IEEE

International Network Generations Roadmap

-2021 Edition-

Standardization Building Blocks

IEEE Future NETWORKS

An IEEE 5G and Beyond Technology Roadmap

futurenetworks.ieee.org/roadmap

This edition of the INGR is dedicated to the memory of Earl McCune Jr., who left us tragically and too soon on 27 May 2020. Earl was a microwave/RF guru, brilliant technologist, major industry/IEEE contributor, global visionary, keen skeptic, and all around fantastic human being. He was a major contributor to the INGR's early work on energy efficiency, millimeter-wave, and hardware. He worked for a technologically advanced yet more energy efficient world, and the contents of the INGR are a tribute to that vision. Rest in peace, Earl!

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Abstract

This chapter, produced by the Standardization Building Blocks (SBB) Roadmap Working Group, describes a wide range of global standards, consortia, and alliance activities enabling and defining future networks use cases, architectures, technical interface specifications, compliance, and test requirements, and regulatory environment over a ten-year time horizon.

The primary objective of the SBB Roadmap is to illustrate the "master timeline" for the standardization of wireless communications technologies. With the advent of every new generation of wireless networks, the capabilities of technologies expand, and economic conditions change resulting in an increasingly broader standardization scope. Accordingly, the scope of the SBB includes:

- depicting the value chain of the global system integrator Standards Developing Organizations (SDOs),
- illustrating the effort of relevant alliances and consortia that drive standardization, and open source activities.

The target audience for this road map are end-users, content producers using networks for content distribution, network service providers, equipment manufacturers, infrastructure vendors, component suppliers, and test and measurement service and equipment providers.

This roadmap recommends that the core technology stakeholders take a proactive approach to harmonize standardization with their vision for long-term technology evolution.

Keywords:

Emerging Technologies, Fifth Generation (5G), Industry consortia, Future Networks Initiative, Institute of Electrical and Electronics Engineers (IEEE), IEEE Standards Association (IEEE-SA), Internet Engineering Task Force (IETF), Industrial Internet Consortium, Internet Research Task Force (IRTF), International Organization for Standardization (ISO), International Telecommunication Union (ITU), Multiple In-Multiple Out (MIMO), Millimeter-Wave (mmWave), New Radio (NR), Open RAN, Open Source Organizations, Reference Architecture, Standards Developing Organizations (SDOs), European Telecommunications Standards Institute (ETSI), Autonomic/Autonomous Networking Standards.

INGR ROADMAP

1. Introduction

This section is produced by the Standardization Building Blocks (SBB) roadmap working group (WG) team. This roadmap describes the wide range of global standards, consortia, and alliance activities enabling and defining future networks' regulatory environment, use cases, architectures, technical interface specifications, compliance, and test requirements over a ten-year time horizon. The target audiences are end-users, content producers using networks for content distribution, network service providers, infrastructure vendors, equipment manufacturers, component suppliers, providers of test and measurement services and equipment.

This edition adds new perspective on standardization of future networks. It expands the issue of cooperation among SDOs, industry/academia alliances, and open source communities.

2. Working Group Vision

With every generation of wireless networks, economic conditions improve, and the capabilities of technologies expand, new technologies come into the picture resulting in standardization scope expansion. While progressing from generation to generation, more technologies and thus more industry players appear. Future networks standardization building block suppliers expand beyond traditional telecommunication Standards Developing Organizations (SDOs) as the stakeholder community includes a much wider variety of SDOs and industry alliances.

2.1. Scope of Working Group Effort

The scope of the Standardization Building Blocks Working Group is to depict the ever expanding Standardization Landscape and identify its evolution and challenges, as well as indicate trends and processes that occur globally as the wireless service generations progress. Another part of the mission is to support the IEEE International Network Generations Roadmap (INGR) Technology Working Groups' roadmaps in producing the Standardization Building Block components that are relevant to their technologies.

2.2. Linkages and Stakeholders

The stakeholders are end-users, content producers using networks for content distribution, network service providers, infrastructure vendors, equipment manufacturers, component suppliers, and test and measurement service and equipment providers.

3. Today's Landscape

3.1. Major System Integrator Organizations

The SDOs in this category produce volunteer standards that also normatively and informatively reference standards developed by other SDOs, especially the ones that develop standards in core technologies. The SDOs discussed in this category may be viewed as "the integrators" as well. Examples are Third Generation Partnership Project (3GPP), ITU Telecommunication Standardization Sector (ITU-T), ITU Radiocommunication Sector (ITU-R), and the International Organization for Standardization/ International Electrotechnical Commission/ Joint Technical Committee 1 (ISO/IEC/JTC1), ETSI, BroadBand Forum (BBF), TM Forum, and others.

The ecosystem related to future networks needs to be considered from multiple angles. It is valuable to understand how the standards bodies and relevant open source activities are related to one another.

In Figure 1 below, SDOs are segregated by the focus areas.

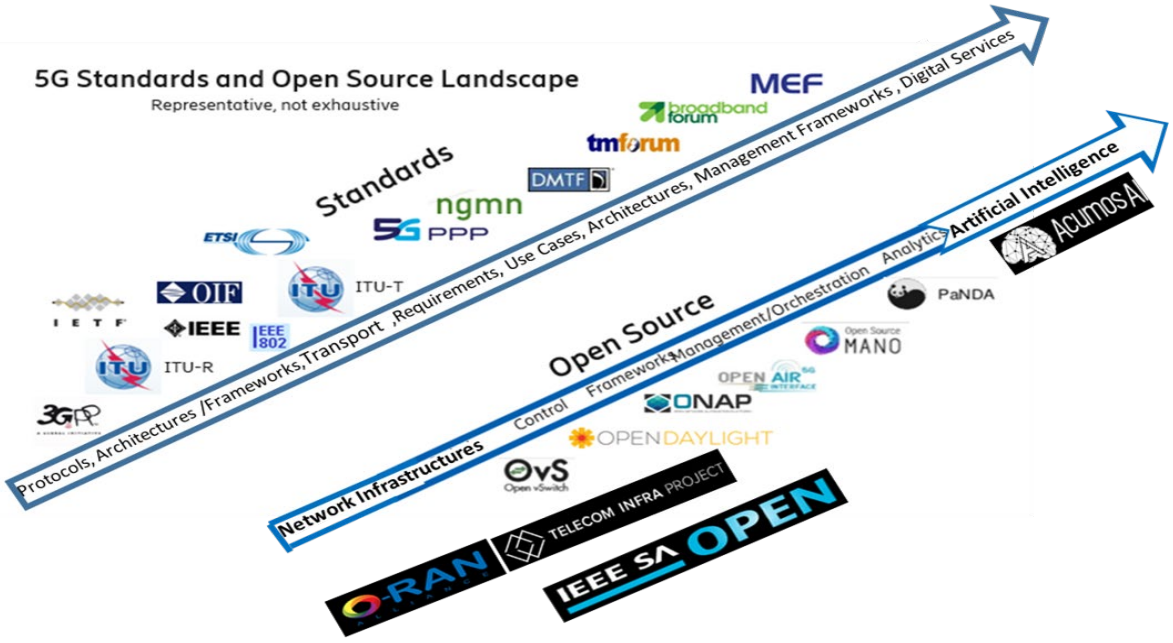


Figure 1. 5G Standards and Open-Source Landscape

Figure 2 illustrates the interaction among the SDOs participating in 3GPP related activities (presented at a high-level).

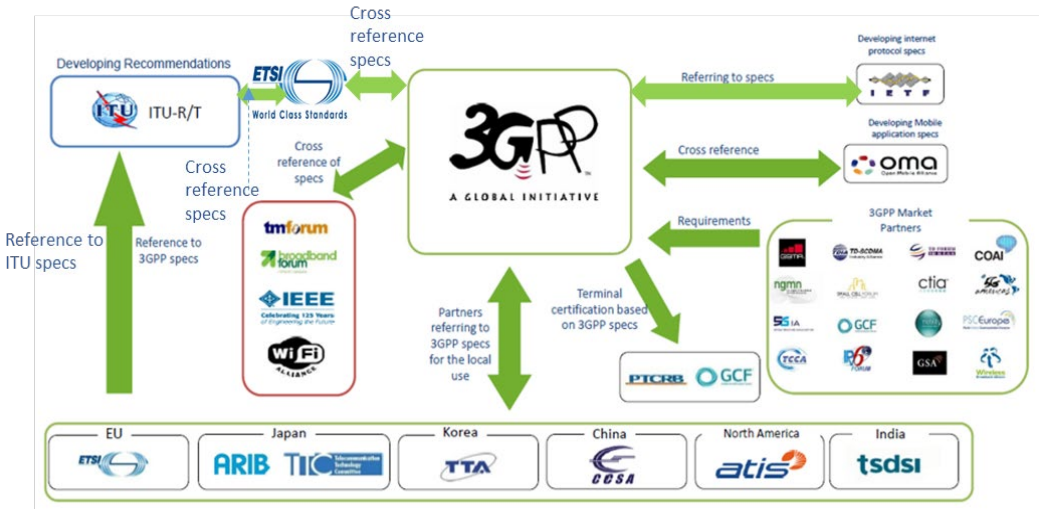


Figure 2. Interaction Among the SDOs with respect to 3GPP

Figure 3 provides another example that provides a view of the touchpoints among standards.

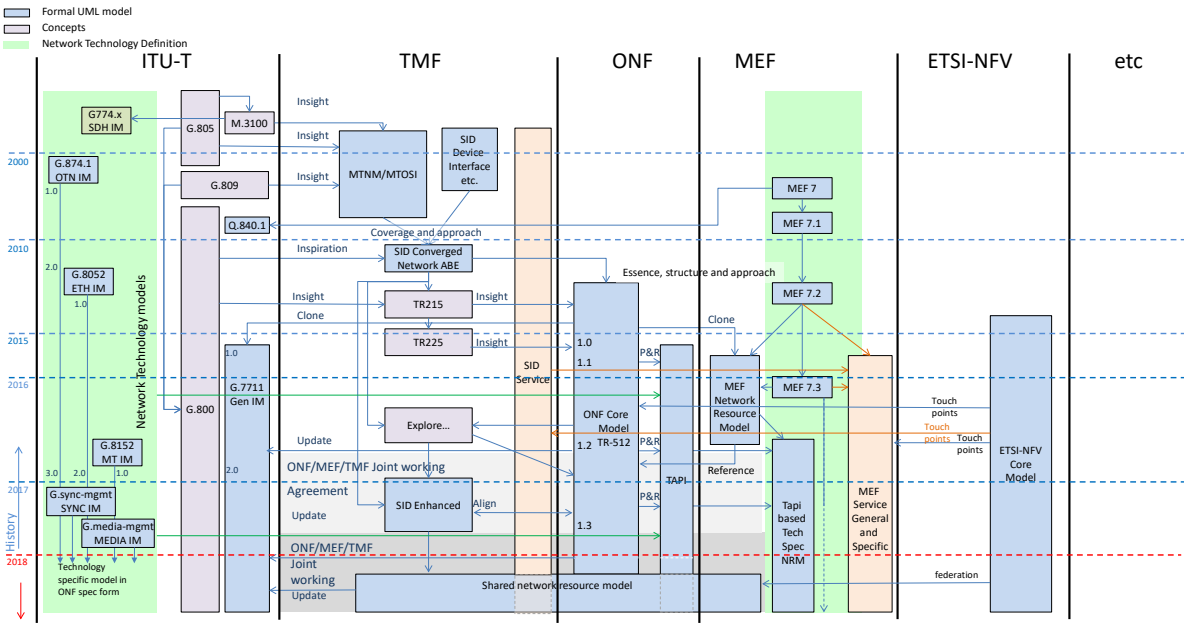


Figure 3. A View of Touchpoints Among Standards

Another example of the collaboration among SDOs/Fora on a specific topic, in this case on the topic of Autonomics and Autonomic Networking in Evolving and Future Networks, is illustrated in Figure 4. With Generic Autonomic Network Architecture (GANA) being native to ETSI, liaisons are established with the various SDOs/Fora. Artificial Intelligence (AI) and Machine Learning (ML) play a role in Autonomics.

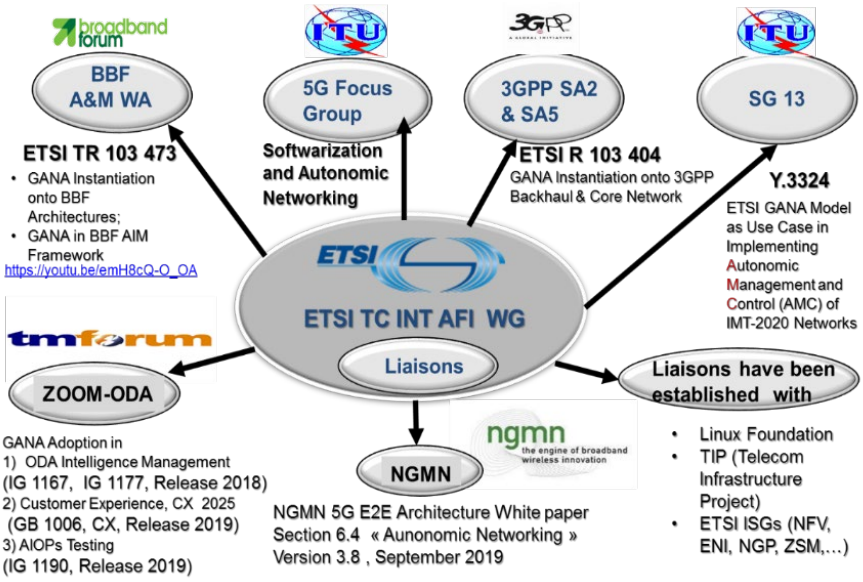


Figure 4. The collaboration of SDOs/Fora with ETSI on ETSI GANA Multi-Layer AI & Autonomics Framework

3.2. Core Technology Organizations

Core technology SDOs are those that produce volunteer standards in fundamental or core technologies.

Typically, these organizations are not associated with governments and may or may not be associated with corporate entities. Individual contributors, often with non-material but rather professed interest in technologies, make up a significant segment of standards developers in core technology SDOs. Among the most prominent core technology SDOs are organizations like IEEE, Internet Engineering Task Force (IETF), and the World Wide Web Consortium (W3C). These organizations predominantly or exclusively utilize individual contributors for development of standards. The following SDOs are based on corporate or national memberships and contribute to core technologies standards: ITU, ETSI, IEC.

Standards from these organizations are adopted and/or normatively referenced by standards documents from International Integrator SDOs.

Core technology SDOs leverage a significant academic and industrial research potential of global academia and industry.

3.2.1. IEEE - Core Technologies Standards Development Organization

The IEEE Standards Association (IEEE SA) is an Organizational Unit within the IEEE, the world's largest professional association with more than 400,000 members. IEEE SA develops well-known global standards in core technologies. It brings together expert individuals and/or organizations around the world to collaborate in developing standards. IEEE SA facilitates the development of standards through an open and transparent consensus-building process.

The IEEE SA standards development process is open to everyone. However, IEEE SA membership has significant advantages - "Members can engage in the standards development process at a deeper and more meaningful level, by providing additional balloting and participation opportunities."

IEEE SA develops standards in electrical and computer engineering areas, including power and energy, biomedical and health care, information technology and robotics, telecommunication and home automation, transportation, nanotechnology, information assurance, and software engineering.

3.2.2. Internet Engineering Task Force (IETF)

The IETF and the Internet Research Task Force (IRTF) are two parallel organizations that are dedicated to making the Internet better. The mission of the IETF is focused on producing high quality, relevant technical documents that influence the way people design, use, and manage the Internet (https://ietf.org/about/mission/). The IRTF (https://irtf.org/) addresses research of importance to the evolution of the Internet by creating focused, long-term Research Groups working on topics related to Internet protocols, applications, architecture, and technology.

The ecosystem related to future networks, including 5G, relies heavily on protocols, architectures, frameworks, and best practices from the IETF. The IETF has six areas that provide focus on technologies related to the Internet, Routing, Operations and Management, Transport (Layer 4 and above), Applications and Real-Time, and Security. Examples of technologies that are developed at the IETF that are relevant for the 5G ecosystem 5G include IPv4 and IPv6, routing protocols, traffic engineering, management techniques (like Network Configuration Protocol (NETCONF) and Yet Another Next Generation (YANG), security protocols, and new web-oriented transport protocols (like Quick UDP Internet Connections (QUIC)). Deterministic networking is a focus area of the IETF that brings together control-plane, data-plane, and management-plane technologies to provide a capability for Layer 2 and Layer 3 deterministic data paths. This work is coordinated with the IEEE 802.1 Time-Sensitive Networking activity that is focused on Layer 2.

The IRTF is a forward-looking task force that has currently 13 operating research groups that are focused on areas that will drive standardization because of well-considered research on a variety of topics. For example, the Crypto Forum Research Group is looking for new mechanisms for public-key encryption that could have far-reaching impacts on the use of end-to-end encryption.

3.2.3. Other Core Technology SDOs/Fora

ITU-R is responsible for setting and defining the 5G high-level features within the IMT-2020 project targeting the mobile network's standard for 2020 and beyond. For instance, ITU-R (through the ITU-R Working Party 5D) has introduced several recommendations, including the ITU-R M.2320 to study the future technology trends to prepare the development of the IMT-2020 standard and ITU-R M.2083 to define its main usage scenarios and key capabilities. To meet IMT-2020 requirements, 3GPP currently develops technical specifications and reports that need to be submitted and assessed by ITU-R to be qualified as standards. 3GPP has been working on release 15 and 16 that have been frozen, and recently (December 2020) agreed to a timeline of release 17. Within its November 2020 e-meeting, ITU-R successfully evaluated three new technologies (i.e., 3GPP 5G-SRIT and 3GPP 5G-RIT submitted by 3GPP, and 5G Radio Interface (TSDSI RIT) submitted by Telecommunications Standards Development Society India (TSDSI)) recognized as conforming to IMT-2020. The process now is on the road to introduce the first release of the IMT-2020 standard as a part of a new ITU-R Recommendation,

expected to be approved in February 2021 as Recommendation ITU-R M.2150. It is critical to note that the frequencies to be used with M.2150 are specified in an unfinished revision to ITU-R M.1036 IMT Frequency Arrangements (to include the mmWawe frequencies approved at WRC 19). Next opportunity for submission to ITU-R Study Group D is November 2021. Some specific 5G components like Network Functions Virtualization (NFV), Mobile Edge Computing (MEC), Millimeter Wave Transmission (mWT), and Non-IP Networking (NIN) are being developed in ETSI and are directly integrated as a part of 5G building blocks.

Other SDOs and alliances are also actively involved in shaping the current 5G standard. BBF is working with CableLabs and 3GPP to integrate wireline access into the 5G Core to support wireless and wireline convergence (WWC). This has been a part of 3GPP Release 16. The NGMN Alliance complements the standardization process by including the consolidated views and needs of mobile operators and verticals. NGMN has released two 5G white papers and initiated a work program comprising a portfolio of projects. Recently, NGMN launched the Green Future Networks Project to quantify the impact of the mobile ecosystem on the environment.

5G is not only about stretching the network features, but the application layer (e.g., the Web) also needs to follow the same trend. In particular, W3C's vision is to encourage content development and delivery players to get involved in evolving web technologies and 5G use cases in tandem. Under the umbrella of the Web5G project, W3C is trying to underline the current bottlenecks and prepare for new 5G-empowered network capabilities and applications.

A smooth migration towards digitized environments is also a key component of the 5G era. Open and collaborative environments of TM Forum (e.g., Open API & Open Digital Architecture Manifesto) are bringing cloud-native and software-enabled capabilities to traditional IT systems for a successful 5G monetization.

3.3. Industry Alliances

In addition to the SDOs discussed in Section 3.1 and Section 3.2, many industry consortia and alliances are addressing various aspects of future networks. Some of these are regional and others are international organizations. The following is a list of these alliances with brief descriptions:

- 5G World Alliance (5G WA)—A relatively new global organization to provide a key platform for 5G development across all technologies. No members yet.
- 5G Alliance for Connected Industries and Automation (5G-ACIA)—Another forum for collaboration between automation, engineering, and process industries on the one hand, and telecom operators and suppliers on the other, as well as universities. Led by Ericsson. Includes about 30 members mainly from Europe.
- Wireless Broadband Alliance (WBA)—An older group focusing on the development of the converged wireless broadband ecosystem through seamless, secure, and interoperable unlicensed wireless. Members include major vendors and service providers.
- Open Mobile Alliance (OMA)—A standards body, which develops open standards for the mobile phone industry. Focusing on application/service layer protocols.
- Next Generation Mobile Networks (NGMN) Alliance—A major player in the mobile communications industry to drive technology requirements to the industry standards groups and includes influential representatives from most of the world's largest mobile operators.

- 5G mm Wave Channel Model Alliance—Formed by National Institute of Standardization and Technology (NIST) to accelerate the development and use of accurate measurements and models for next-generation communications technology.
- 5G Infrastructure Public-Private Partnership (5G-PPP)—A joint initiative between the European Commission and the European ICT industry (ICT manufacturers, telecommunications operators, service providers, Subject Matter Experts (SMEs), and researcher institutions).
- Industrial Internet Consortium (IIC)—Founded in 2014 to speed the commercial use of advanced technologies, including the industrial Internet, by promoting best practices. Although, mainly focused on the use of the IoT in manufacturing, but the IIC is expanding its focus on the Energy, Transportation, Healthcare, and Smart Cities sectors as well.
- Dynamic Spectrum Alliance (DSA)—A global, cross-industry alliance focused on increasing dynamic access to unused radio frequencies.
- C-Band Alliance (CBA)—Formed recently by satellite operators to sell US spectrum to 5G operators.
- Open RAN (O-RAN) Alliance—Recently created by merging the xRAN Forum with the C-RAN Alliance. A "carrier-le"' effort to push more openness into the radio access network of the next-generation wireless systems. Members include AT&T, China Mobile, Deutsche Telekom, NTT DOCOMO, and Orange.

The following is a list of some other industry alliances:

- 5GAA (5G Automotive Association)—http://www.5gaa.org/
- ACEA (European Automobile Manufacturing Association)—http://www.acea.be/
- AEF (Agricultural Industry Electronics Foundation)—http://www.aef-online.org/
- AIOTI (Alliance for the Internet of Things Innovation)—http://www.aioti.eu/
- ASHRAE—https://www.ashrae.org/
- Automation ML—https://www.automationml.org/
- AVNU—http://avnu.org/
- Bluetooth—http://www.bluetooth.com/
- Broadband Forum—https://www.broadband-forum.org/
- Calypso—https://www.calypsonet-asso.org/
- C2C-CC (Car-2-Car Communication Consortium)—https://www.car-2-car.org/
- CCC (Car Connectivity Consortium)—http://carconnectivity.org/
- CC-Link—http://www.cclinkamerica.org
- CEN (European Committee for Standardization)—https://www.cen.eu/
- CENELEC (European Committee for Electrotechnical Standardization)—http://www.cenelec.eu/

- CIA (CAN IN Automation)—http://www.can-cia.org/
- CLEPA—http://www.clepa.eu/
- Continua: Health Alliance—http://www.continuaalliance.org/
- DICOM (Digital Imaging and Communications in Medicine)—http://dicom.nema.org/
- easyway—https://www.easyway-its.eu/
- EEBUS—https://www.eebus.org/
- eCl@ss—http://www.eclass.de/
- ERTICO – ITS Europe—http://ertico.com/
- ESMIG—https://esmig.eu/
- Enocean Alliance—https://www.enocean-alliance.org/
- GlobalPlatform—http://www.globalplatform.org/
- GSMA—http://www.gsma.com/
- GS1 (Global Standards 1)—http://www.gs1.org/
- HL7 International (Health Level 7)—http://www.hl7.org/
- HYPER/CAT—http://www.hypercat.io/
- IEC (International Electrotechnical Commission)—http://www.iec.ch/
- IHE (Integrating the Healthcare Enterprise)—http://www.ihe.net/
- IIC (Industrial Internet Consortium)—http://www.industrialinternetconsortium.org/
- IPEN (Internet Privacy Engineering Network)—https://secure.edps.europa.eu/EDPSWEB/edps/EDPS/IPEN
- IPSO (Internet Protocol for Smart Object)—http://www.ipso-alliance.org/
- IPv6 Forum—http://www.ipv6forum.com/
- IO-Link—http://www.io-link.com/
- IoT Security Foundation—https://www.iotsecurityfoundation.org/
- The KNX Association—http://www.knx.org/
- LoRa Alliance—https://www.lora-alliance.org/
- MIPI Alliance—http://mipi.org/
- NB-IoT Forum—https://www.gsma.com/iot/narrow-band-internet-of-things-nb-iot/
- NFC Forum—https://nfc-forum.org/
- OASIS—https://www.oasis-open.org/
- OAA(Open Automotive Alliance)—http://www.openautoalliance.net

- Open Connectivity Forum—http://openconnectivity.org/
- ODVA—https://www.odva.org/
- OGC (Open Geospatial Consortium)—http://www.opengeospatial.org/
- OMA (Open Mobile Alliance)—http://openmobilealliance.org/
- The ULE (Ultra Low Energy) Alliance—http://www.ulealliance.org/
- OMG (Object Management Group)—http://www.omg.org/
- OPC (Open Platform Communications) Foundation—https://opcfoundation.org/
- The Open Group—http://www.opengroup.org/
- OSGi Alliance—http://www.osgi.org/
- PI (Profibus – Profinet) International—http://www.profibus.com/
- Platform Industrie 4.0—http://www.plattform-i40.de/
- SAE International—http://www.sae.org/
- SGIP (Smart Grid Interoperability Panel)—http://sgip.org/
- Thread group—http://threadgroup.org/
- Trusted Computing Group—http://www.trustedcomputinggroup.org/
- UDG Alliance USEF (Universal Smart Energy Framework)—https://www.usef.energy/
- Weightless—http://www.weightless.org/
- Wireless World Research Forum—http://www.wwrf.ch/
- The ZigBee Alliance—http://www.zigbee.org/
- XMPP—http://xmpp.org/

3.4. Open Source Organizations

There are many Open Source Organizations, but only a few that are driving engagement and thought leadership in the 5G space. The list in Section 3.3 provides a few of the major ones. Below is an explanation of their activities.

- O-RAN Software Community (SC) (https://o-ran-sc.org)—The O-RAN Software Community aspires to create software for the Radio Access Network.

- OpenStack (https://openstack.org)— OpenStack provides the tools necessary to manage large pools of computing, storage, and networking resources. The applicability to 5G is in the decomposition of the functionality that will provide RAN and CORE networks. As more

functionality is deployed as network functions, the ability to control the deployment of those network functions dynamically will be important.

- Kubernetes (https://kubernetes.io)— Kubernetes is an open-source container orchestration platform. Containers make the creation and moving of sets of functionalities around the network possible. Kubernetes is developed by the Cloud Native Computing Foundation (https://cncf.io).

- OpenAirInterface (https://openairinterface.org)—The OpenAirInterface is working on open-source software and hardware that would create a 5G Cellular Stack. A collaboration between O-RAN (Open-RAN Alliance) and Linux Foundation has created open and intelligent software for RANs. The work is guided by an architecture that has identified the building blocks of a RAN and the interface between those building blocks. For example, there are specifications for front haul control and management along with a software architecture for base stations (for more information on what is published see https://www.o-ran.org/specifications and https://www.o-ran.org/software). O-RAN is providing an open-source solution for the RAN that can be leveraged in a system that is using ONAP/OPNFV (along with container and OpenStack functionality) in the edge, core, and cloud.
- TIP (https://telecominfraproject.com/)— A new approach to building and deploying telecom network infrastructure. The Telecom Infra Project (TIP) is a global community of companies and organizations working together to accelerate the development and deployment of open, disaggregated, and standards-based technology solutions that deliver the high-quality connectivity that the world needs – now and in the decades to come.
- ACUMOS (https://www.acumos.org/) — Making Artificial Intelligence Accessible to Everyone: Acumos AI is a platform and open-source framework that makes it easy to build, share, and deploy AI apps. Acumos standardizes the infrastructure stack and components required to run an out-of-the-box general AI environment. This frees data scientists and model trainers to focus on their core competencies and accelerates innovation.
- IEEE SA Open Source Program (https://standards.ieee.org/initiatives/opensource/index.html) - IEEE Standards Association provides a hosting platform for open source communities for projects that are related and not related to standards.
- Open Network Foundation (https://opennetworking.org/) – It is an operator led consortium to develop open source solutions for operators. The ONF is well known for its Software Defined Networking related projects.
- Linux Foundation (https://www.linuxfoundation.org) – It is a non-profit technology consortium to standardize Linux, support its growth, and promote its commercial adoption. Also, Linux Foundation has several networking and edge projects.

3.5. A Matrix of Topics Addressed in Various SDOs/Fora

The matrix presented in Figure 5 below is on a mapping of various topics linked to evolving and future networks related standards that are being addressed in various SDOs/Fora. The topics are described by the legend given at the bottom of Figure 5.

Organization (SDO/Fora), or Other Kind of Initiative	Group	Topics of Relevance to the Group
Multi-SDO (Joint-SDO/Fora) Industry Harmonization Initiative on Standards, Architectural Frameworks, and Taxonomy	Harmonization of E2E 5G Architectures and Multi-Layer & Multi-Domain AI Frameworks for Autonomic (Closed-Loop) Network Automation	
BroadBand Forum (BBF)	5G related WAs, and Automated Intelligent Management (AIM) Framework	
3GPP	SA Groups on 5G Architectures and Management	
ETSI	TC INT/AFI WG on GANA Standards for Autonomic Network Engineering for Self-Managing Future Internet and Self-Managed Fixed & Mobile Integrated Networks	
ETSI	NFV ISG	
ETSI	MEC ISG	
ETSI	ENI ISG	
ETSI	SAI ISG	
ETSI	ZSM ISG	
ETSI	F5G ISG	
ETSI	TC INT & TC MTS Joint Work on "AI in Test Systems, and Testing AI Models"	
ETSI & IPv6 Forum	IP6 ISG	
GSMA	Telco Operating Platform	
GSMA	Future Networks Project & Autonomous Networks	
IEEE	The IEEE Global Initiative on Ethics of Autonomous and Intelligent Systems	
IEEE	IEEE Future Networks Standardization	
IEEE	5G related Standardization	

Organization (SDO/Fora), or Other Kind of Initiative	Group	Topics of Relevance to the Group
IETF/IRTF	Various groups on IETF Protocols (mainly IP based Protocols) required in 5G & Future Networks	
ITU-T	SG13 and SG11, SG17(Security), SG20 (IoT)	
ITU-T	Focus group on ML for Future Networks	
MEF	Network Automation & Service Orchestration	
NGMN	E2E 5G Architecture	
NIST	AI Standards	
OMG	Metamodeling Tools; and Model-Driven Information Networking for Networks & Models for Knowledge Representation	
ONF	SDN, and Intent based management	
3GPP	SA5 WG5 Intent Based Networking (IBN)	
3GPP	SA2 & SA5: Self-Organising Networks(SON), SBA (Sevice Based Architecture, R16)	
TM Forum	Autonomous Networks (ANs)	
TM Forum	AI Program	
TM Forum	Open Digital Architecture (ODA)	
CEN/CENELEC	Focus Group on Artificial Intelligence	
5GPPP Consortium	5G experimentation platforms	
European Commission (EC) funded StandICT Project's Standards Watch Portal	Standards Watch Repository for Tracking Standards Outputs & Roadmaps	

Symbol	Evolving & Future Networks Topics: Legend
	5G related Architectural Frameworks and Requirements
	Management and Orchestration (MANO) Frameworks
	Autonomic Network (AN) Engineering, Reference Models, Architectural and Operational Principles for Self-Organizing and Self-Managing Networks; Autonomous Networks
	Big Data Analytics, AI for Business Intelligence, AI for Multi-Layer Autonomics (up to the Business Layer), Analytics
	Services Management Frameworks and Tools
	(Meta-)Modeling, Model-Driven Information Networking for Network Automation, Models for Knowledge Representation in Autonomic/Autonomous Networks, and Tools
	IPv6 and Next Generation Protocols (including Non-IP Future Protocols) and Future Internet
	Evolving/Future Networks Testbeds, and Federated TestBeds for Innovation and Validation of Standards based Solutions
	Telco Networks (RAN, MEC, X-Haul Transport, Core, Wireless, Fixed), Data Center Networks, Clouds, Enterprise Networks; and their associated Management and Control Systems
	IoT Networks, Industrial Networks, and their associated Management and Control Systems
	Testing and Certifications of AI powered Networks
	Multi-SDO (Joint-SDO/Fora) Industry Harmonization Initiative on Standards, Architectural Frameworks & Taxonomy
	Standards Watch Repository for Tracking Standards Outputs & Roadmaps

Figure 5. Matrix of the mapping of various Topics linked to Evolving and Future Networks related Standards that are being addressed in various SDOs/For a

4. Future State (2031)

In the long term, the technological components of the future networks will grow far beyond the present in both numbers and sophistication. In addition, the number of relevant SDOs and Industry and Academia Alliances will increase.

In addition, we expect that the flow of new technologies will trigger industry's interest and the market will become impatient and pressure industry to integrate new technologies into products as soon as possible. This pressure can only be satisfied by early standardization of emerging technologies.

4.1. Major System Integrator SDOs

The existing standards bodies listed in the current future network ecosystem are using various mechanisms to expand their relevance in the utilization of the evolving future network landscape.

The ITU-T is using focus groups to determine the needs of the ecosystem (and the SDOs to engage) to enhance the protocols used on wireless networks and the Internet to support the latency, speeds, reliability, and scale required by future network use-cases. The Focus Group on NET2030

(https://www.itu.int/en/ITU-T/focusgroups/net2030/Pages/default.aspx) is one example; another example is the Focus Group on Machine Learning for 5G (https://www.itu.int/en/ITU-T/focusgroups/ml5g/Pages/default.aspx).

The Metro Ethernet Forum (MEF) is continuing its engagement related to Lifecycle Service Orchestration and engaging groups like Open Networking User Group (ONUG) to build use-cases for the MEF's orchestration platform.

4.2. Core Technology SDOs

Core technology SDOs will compete in the standards marketplace and increasingly focus on standardization in emerging technologies. Cooperation between core technology SDOs and Industry/Academia Fora and Alliances will enable fast tracks for research to establish standards and significantly reduce the time-to-market for core technologies.

Many of the emerging technologies require multi-disciplinary teams for technology development and standardization.

4.2.1. IEEE Core Technologies Standards

IEEE is strategically positioned to produce emerging technology standards. Openness and flexibility of the IEEE Standards development process combined with an enormous resident technical expertise enables wide participation of highly qualified technical experts in standards development and review. Broad technical scope makes IEEE ready to meet any challenge posed by emergence of multi-disciplinary standardization projects. There are mechanisms in IEEE for initiation and hosting such projects.

A natural value chain for the multi-disciplinary projects initiation and execution is the environment of the Future Directions Committee's Emerging Technology Initiatives leading to an interdisciplinary non-parochial standards project execution mechanism – Strategic and Emerging Standards Committee in IEEE SA.

IEEE projects that are relevant to Future Networks are shown in Figure 6.

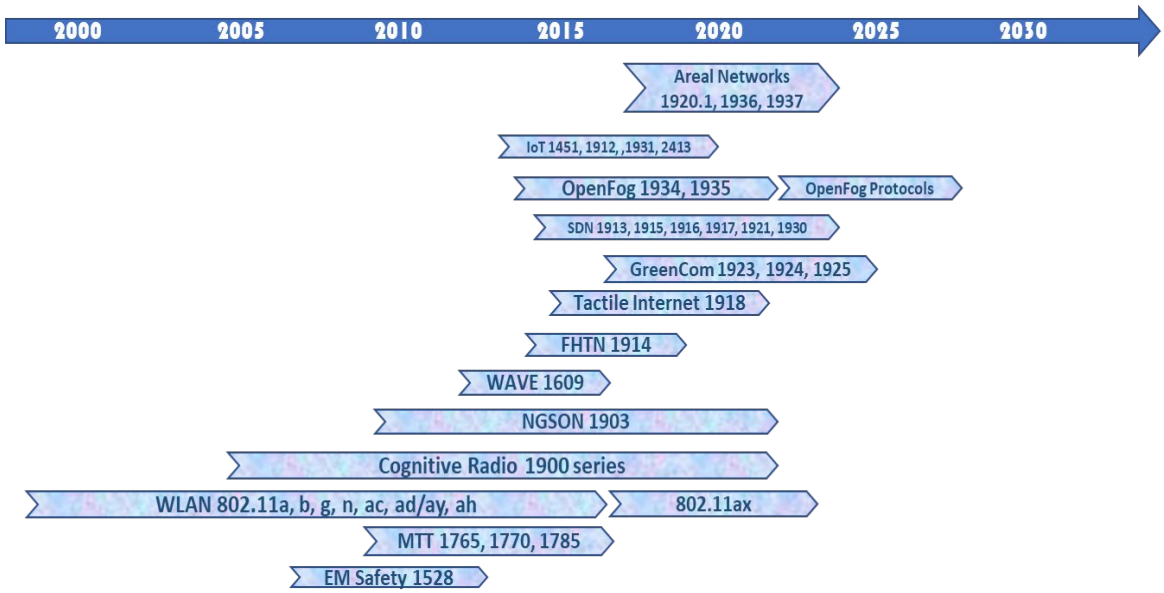


Figure 6. 5G and Future Networks Related IEEE Standards Timeline

- P1900.1—Standard Definitions and Concepts for Dynamic Spectrum Access: Terminology Relating to Emerging Wireless Networks, System Functionality, and Spectrum Management
- P1900.5.1—Standard Policy Language for Dynamic Spectrum Access Systems
- P1900.6b—Standard for Spectrum Sensing Interfaces and Data Structures for Dynamic Spectrum Access and other Advanced Radio Communication Systems. Spectrum Database Interfaces Amendment.
- P1913—Software-Defined Quantum Communication
- P1916.1—Standard for Software Defined Networking and Network Function Virtualization Performance
- P1917.1—Standard for Software Defined Networking and Network Function Virtualization Reliability
- P1930.1—Recommended Practice for Software Defined Networking (SDN) based Middleware for Control and Management of Wireless Networks
- P1922.1—A method for calculating anticipated emissions caused by virtual machine migration and placement
- P1922.2—A method to calculate near real-time emissions of information and communication technology infrastructure
- P1923.1—Computation of energy efficiency upper bound for apparatus processing communication signal waveforms
- P1924.1—Recommended practice for developing energy-efficient, power-proportional digital architectures

- P1925.1—Energy Efficient Dynamic Line Rate Transmission System
- P1926.1—A Functional Architecture of Distributed Energy Efficient Big Data Processing
- P1927.1—Services Provided by the Energy-efficient Orchestration and Management of Virtualized Distributed Data Centers Interconnected by a Virtualized Network
- P1928.1—A Mechanism for Energy Efficient Virtual Machine Placement
- P1929.1—An Architectural Framework for Energy Efficient Content Distribution
- P1914.1—Standard for Packet-based Fronthaul Transport Networks
- P1914.3—Standard for Radio Over Ethernet Encapsulations and Mappings
- P1918.1—Tactile Internet: Application Scenarios, Definitions and Terminology, Architecture, Functions, and Technical Assumptions
- P1918.1.1—Haptic Codecs for the Tactile Internet
- P1920.1—Aerial Communications and Networking Standards
- P1931.1—An Architectural Framework for Real-time Onsite Operations Facilitation (ROOF) for the Internet of Things
- P1932.1—Licensed/Unlicensed Spectrum Interoperability in Wireless Mobile Networks
- IEEE 1906.1-2015—Nanoscale and Molecular Communication Framework
- IEEE 2410-2017—Biometrics Open Protocol Standard
- P1912—Privacy and Security Architecture for Consumer Wireless Devices
- P1906.1.1—Standard Data Model for Nanoscale Communication Systems
- P1934—OpenFog Reference Architecture for Fog Computing
- P1904.2—Management Channel for Customer-Premises Equipment Connected to Ethernet-Based Subscriber Access Networks
- P1910.1—Meshed Tree Bridging with Loop-Free Forwarding
- P2413—Standard for an Architectural Framework for the Internet of Things (IoT)
- 802.11 series of standards
- MTT 1765—Estimating the Uncertainty in Error Vector Magnitude of Measured Digitally Modulated Signals for Wireless Communications
- MTT 1770—The Usage of Terms Commonly Employed in the Field of Large-Signal Vector Network Analysis
- MTT 1785—Standard for Rectangular Metallic Waveguides and Their Interfaces for Frequencies of 110 GHz and Above
- EM Safety 1528—Measurement Procedures for the Assessment of Specific Absorption Rate (SAR) of Human Exposure to Radio Frequency Fields from Hand-Held and Body-Worn Wireless Communication Devices (Frequency Range of 4 MHz to 10 GHz)

4.2.2. Internet Research Task Force (IRTF)

The IRTF does not have its own 5G Initiative, but they have many research groups that are involved in work that will be relevant to the future network ecosystem.

For example, Compute In the Network (COIN) https://datatracker.ietf.org/rg/coinrg/about/ provides a group to research on how the network would change when network elements are programmable and can support more than just routing traffic, but also computing. The work will be important to 5G, as the 5G infrastructure requires more edge computing.

Related to COIN is DINRG (Decentralized Internet Infrastructure Research Group https://datatracker.ietf.org/rg/dinrg/about/ and ICCRG (Internet Congestion Control Research Group https://datatracker.ietf.org/rg/iccrg/about/). There is nothing specific to 5G. However, there are IoT and decentralized aspects, which are important to support the end goals of future networks.

4.2.3. Other Core Technology SDOs/Fora

While the strength and core focus of IETF/IRTF lies in protocol design, other SDOs/Fora complement that with the industry de-facto Architectural Frameworks and in some cases protocols as well. The architectural frameworks are considered as core technologies as well and are the drivers from which requirements for protocol designs or exploitations are then derived in SDOs such as IETF/IRTF. Examples are ETSI NFV architectural frameworks, ETSI MEC, ETSI GANA Framework, and other frameworks that are fueling the development of new protocols in SDOs such as IETF. Similarly, 3GPP is the de-facto SDO responsible for 5G Releases Standards. Other SDOs/Fora e.g., NGMN, BBF, TM Forum, ITU-T, GSMA, produce architectural frameworks for 5G from which various requirements, e.g., protocol-level are derived.

4.3. Industry Alliances

The industry alliances and consortia mentioned in Section 3.3 all have been engaged in various activities that deal with future network (beyond 5G) issues. Some of them call it 6G already. Yet, some of those are strictly focused on 5G implementation and interoperability to make sure that 5G is accepted and used ubiquitously. The following is a list of the alliances looking into beyond 5G.

- Wireless Broadband Alliance (WBA)—It has a broader and longer-term approach to future wireless systems. The WBA has initiatives to drive the evolution of Carrier Wi-Fi Services, Next Generation Wireless, and Internet of Things & Connected Cities. https://www.wballiance.com/what-we-do/at-a-glance
- Next Generation Mobile Networks (NGMN) Alliance—Currently focusing on making 5G and related vertical sectors such as Intelligent Transport Systems. It is expected that NGMN soon will start putting together a program for developing requirements for the future networks beyond 5G.
- 5G mmWave Channel Model Alliance—Although this alliance is established to deal with 5G specific spectrum bands, its work will apply to future wireless networks, since some of the higher frequency mmWave channels (above 30 GHz) may not be readily available/practical for 5G.

- Industrial Internet Consortium (IIC) – An industry alliance, which merged with the OpenFog Consortium to add edge computing and communications to their portfolio
- Dynamic Spectrum Alliance (DSA)—A global, cross-industry alliance focused on increasing dynamic access to unused radio frequencies.
- C-Band Alliance (CBA)— Although the current focus is on selling US C-band spectrum to 5G operators, the push is expected to continue for future wireless networks.
- Open RAN (O-RAN) Alliance—This "carrier-led" effort to push more openness into the radio access network of the next-generation wireless systems is in the process of defining an open RAN architecture that is being pushed for not only 5G but also for future wireless networks.

5. Needs, Challenges, and Enablers and Potential Solutions

5.1. Summary

Numerous standardization building blocks are needed for a complete future network ecosystem. Radio spectrum, radio access network (including front haul topologies), access edge, core networks, various service overlays, and underlays to name a few. Numerous groups are involved in the standardization of these and other components, and in efforts to achieve synergy among them. Cooperation and coordination among the groups are extremely important to harmonize global standardization activities. Among other issues, aligning copyright and patent policies for individual and industry protection is critical to successful interaction among the SDOs and open-source communities.

The IEEE INGR SBB roadmap helps to raise the awareness about the global standardization ecosystem. Other organizations have similar activities—ITU-T has Joint Collaboration Activities and Focus Groups, ETSI has Industry Specification Groups, and Open-Source Communities have software projects for future networks.

The major long-term challenges in future networks standardization are:

- Growing trend relevant to Open Source projects, and the relations between the standardization and open source communities.
- Exponentially growing number of relevant core technologies, SDOs, Alliances and Fora. The entropy in the standards and alliances arena grows beyond the ability of some stakeholders to handle them.
- Increasing stakeholders' impatience that demands a fast time-to-market track for emerging technologies on one hand, and the risks, and at times disruption, that emerging technologies present to the Industry on the other hand, and the required special ecosystem that attracts to standards development industrial and academic researchers.

5.2. Cooperation between SDOs and Open Source Communities

Open Source is an engagement practice that is challenging the status quo. Traditional standards bodies are changing their working methods to leverage the productivity, flexibility, and diversity that Open-Source projects bring to the table. Among important issues are copyright and patent policies. Figure 7 provides an example of integration in an SDO workflow with an Open-Source projects.

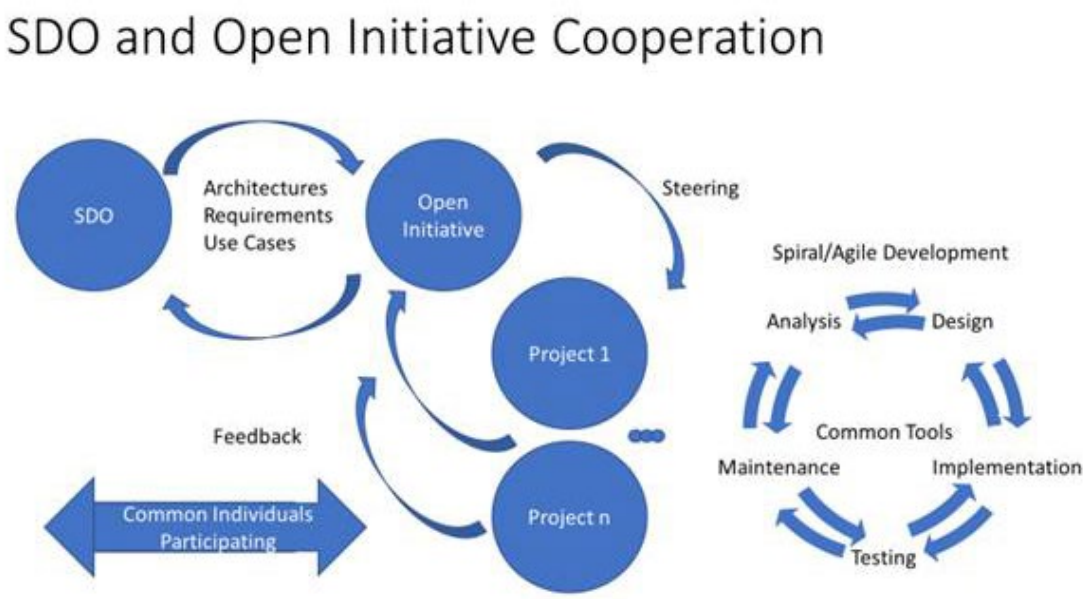


Figure 7. Cooperation among SDOs and Open-Source Initiatives

SDOs/Fora increasingly support collaborations with SDOs/Fora and Open-Source Projects. IEEE Standards Association is an example of an SDO housing both standards development and an Open-Source programs:

- **IEEE SA Open Source Program** (https://standards.ieee.org/initiatives/opensource/index.html) - IEEE Standards Association provides a hosting platform for Open-Source communities for projects that are related and not related to standards. The platform features include:
    - Project planning and management features
    - Source code management
    - Testing, code quality, and continuous integration features
    - Docker container registry and Kubernetes integration
    - Application release and delivery features
    - Integrated Mattermost chat forum w/slash commands; (Android and iPhone apps are fully supported)
    - Capable of bridging the gap between standards development and Open-Source communities to allow for the advancement of nimble and creative technical solutions at a faster pace
    - A safe open space with an enforced code of conduct

  Governance of the Open-Source programs is delegated to the Open-Source Committee (OSCom), which is authorized by the IEEE SA Board of Governors to provide guidance, oversight, and life-cycle management support for IEEE Open-Source Projects, including those incorporated into IEEE standards. The governing document for the program is the Open Source Committee Operations Manual (https://standards.ieee.org/content/dam/ieee-standards/standards/web/documents/other/OSCOM_Operations_Manual.pdf).

5.3. Cooperation among SDOs/Fora

The industry, research, and Open-Source communities can benefit from harmonized and standardized future networks beyond architectures. Coordination can help them to better channel their research and development (R&D) efforts as well as their contributions to standards. Harmonization lowers costs of standardization and R&D by avoiding redundancies in SDOs/Fora.

In principle core technologies benefit from plurality. Competition in solutions drive excellence. Standardization of core technologies exhibits some degree of redundancy as well. System SDOs pick their best core technology standards. The technology marketplace has a word in this as well.

In the meantime, harmonization efforts can benefit all sides by leading to a broader consensus. Sample instruments for use in achieving standards harmonization:

- Recurring joint SDOs/Fora workshops on harmonization of standards and architectures. This instrument helps in the coordination of the actions among interested SDOs/Fora in reducing/avoiding duplication of work and standards collisions, as well as increasing the mutual awareness of roadmaps
- Use of liaisons and joint SDOs/Fora POCs (proofs-of-concept) or catalyst projects/programs on the emerging networking technologies/paradigms
- Harmonization may also follow (be driven-by) standards & architectural roadmaps sharing efforts by SDOss/Fora, and feedback from the ongoing deployment programs for the emerging network technologies in telecom operators' and enterprise environments
- SDOs/Fora & open source collaborations for feedback from implementation experiences by standards-anchored Open-Source projects such as ONAP, OSM, TIP, OPNFV, CloudCO, OpenDaylight, ONOS, ACUMOS, etc.

The following sections provide examples of items that may be considered in pursuing industry & SDO/Fora harmonization efforts.

5.3.1. IEEE Relationships/Interactions with Other Groups

IEEE has cooperation agreements with global SDOs. All relations between IEEE and other SDOs in standards development are managed according to the rules provided by IEEE SA. Fig. 8 illustrates relations with some of the SDOs globally.

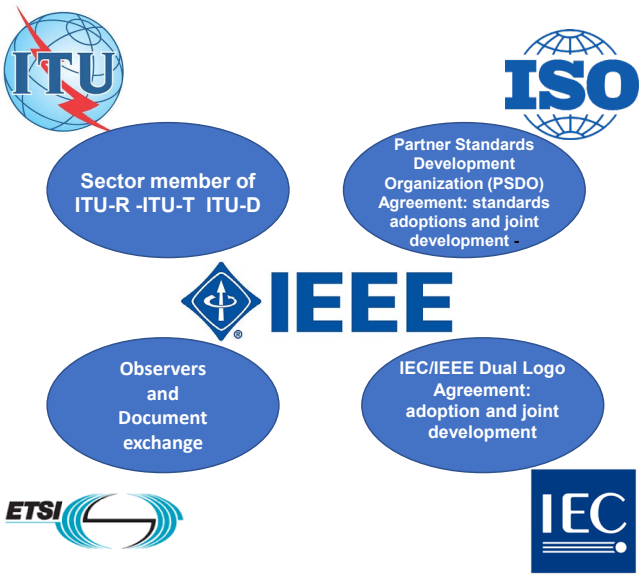


Figure 8. IEEE Agreements with Global SDOs

- International Telecommunication Union (ITU) - IEEE is a sector member of the Telecom Standardization Sector, ITU-T, the Telecom Development sector, ITU-D, and the Radiocommunication Sector, ITU-R.
- IEC - IEEE and IEC have several agreements that include: Dual Logo, Joint Development of standards under both logos, IEEE category A liaison to:
    - TC 51,
    - SyC LVDC,
    - SC 77A

  The IEEE-IEC cooperation in standardization is required to follow the IEEE/IEC Cooperation Guide. It outlines the procedures for mutual adoption and maintenance of dual-logo standards.
- ISO - Cooperation with ISO is governed by the ISO/IEEE Partner Standards Development Organization (PSDO) Agreement, which includes adoptions and joint development work. It covers:
    - ISO/TC 204: Intelligent Transportation Systems
    - ISO/TC 215: Health Informatics
    - ISO/IEC JTC 1
- ETSI - There is a Memorandum of Understanding between IEEE and ETSI. It contains clauses related to the sharing of information and a framework for coordination between Technical Groups.

There is also a process for adoption by IEEE of prominent industry specifications. The process of adoption includes IEEE balloting as described in the IEEE SA Standards Board Operations Manual.

IEEE is open for National Bodies to adopt IEEE Standards. The list of organizations having agreements with IEEE for national adoption of IEEE standards includes:

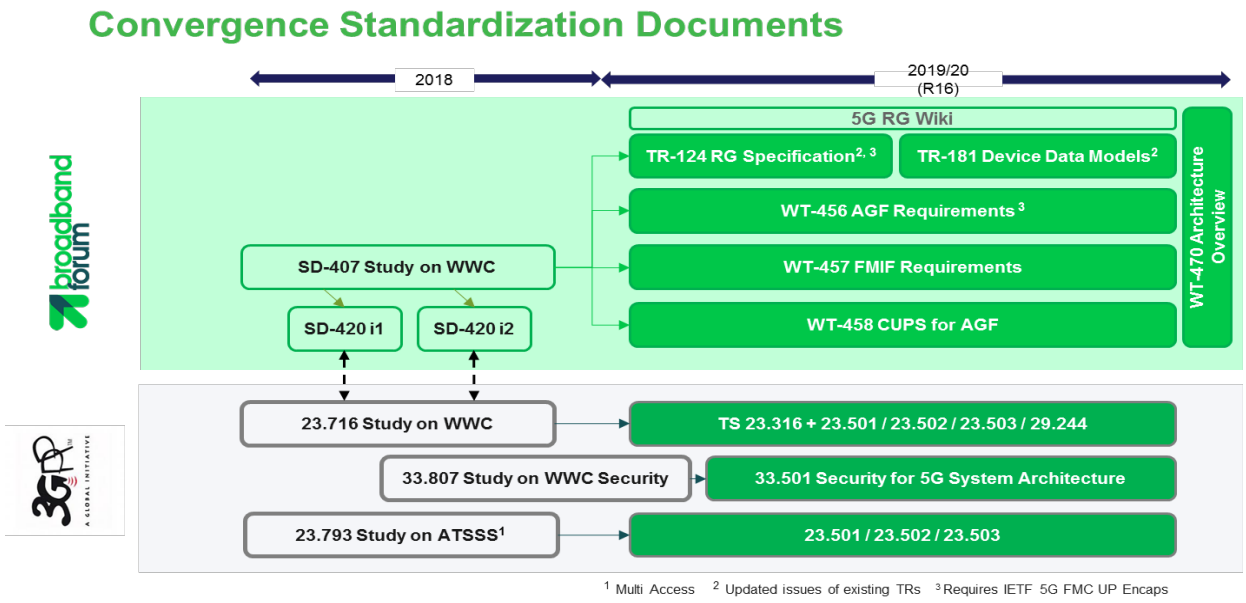
- Bureau of Indian Standards
- The Standards Institution of Israel
- Ghana Standards Authority
- South Africa Bureau of Standards
- Rwanda Standards Board
- Servicio Ecuatoriano de Normalization

Other types of agreements exist between IEEE and the following national Standards Organizations:

- China Communications Standards Association
- African Telecommunications Union
- China Electronics Standardization Institute
- GCC Standardization Organization
- Hungarian Standards Institution
- Institute of Technical Standards of Costa Rica
- Uganda Communications Commission
- The Korean Agency for Technology and Standards
- Standards Australia
- Telecommunications Standards Development Society, India
- Zambia Bureau of Standards

5.3.2. 5G Related Harmonization Efforts

SDOs/Fora are increasing their harmonization efforts by using joint SDOs/Fora Proof-Of-Concept (PoC) programs on 5G as instruments for validating and harmonizing 5G Standards and E2E architectures. For example, Fig. 9 illustrates harmonization efforts by the BBF and 3GPP.



BBF & ETSI Collaboration on Automated Intelligent Management (AIM) & ETSI GANA

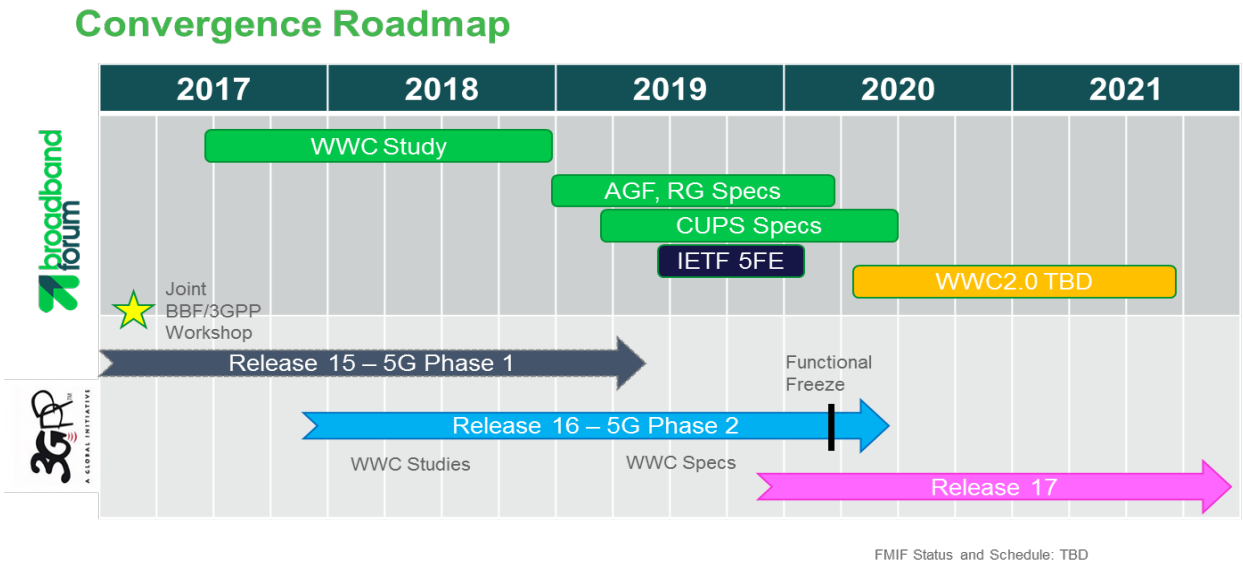


Figure 9. BBF Collaborations with 3GPP, IETF, ETSI, and other Groups

5.3.3. Harmonization of Autonomic Management & Control (AMC)

There are various SDOs/Fora projects on the AMC for evolving and future networks. For example, ETSI TC INT AFI WG is one of the groups working on standards for the Generic Autonomic Networking Architecture (GANA) reference model for autonomic networking, cognitive networking, and self-management, which is being instantiated onto various reference architectures to guide the industry on autonomics implementations.

The Fig. 10 illustrates a roadmap for the standardization work in autonomic/autonomous networking by ETSI AFI Group, which has established a collaboration ecosystem with various SDOs/Fora on

introducing GANA autonomics in various reference architectures developed and maintained by various SDOs/Fora.

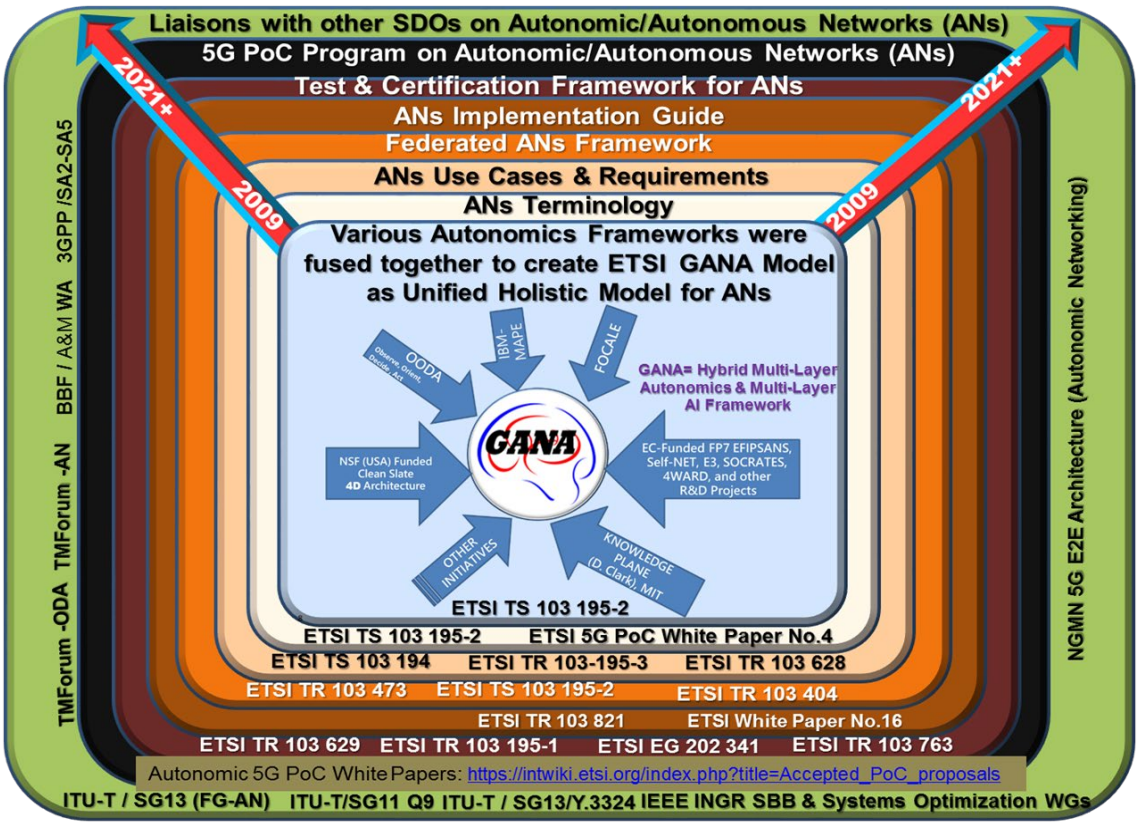


Figure 10. Historical Background on Standardization Efforts for Autonomic/Autonomous Networking Frameworks, and Ecosystem on ETSI Collaboration with other SDOs/Fora on the Topic

Various other SDOs/Fora are working on standardizing frameworks and standards that incorporate Autonomics Principles, e.g., NGMN, BBF, TM Forum, ITU-T SG13, IEEE, 3GPP, GSMA, and others. There are ongoing efforts in Industry Harmonization of Architectural Frameworks and Taxonomy for Autonomic/Autonomous Networking and Autonomic Management & Control (AMC) to avoid standards collisions and reduce or avoid duplication of work across SDOs/Fora.

5.3.4. ITU-T SG13 Harmonization

The following list provides harmonization efforts by ITU-T SG13 on topics of relevance to Evolving and Future Networks.

- Rec. Y.3324 (formerly Y.AMC) work is based on the ETSI GANA reference model. It specifies the Requirements and Architectural Framework for Autonomic management and Control of IMT-2020 networks. It addresses High-level & functional requirements, with harmonized architecture based on the ETSI GANA reference model, Focusing on AMC automation of IMT-2020 networks
- SG13 Exchanged liaisons between SG13/Q.21 & ETSI NTECH/INT AFI WG

- Cooperation initiated to standardize AMC for NGN and continued to Future Networks and IMT-2020
- New work items on IMT-2020 management and orchestration including 3MO & ML-based QoS assurance are the next candidates for harmonization efforts

5.3.5. TM Forum Interaction with Other SDOs/Fora

The following are examples of some of the work TM Forum is doing in collaboration with other SDOs/Fora

- TM Forum has produced what is referred to as Open Digital Architecture (ODA). Autonomics in ODA is based on ETSI GANA Principles for Autonomics (AMC).
- ONAP – TM Forum is actively working with the ONAP community on the North Bound Interfaces. Early ONAP releases have used TM Forum APIs carrying a MEF payload at the NBI. We also interact with them on their Information and Data model.
- MEF – continuing the support of MEF using TM Forum APIs at their Sonata Interface Point.
- GSMA – using NEST as a catalyst and actively feeding back results and suggestions
- Oasis – using TOSCA in several efforts and catalysts and actively feeding suggestions and requests back.
- NGMN – providing feedback on requirements and results experienced in TM Forum Catalyst work
- 3GPP – actively using their new specifications in our catalyst to help refine TM Forum Open APIs to be able to accommodate them.
- Acumos – TM Forum actively exploring how we can work with Acumos to determine if the TM Forum Open APIs and data model can be of use at the point where data is ingested into the Acumos environment.

5.4. Standardization of Emerging Technologies

5.4.1. Bringing Emerging Technologies to Standardization, IEEE Case Study

IEEE is in an excellent position to develop standards for core technologies. IEEE members' expertise ranges from the physical layer to applications and members' skills range from fundamental technology research to deployment and operations.

IEEE is uniquely positioned for the development of standards in emerging technologies. Emerging Technologies undergo evolution from the conceptual phase to the precompetitive research phase followed by competitive research and then deployment (Fig. 11).

Figure 11. Technology Evolution Phases

During the conceptual phase, the intellectual property is typically created first in academic and industrial research laboratories and disclosed publicly in the form of workshop records, conference papers, and later in scholarly publications, early patents, and copyrighted material.

The strength of intellectual property manifests itself by strong and broad patent claims, as well as by conference and journal publications that produce numerous high-quality citations. The strength of the intellectual property diminishes with time as technology progresses through the evolution phases (Fig. 12).

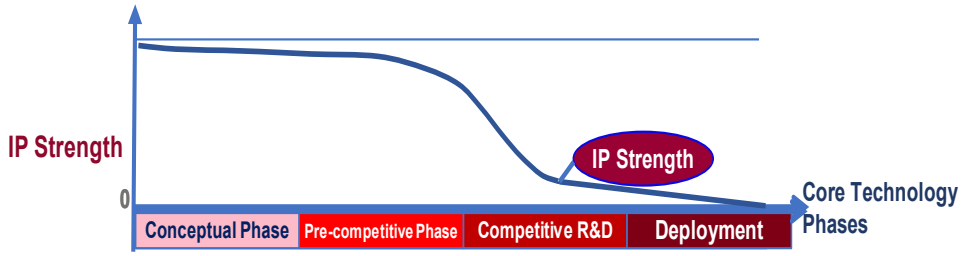


Figure 12. Diminishing Strength of the Intellectual Property

It is often hard to predict in the early phases of a core technology evolution if it will reach market acceptance. Many technologies for various reasons do not make it. Therefore, the relevance of technologies in the early phases of the evolution are low and increase over time (Fig. 13).

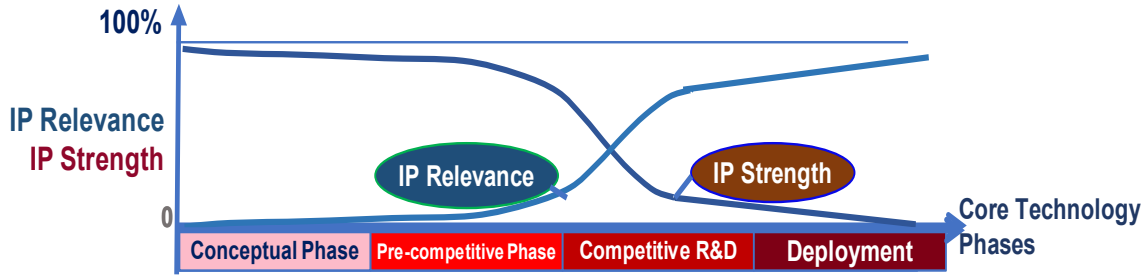


Figure 13. Strength versus Relevance of Intellectual Property

The curves above are not drawn to any scale and timing is indicated only for illustration purposes. They are strictly conceptual and qualitative.

Typically, market-driven standardization occurs during a competitive research and development phase when the industry realizes the need for them and a preliminary consensus at least on the need for standardization is reached (Fig. 14).

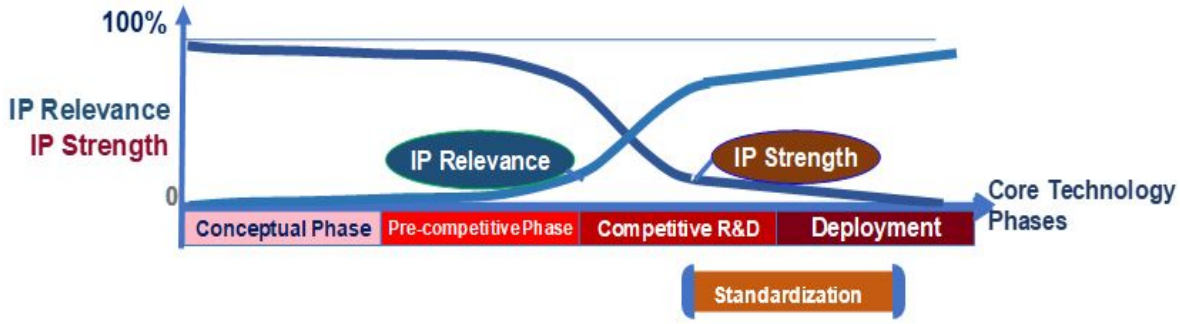


Figure 14. Typical Standardization Interval

During the standardization phases, the technologies, which survive the consensus-building process of the standardization, become increasingly relevant, and intellectual property associated with these technologies approach essentiality potential. The patents that are proven essential to a standard, whether they are strong or otherwise, become most relevant. If these patents are also strong, they can sustain this property if challenged. The above model illustrates the challenge of bringing emerging technologies to standardization. On one hand, early standardization can shorten time to market; on the other hand, the consensus of early standardization is not as broad as one achieved in later stages of technology evolution. However, the benefit of early standardization is a reduction of investment into potentially irrelevant technologies.

Figure 15 illustrates how IEEE products are mapped to the technology evolution timeline

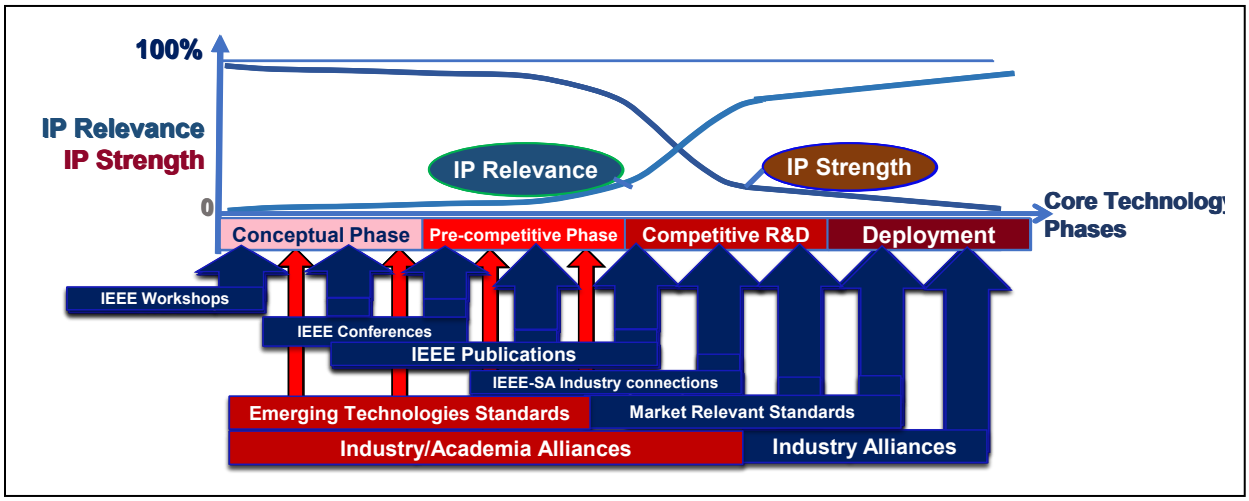


Figure 15. IEEE Products and Standardization positioned in Technology Evolution timeline

In early technology evolution phases, most of the expertise resides in academic and industrial research organizations and in individuals that often have professed (nonmaterial) interest in technologies.

Driving research to standards, thus creating standards in emerging technologies, can be effectively done by bringing researchers into the standardization process.

However, this type of constituency to a significant degree derives a benefit from personal professional positioning in the field, which manifests itself in citations of their contributions. A challenge of engaging academic and industrial researchers in standards development can be solved to a significant degree by producing a citable standards contributions mechanism. A good example of this paradigm is the IETF request for comments (RFC) phenomenon.

Grants from industry and other research funding agencies with standardization output requirements are also a good way to engage researchers.

An additional incentive for researchers can be authorship of patents that positioned in standards and associated with published standards, regardless of the patent assignment scenario. IEEE Standards Association has launched the Standards Contribution Collector for publication of IEEE standards contributions that can be discovered and cited.

5.4.2. Standardization Building Blocks Roadmap Timeline Chart

The considerations described in Section 5.1 illustrate the challenge of extrapolating the Standardization Building Blocks for future networks. The standardization roadmaps are only meaningful within the roadmaps of technologies. The standardization vision can materialize when it is mostly coordinated with the technology roadmap it is harmonized with.

Each core technology in the tracks of the NGNR Roadmap only stands a chance to produce a standardization vision beyond the 5-year horizon if the technology has an autonomous evolution path. In this case, standardization can be predicted and the timing for standardization can be estimated.

6. Conclusions and Recommendations

This edition of SBB roadmap illustrates, first, the current standardization landscape in networks area, and then its evolution towards future networks.

In the process of technology evolution, the challenge for standardization is to arm the industry with a standardization ecosystem that allows the standard development in all phases of technology life cycle, from conceptual to the deployment. In early stages, the ecosystem needs to be compatible with the modus operandi of industrial and academic researchers for early standardization of emerging technologies. Then, the ecosystem needs to progress to engage industry practitioners as standardization moves to market-relevant standards and deployment.

The SBB team recommends that the core technology stakeholders take a proactive approach to harmonize standardization with their vision for long-term technology evolution. This means that there should be no prejudice against early standardization for emerging technologies even in conceptual and precompetitive phases of technology evolution.

7. Contributors

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8. References

The two white papers published by NGMN (https://www.ngmn.org/publications/5g-end-to-end-architecture-framework-v3-0-8.html) capture requirements for AMC in 5G (among other requirements) that are a good basis for industry harmonization by various SDOs/Fora.

The White Paper (published in June 2020) provides useful insights on AI-related standardization activities in ETSI and other Organizations and provides insights on future directions for ETSI that help other organizations to identify gaps they may cover. The paper is accessible here: https://www.etsi.org/images/files/ETSIWhitePapers/etsi_wp34_Artificial_Intellignce_and_future_directions_for_ETSI.pdf.

Examples of collaboration efforts among SDOs:

TechNexus: https://tecknexus.com/5g-telecom-proofs-of-concept/

W5: https://event.on24.com/wcc/r/2336372/9C87E84B1577D28976483914D186A5AF

ITU: https://www.itu.int/dms_pub/itu-t/opb/tut/T-TUT-IMT-2017-PDF-E.pdf

Brooklyn 5G Summit: https://ieeetv.ieee.org/ieeetv-specials/5g-proof-of-concept-poc-systems-with-focus-on-real-use-cases-juha-silipa-and-mark-cudak-brooklyn-5g-summit-2017

9. Acronyms/abbreviations

Term	Definition
5G-ACIA	5G Alliance for Connected Industries and Automation
5G-PPP	5G Infrastructure Public-Private Partnership
5G WA	5G World Alliance
AI	Artificial Intelligence
AMC	Autonomic Management and Control
BBF	BroadBand Forum
CBA	C-Band Alliance
COIN	Compute In the Network
DINRG	Decentralized Internet Infrastructure Research Group
DSA	Dynamic Spectrum Alliance
ETSI	European Telecommunications Standards Institute
5G	Fifth Generation
GANA	Generic Autonomic Network Architecture
IEEE-SA	IEEE Standards Association
IIC	Industrial Internet Consortium
IRTF	Industrial Internet Consortium, Internet Research Task Force
IEEE	Institute of Electrical and Electronics Engineers
IEC	International Electrotechnical Commission
INGR	International Network Generations Roadmap
ISO	International Organization for Standardization
ITU	International Telecommunication Union
ICCRG	Internet Congestion Control Research Group
IETF	Internet Engineering Task Force
IoT	Internet of Things
ITU-R	ITU Radiocommunication Sector
ITU-T	ITU Telecommunication Standardization Sector
JTC1	Joint Technical Committee 1
ML	Machine Learning
MEF	Metro Ethernet Forum
mWT	Millimeter Wave Transmission
mmWave	Millimeter-Wave
MEC	Mobile Edge Computing
MIMO	Multiple In-Multiple Out
NIST	National Institute of Standardization and Technology
NETCONF	Network Configuration Protocol
NFV	Network Functions Virtualization
NR	New Radio
NGMN	Next Generation Mobile Networks

NIN	Non-IP Networking
ODA	Open Digital Architecture
OMA	Open Mobile Alliance
ONUG	Open Networking User Group
O-RAN	Open RAN
PSDO	Partner Standards Development Organization
PoC	Proof-of-Concept
QUIC	Quick UDP Internet Connections
RFC	Request for Comment
R&D	Research and Development
SC	Software Community
SDN	Software Defined Networking
SBB	Standardization Building Blocks
SDO	Standards Developing Organization
TSDSI	Telecommunications Standards Development Society India
3GPP	Third Generation Partnership Project
WWC	Wireless and Wireline Convergence
WBA	Wireless Broadband Alliance
WG	Working Group
W3C	World Wide Web Consortium
YANG	Yet Another Next Generation

10. Appendix

List of Figures

Anti-trust Statement

Generally speaking, most of the world prohibits agreements and certain other activities that unreasonably restrain trade. The IEEE Future Networks Initiative follows the Anti-trust and Competition policy set forth by the IEEE Standards Association (IEEE-SA). That policy can be found at https://standards.ieee.org/develop/policies/antitrust.pdf.