exist now and in the future is vital. Therefore, standards have a key role to play in improving cyber security 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 standards on IoT security, data protection and privacy, network 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, artificial intelligence, privacy-preserving pandemic protection; or
- Specific security tools and techniques such as lawful interception & retained data, digital signatures & trust services, permissioned distributed ledgers, smart cards / secure elements

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

3.2.4.3 Time Frame

The technical trends (More, Fewer, Shift) 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 over their expected lifetime.

Security, privacy, and trust will continue to be important throughout 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, innovations can create new attacks and worsen existing security measures.

3.2.4.4 Recommendations

Without excellent technical standards, well-considered threat models, and good practices, technologies may fall victim to new attacks and worsen existing security measures – and that is where ETSI can help.

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

Recommendation #2: ETSI needs to be able to begin 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:

- **Centralisation and consolidation (Fewer):** Rapidly changing technologies and new use cases require variety and choice for users. Many security, privacy and trust technologies are based on standards and have been for decades. More recently, these standards can be from a couple of ‘large companies’ that result in aggressive industry moves towards consolidation and centralisation of technology. Though this is often done under the guise of security, ultimately this actually lessens security and increases fragility, while simultaneously leading to greater privacy concerns than ever before. ETSI's security and trust work can create a more open, balanced, and diverse market that works best for citizens, governments and industry.
- **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 given, through high-quality technical standards.
- **Microservice environments (Shifts):** Microservices are growing in ubiquity, now present in the cloud and edge of networks. They serve IoT devices, process data and exchange information with neighbouring services to create a seamless user experience. Their security practices are not yet interoperable or necessarily heterogeneous, making this a key area for future standardization work in security, privacy, and trust.
- **Virtualisation (Shifts):** Moving to network architectures of the future, virtualisation 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.

Recommendation #3: As a leading SDO in the security, privacy, and trust arena, with cross-industry engagement and expertise, ETSI should take steps to actively share its work and the topics it addresses with key stakeholders. Therefore, ETSI should actively work on its presence with key stakeholders and European bodies via communications and formal efforts in the organization to build relationships. This presence will allow ETSI to take its leading role in providing industry expertise, viewpoints and practices on the range of topics covered by security, privacy, and trust.

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 new and promising technologies used to 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 edge computing, network automation and massive machine type communication introduce new technology challenges that can benefit from the use of DLTs. More than just a technology, in these sectors DLTs could lead to a major innovation by completely redefining the way transactions, information access and data sharing are operated among the stakeholders and how they participate in the process.

DLTs comprise a wide range of different participation schemes, ranging from fully non-permissioned approaches, adopted from the Fintech areas, to various forms of permissioned DLTs. They mainly differ in the trust scheme defining who can register transactions in the DLT. Non-permissioned approaches allow any participant, as long as it can bring a proof of its commitment to the ledger. 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, what 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.

Additionally, further technologies are under study, for example the use of Directed Acyclic Graphs (DAG) instead of blockchains: the main benefit of DAG-based DLTs (no matter whether permissioned or not) is that transactions are registered based on previous transaction history, so no trust has to be assigned to a concrete node to record them, and thus DAGs can process even larger amounts of transactions with shorter delays and much lower energy consumption.

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:

- **A new security paradigm** that overcomes the limitation of current perimetric security technologies not tailored to 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

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

- Interoperability issues between the various numerous private/public initiatives on DLT
- Optimal DLT scalability and reduced 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.

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 ETSI ISG PDL is committed to analyze 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. The ISG PDL intends to incorporate research and new development results in the field as they become available. The group is actively working to facilitate the coordination and cooperation between relevant standardization bodies and open source projects".

3.2.5.3 Time Frame

DLT potential is still to become a consolidated reality in industry and society. It is expected that it will emerge within 2 to 4 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, 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, IETF IERF, W3C, IEEE, ISO TC 307, CEN-CLC/JTC 19, mainly on identity management, and verticals markets (e.g. precision agriculture, healthcare, energy, and connected and autonomous vehicles).

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 infrastructure. Although many industry "verticals" have individually developed extensive sets of (de facto) standards and agreed workflows, the operating costs of collecting, cleaning and reliable re-use of (real-time) data remains very high in each domain and indeed accelerates in so-called Volume and Velocity [18]. 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.

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 (a topic currently under investigation in ETSI ISG 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 cross-domain and higher-layer aspects.

TC SmartM2M already begins considering 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, supporting human experts. The SmartM2M activity evolves specifications for use in oneM2M and the SAREF [19] 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 SmartBAN (Smart Body Area Network) reference architecture [20], 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 ARF (Augmented Reality Framework) is defining an interoperability framework for augmented reality after thoroughly studying the existing SDO landscape in the report GR ARF 001 [21]. 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 CIM (cross-cutting Context Information Management) exchange of data and metadata 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 [22] and also security functions. NGSI-LD API uses linked open data and property graphs to reference basically any data and definitions (ontologies), for example those in SAREF that are specified within SmartM2M.

3.2.6.3 Time Frame

There is no "big bang" for enabling of dynamic data. The gradually increasing efficiency of data processing, and the increasing availability of such data through digitalisation, is 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 with IDs accessed over Covid-19 tracing, lock-down of two 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, licensing, etc.). Even "free open data" has very significant production and import costs today (see reference [23] 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 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 future immersive technologies yet to be developed. XR covers the full spectrum of real and virtual environments. Figure 6 illustrates how the different ‘realities’ relate to each other; it is based on the Reality-Virtuality Continuum defined by Paul Milgram in 1994 [24].

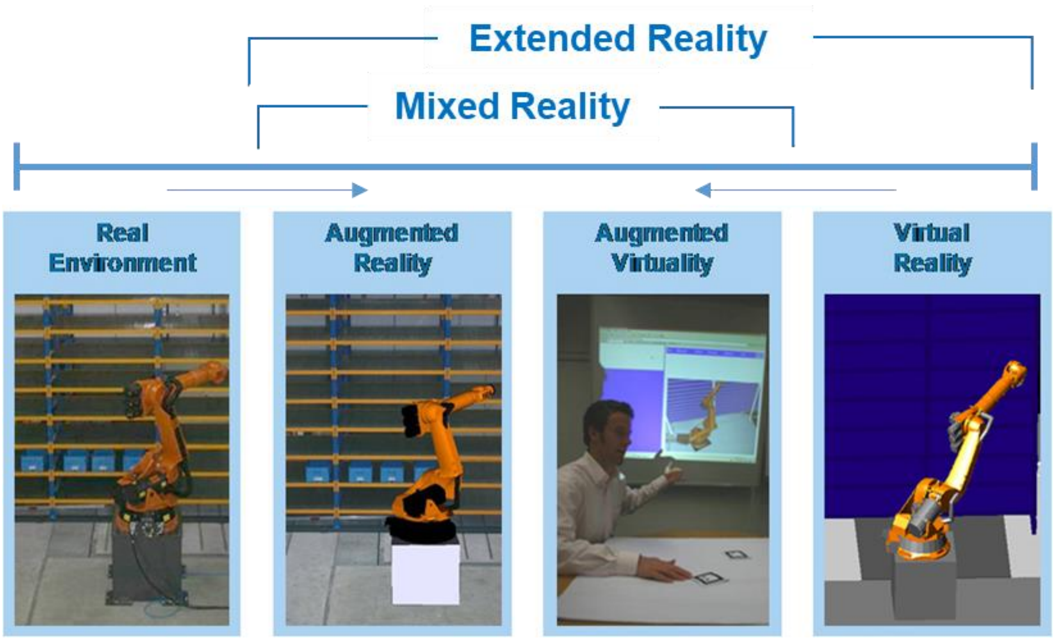

Figure 6: The eXtended Reality Landscape

Mixed Reality (MR) allows to augment the user perception of the real world with additional digital content.

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 user to be able to interact with virtual environments have gained much popularity over recent years.

However that is rapidly changing and research 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 whilst ensuring the safety of workers in potentially hazardous environments.

Examples include the use of VR for training or optimization purposes to fully simulate dangerous working environments and/or working with expensive, easily damaged equipment, without the potential risks to the materials or to the user.

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 [25]) 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.

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

- Video Gaming
- Events and live/immersive experiences (sporting / musical / cultural)
- Video entertainment
- Tourism / navigation
- Construction / Manufacturing
- Retail
- Military
- Education
- … and many more.

Of course all of these applications require ultra-reliable and ultra-fast connectivity, which means their 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 ensure that Augmented Reality services and platforms will be easier to design, deploy and operate than today taking into account the advent of 5G networks;

• to enable 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 ARF (Augmented Reality Framework) has defined a functional reference architecture for augmented reality solutions (ETSI GS ARF 003 [26]). 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 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 activities in 3GPP SA4 on XR and 5G that are currently part of Release 17 delivery expected to be completed in 2022. 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) [27]) indicate the number of XR consumer devices could double from 2018 to 2022, to target around 70 M 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 organisations 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 ISF ARF on XR enablers, with particular focus on architectural frameworks, media component interoperability, cloudification
- ***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 MoU with the following organisations:

- 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 AREA, the Augmented Reality for Enterprise Alliance, is 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.

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 analyzed for decades, so it cannot really be categorized as a new trend. However, the IoT creates a fundamental transition for ”man-the-tool-user” whereby the tool and the workplace are directly "at hand", as they have been for thousands of years, to a digital environment whereby direct human senses are substituted by electronic sensors and human actions actuate machines thousands of kilometres distant (e.g. remote drones scanning disaster areas) and other inaccessible locations such as laying of deep-sea submarine cables or at a smaller scale with targeted delivery of medicine using nanorobots inside the human body.

Back in 2018 we witnessed a tipping point, where the number of IoT connected "things" exceeded the number of connected humans and of course the growth rate for connecting humans is much lower than that for things and objects (10% to 40% per year, depending on application area). 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 requirements, 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 five different dimensions, towards:

(1) 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

(2) 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

(3) 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

(4) 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

(5) 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

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 [28] in oneM2M or MQTT interfaces [29] 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 Cyber Security, 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.

This is indicated in the figure below which illustrates an example for city vehicular traffic management:

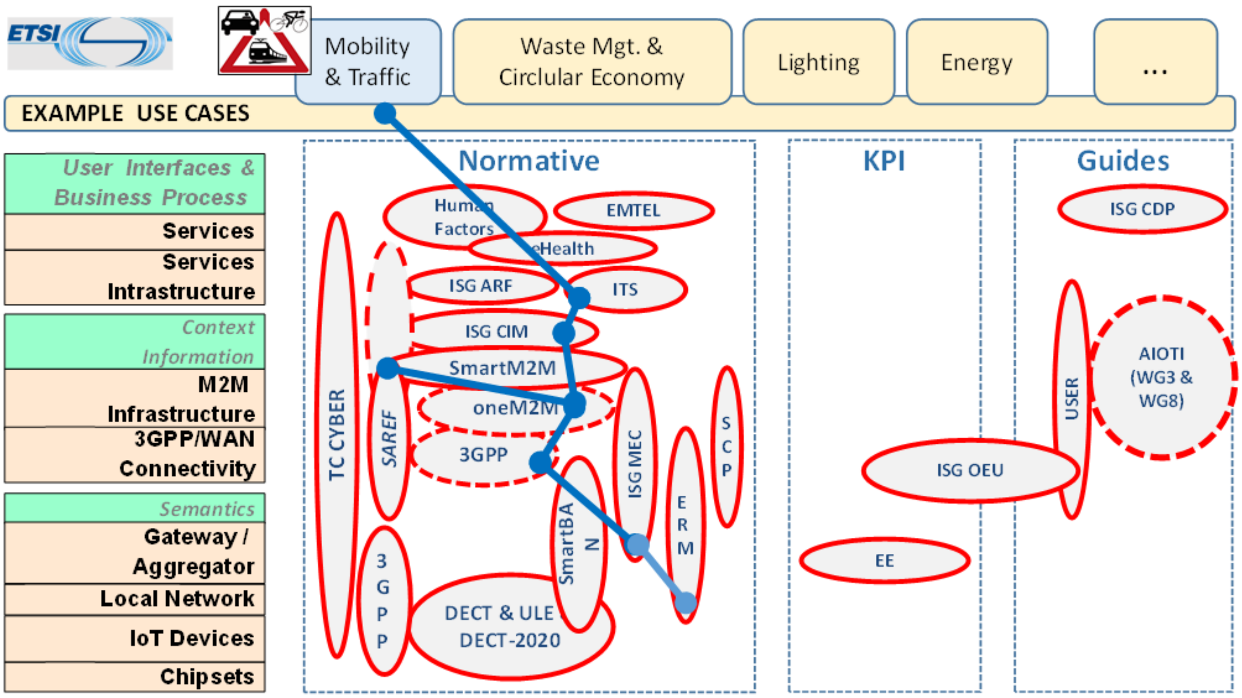

Figure 7: ETSI approach to build interoperability for IoT solutions using multiple standards

The above figure illustrates that 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.
- 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 [28], automotive domain [29], etc.

- 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 API 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 highly 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 shown in the figure 7, although oneM2M has partnered in mid-2020 with GCF to offer global conformance testing and also ISG CIM is creating 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.

3.2.8.3 Time Frame

The time frame for IoT is today / now. Below are a number of recommendations 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 organisations 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
- 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 when 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

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 are allowed to be in multiple states until they are observed), measurement (an object in a superposition state may 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 qubits 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 (copy and forward) 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 qubits 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 in 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/QSC (Quantum Safe Cryptography and Security) 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 that is currently in its ramp-up phase and the construction of an Open European Quantum Key Distribution testbed is underway. The results will come in a progressive way and it is expected to have primary results in the next 3 years with more advanced quantum technologies being introduced to remove limits and improve scalability through the remainder of the decade.

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

Availability of **Robotics and Autonomous Systems** (RAS) represents a growing trend in our daily life. RAS can be referred to as a “*multidisciplinary scientific and technological domain for implementing complex systems with cognitive capabilities*” (see the EU ICT Standardization Rolling Plan [30].

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 use of RAS, for example in precision farming, autonomous or assisted driving, Unmanned Aerial Systems, surveillance, emergency and rescue, Machine to Human social / commercial interactions, health care, assistive living, entertainment, education. RAS diffusion, too, brings a strong economic contribution as an industrial and commercial activity on its own, and 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 can have, too, a deep impact on jobs and skills, leading to replacement of humans 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, semantic, communication technologies, from short range communication to 4G and 5G.

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).
- **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**, a SW 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 picture is currently jeopardized:

- Robotics, cloud robotics, autonomous systems are not in the mainstream of ETSI activities and are not cited in the ETS DGs progress report 2019 (see [5])
- 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 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 thereof indirectly addressed by ETSI in the relevant TCs/ISGs

3.2.10.3 Time Frame

The advent of RAS is already a reality in Industry and society. All analysts agree that RAS represent a fundamental shift in many economic sectors since now to the forthcoming years.

3.2.10.4 Recommendations

As highlighted in the EC Standardization Rolling Plan (ref. [30]), 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 recommendation for ETSI Community could therefore be multi-folded:

- ***Follow*** the activities carried out in other SDO, 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.

3.3 Challenges and opportunities

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

Table 2: Summary of the recommendations related to the 10 technical trends

Trend Name	ETSI Affinity	Timescales	Recommendations
5G Evolution	3GPP has active contribution from more than 30 ETSI TB/ISGs	5G evolution expected in the next 3 to 5 years,	5G is a key pillar in ETSI activities, as should be 5G evolutionary themes. Therefore the recommendation is to: ▪ Promote high level debate in ETSI (Board and OCG) on 5G evolution (e.g. workshops, white papers, collaboration with academia) The recipient for ETSI work strongly remains 3GPP
Artificial Intelligence	ISG ZSM ISG ENI TC INT SmartM2M ISG CIM oneM2M EP eHealth ISG SAI. AI OCG group	AI to be increasingly used in many context	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.
Autonomous Networks	ISG ZSM ISG ENI Other ETSI groups with activities related to Autonomous Networks are: ISG F5G ISG MEC ISG NFV	Autonomous Networks trend as end-to-end solution for the growing complexity of networks . Fully Autonomous Networks is a long-term goal	▪ Coordinated effort by leading SDOs, cross industry and vertical organisations, open source alliances and regulatory entities in order to succeed in this digital telecommunication transformation. a) Firstly, groups within ETSI focused on Autonomous Networks security should increase coordination and align objectives to allow ETSI to take a leading role in this domain. b) Secondly, ETSI should establish coordination with other organizations to share its work and expertise. The main organizations with ongoing activities in Autonomous Networks are TM Forum, GSMA, ITU-T SG13, 3GPP SA5 and CCSA TC7. It is recommended that ETSI leads the required effort by working together with relevant organizations to facilitate the adoption of common standards and avoid market fragmentation.

Trend Name	ETSI Affinity	Timescales	Recommendations
	ISG SAI		
Cyber Security, Privacy and Trust	TC CYBER ISG SAI Embedded in several ETSI groups .	Security, privacy and trust needs with increasing relevance. .	▪ Begin WIs, scope groups, host workshops or send expert liaison statements to relevant SDOs/EC stakeholders on topics as needed to adapt to the future trends, including: a) Centralisation and consolidation (Fewer) b) Automated data exchange (More) c) Advanced cryptography for nuanced use cases (More): d) Microservice environments (Shifts) e) Virtualisation (Shifts): ▪ Promote an active share of ETSI work and the topics it addresses with key stakeholders.
Distributed Ledgers (Blockchain)	ETSI ISG PDL TC SES TC eHealth, TC SmartM2M	Appropriate resolution of the key challenges within 2 to 4 years,	▪ Build on the work carried out in ETSI ISG PDL to position ETSI as the leader in Permissioned DLTs for the ICT Industry and 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, IETF IERF, W3C, IEEE, ISO TC 307, CEN-CLC/JTC 19, mainly on identity management, and verticals markets (e.g. precision agriculture, healthcare, energy, and connected and autonomous vehicles)
Dynamic Data	Network operations and IoT as main areas. TC SmartM2M TC SmartBAN ISG ARF ISG CIM	Gradually increasing efficiency of data processing, and the increasing availability of such data through digitalisation	▪ Key recommendation for ETSI is to collaborate with other organisations 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 perhaps need to adapt.
eXtended Reality (XR)	ISG ARF	Market to expand into multiple sectors over the coming 2-3 years, increases the need for interoperabl	▪ Collaborate with other organisations 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 ISF ARF on XR enablers, with particular focus on architectural frameworks, media component interoperability, cloudification ▪ 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.

Trend Name	ETSI Affinity	Timescales	Recommendations
		e products and services	
Internet of Things	TC SmartM2M TC SmartBAN ISG CIM oneM2M	The next 2-4 years are crucial for improving interoperability.	▪ 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 organisations ▪ Promote consensus-driven development of ontologies, e.g. SAREF and reuse of ontologies, e.g. in ISG CIM ▪ Collaborate with research projects so that 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
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 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 SDO, 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

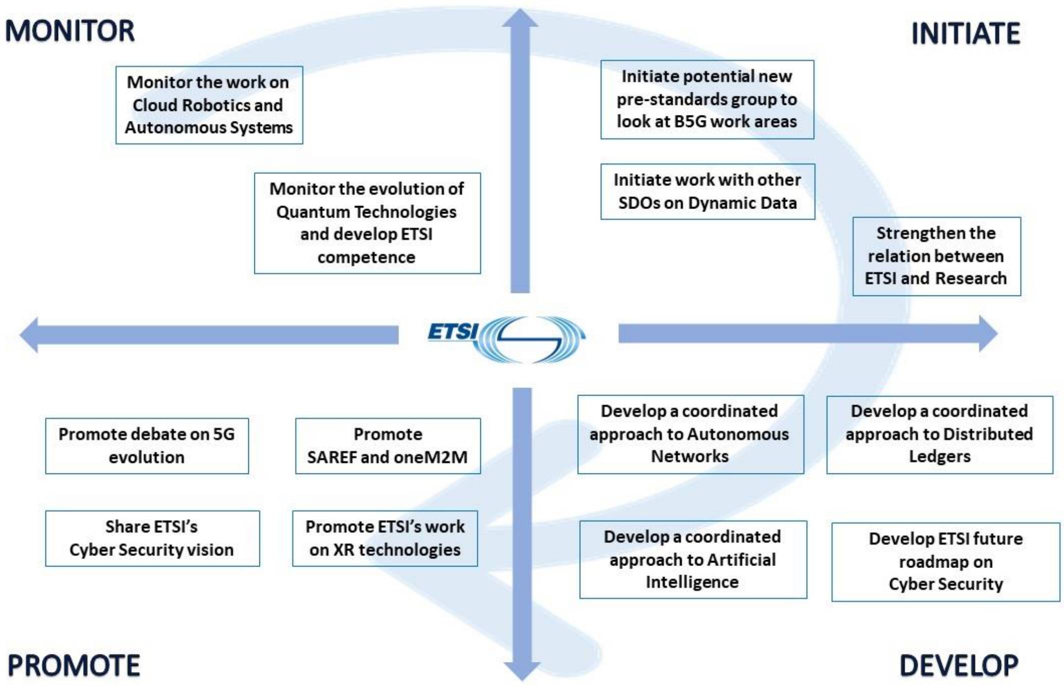

Figure 8: Summary of the recommendations for the 10 technical trends

4 Conclusions

The principle 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 10 technical trends reported in Chapter 3 are key examples of technology evolutions that are likely to impact not only the present of ETSI but, too, its future. 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 work ISG/TBs in ETSI. However the level of maturity is different and could evolve in the next years. Therefore it is not just 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 the ten addressed trends, the document has identified affinities with the ETSI work and suggested specific actions for ETSI. These actions could be reviewed in the next Board period, shared with OCG and inform actions and partnerships whenever appropriate.

Future: No matter on 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
CIM	cross-cutting Context Information Management
CT	Core and Terminals
DAG	Directed Acyclic Graphs
DECT	Enhanced Cordless Telecommunications
DLT	Distributed Ledger Technology
ENI	Experiential Networked Intelligence
ETR	ETSI Technology Radar
F5G	5th Generation Fixed network
GA	Assembly
GDPR	General Data Protection Regulation
GPS	Global Positioning System
ICT	Information and Communication Technology
INT	Core Network and Interoperability Testing
IoT	Internet of Things
ISG	Industry Specification Group
LiFI	Light Fidelity
LTE	Long Term Evolution
LTE-M	LTE-Mobile
M2M	Machine to Machine
MEC	Multi-access Edge Computing
ML	Machine Learning
mmW	Millimeter Wave
MoU	Memorandum of Understanding
MQTT	Message Queuing Telemetry Transport
MR	Mixed Reality
MTC	Machine Type Communications
NB-IoT	Narrowband IoT
NFV	Network Functions Virtualization
OCG	Operational Co-ordination Group
PAS	Publicly Available Specification
PDL	Permissioned Distributed Ledger

QKD	Quantum Key Distribution
QSC	Quantum Safe Cryptography
RAN	Radio Access Network
RAS	Robotics and Autonomous System
RFID	Radio Frequency IDentification
RRS	Reconfiguarable 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
SON	Self Organizing Network
SRIA	Strategic Research and Innovation Agenda
TB	Technical Body
TETRA	Terrestrial Trunked Radio
THz	TeraHertz
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
ULE	Ultra Low Energy
VR	Virtual Reality
VRARA	VR/AR Association
W3C	World Wide Web Consortium
WoT	Web of Things
XaaS	everything-as-a-service
XR	eXtended Reality
ZSM	Zero-touch Network and Service Management

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