IEEE

IEEE INGR

International Network Generations Roadmap

2022 Edition

Standardization Building Blocks

IEEE Future NETWORKS™

An IEEE 5G and Beyond Technology Roadmap

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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.

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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.

1.1. 2022 Edition Update

This edition of the SBB chapter contains updated standardization status and plans in the area of 5G and beyond. More specifically:

- Updated relevant industry alliances and open-source organizations in Sections 3.3 and 3.4 reflecting the dynamics of the global industry.
- Updated future landscape related to SDOs, industry alliances, and open-source anticipated activities in Section 4.
- In Section 5.2, the latest developments on the O-RAN community were added. In Section 5.3, an example on inter-SDO cooperation was added. A new subsection (5.3.3.1) on standardization of Inter-System Coordination for Exchanging Network Service Level Assurance Information were added. Another new section 5.3.6 on the federated testbeds example of SDO/Fora collaboration was added. Section 5.4 was reorganized by inserting a new section upfront (5.4.1) to include advanced standardization of emerging technologies.

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

This section provides a brief overview of the current standardization activities of the major system integrator organizations, core technology organizations, industry alliances, and open-source organizations. This section also presents a matrix illustrating how various topics are linked to evolving and future networks.

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), Tele Management (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.

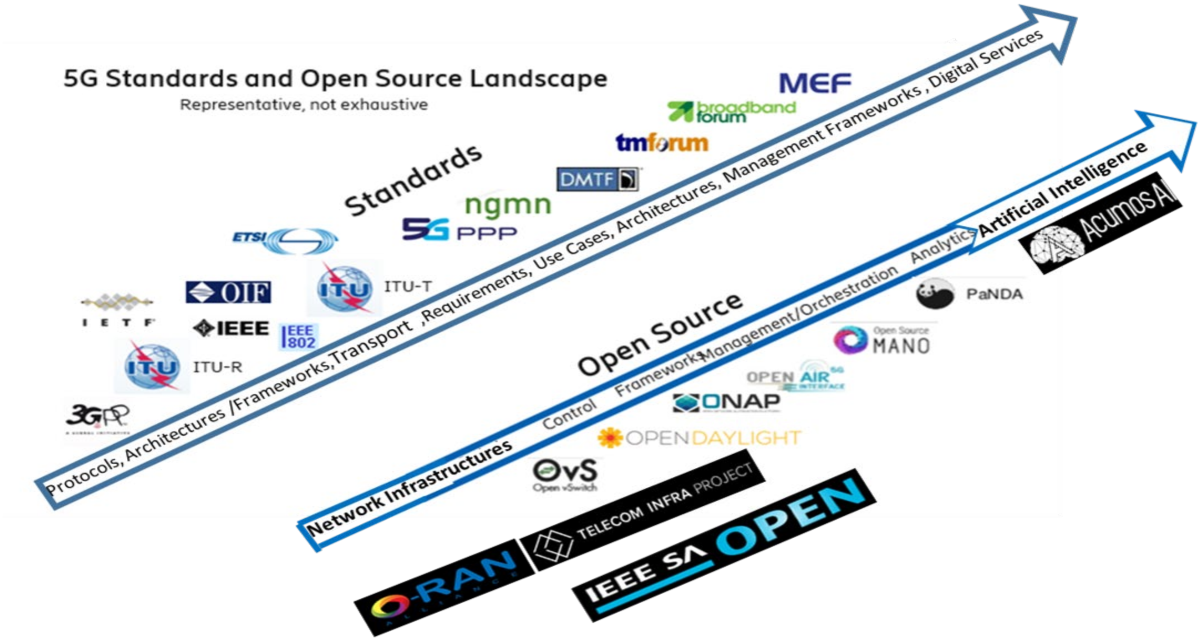

Figure 1. 5G Standards and Open-Source Landscape

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

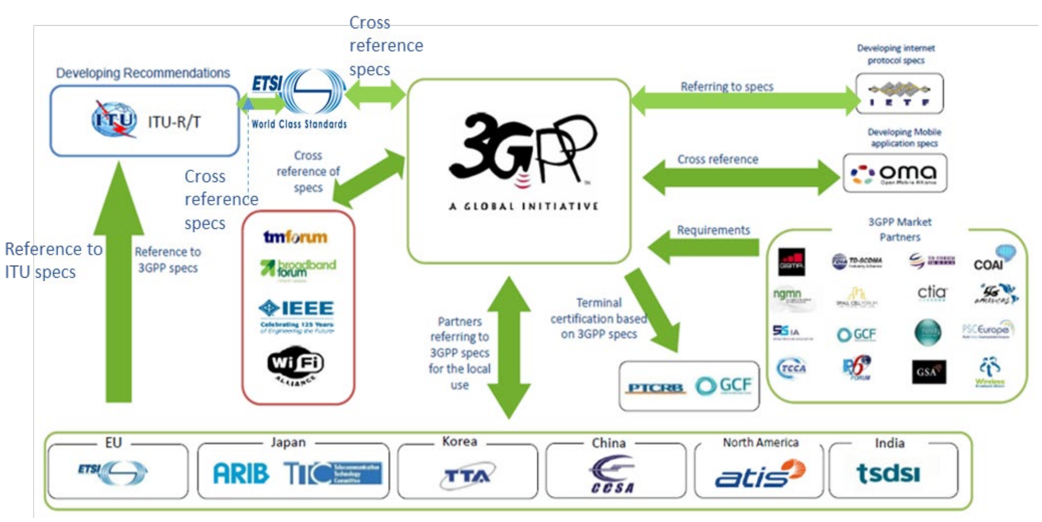

Figure 2. Interaction Among the SDOs with respect to 3GPP

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

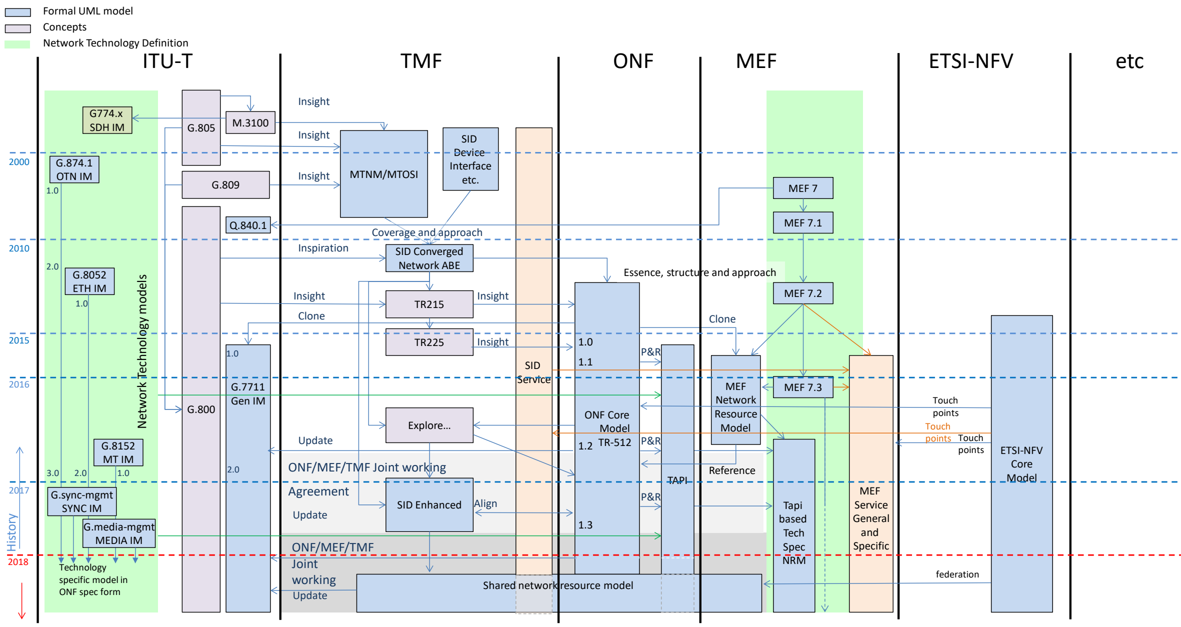

Figure 3. A View of Touchpoints Among Standards

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.

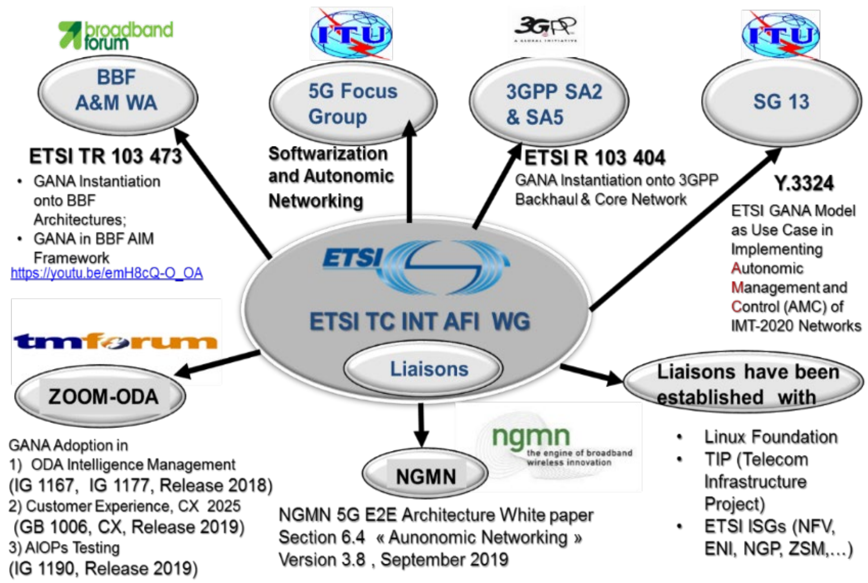

Figure 4. The collaboration of SDOs/Fora with ETSI on ETSI GANA Multi-Layer AI & Autonomics Framework

Other perspectives on the collaboration of SDOs/Fora on various topics are discussed in Section 5.3.

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 mmWave frequencies approved at WRC 19). The 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 Alliance for Connected Industries and Automation (5G-ACIA)— A 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.
- OMA SpecWorks – (previously 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.

- NextG Channel Model Alliance (formally operated as 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).
- 6G Smart Networks and Services Industry Association (6G-IA) – recently formed to address European Industry and Research for next-generation networks and services.
- Industrial IoT Consortium (IIC) (formally operated as Industrial Internet Consortium) —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, 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— founded in 2018, is a community of mobile network operators, vendors, and research & academic institutions operating in the Radio Access Network (RAN) industry. operators. 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)—https://www.acea.auto/
- AEF (Agricultural Industry Electronics Foundation)—https://www.aef-online.org/
- AIOTI (Alliance for the Internet of Things Innovation)—http://www.aioti.eu/
- Automation ML—https://www.automationml.org/
- AVNU—https://avnu.org/
- Bluetooth SIG—https://www.bluetooth.com/
- BBF - Broadband Forum—https://www.broadband-forum.org/
- C2C-CC (Car-2-Car Communication Consortium)—https://www.car-2-car.org/
- CableLabs (Cable Television Laboratories)[1] – https://www.cablelabs.com/
- CCC (Car Connectivity Consortium)—https://carconnectivity.org/

[1] CableLabs is both an industry alliance (for the cable operators) as well as an SDO (for defining DOCSIS as well as the Coherent Optics standards)

- CEN (European Committee for Standardization)—https://www.cen.eu/
- CENELEC (European Committee for Electrotechnical Standardization)—https://www.cenelec.eu/
- CiA (CAN IN Automation)—https://www.can-cia.org/
- CLEPA (European Association for Automotive Supplies)—https://www.clepa.eu/
- Personal Connectivity Health Alliance—https://www.pchalliance.org/
- DICOM (Digital Imaging and Communications in Medicine)—https://www.dicomstandard.org/
- ECLASS—https://www.eclass.eu/
- ERTICO – ITS Europe—http://ertico.com/
- ESMIG—https://esmig.eu/
- GlobalPlatform—https://globalplatform.org/
- GSMA—https://www.gsma.com/
- HL7 International (Health Level 7)—http://www.hl7.org/
- IEC (International Electrotechnical Commission)—http://www.iec.ch/
- IHE (Integrating the Healthcare Enterprise)—http://www.ihe.net/
- IPEN (Internet Privacy Engineering Network)—
https://secure.edps.europa.eu/EDPSWEB/edps/EDPS/IPEN
- IPv6 Forum—http://www.ipv6forum.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/
- NFC Forum—https://nfc-forum.org/
- OASIS—https://www.oasis-open.org/
- OAA(Open Automotive Alliance)—http://www.openautoalliance.net
- Open Connectivity Foundation—http://openconnectivity.org/
- ODVA—https://www.odva.org/
- OGC (Open Geospatial Consortium)—http://www.opengeospatial.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/
- Wi-Fi Alliance – https://www.wi-fi.org/
- Wireless Broadband Alliance – https://extranet.wballiance.com/
- Weightless—http://www.weightless.org/
- Wireless World Research Forum—http://www.wwrf.ch/
- CSA (Connectivity Standards Alliance) (formerly ZigBee Alliance)- https://csa-iot.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. More importantly, O-RAN targets the split of RAN functions and the creation of open interfaces that will support vendor independence as well as software and hardware decoupling while achieving substantial cost savings.
- 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/) - 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 (e.g., software-defined RAN).
- OpenSync (https://opensync.io/) – open-source software that brings the home network's control plane into the Cloud.
- RDK (https://www.rdkcentral.com/) – open-source software that standardizes core functions used in broadband, video, and IoT devices.
- 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 *(See Legends below)*
Multi-SDO (Joint-SDO/Fora) Industry Harmonization Initiative on Standards, Architectural	Harmonization of E2E 5G Architectures and Multi-Layer & Multi-Domain AI Frameworks for Autonomic (Closed-Loop) Network Automation	**n**

Frameworks, and Taxonomy		
BroadBand Forum (BBF)	5G related WAs, and Automated Intelligent Management (AIM) Framework	**a, b, e, i**
3GPP	SA Groups on 5G Architecture and Management	**a, b, e, i**
ETSI	TC INT/AFI WG on GANA Standards for Autonomic Network Engineering for Self-Managing Future Internet and Self-Managed Fixed & Mobile Integrated Networks; Autonomous Networks (ANs)	**a, b, c, d, e, f, h, i**
ETSI	NFV ISG	**a, b, e, d, i**
ETSI	MEC ISG	**a, b, e, d, i**
ETSI	ENI ISG	**e, d, i**
ETSI	SAI ISG	**e, d, i**
ETSI	ZSM ISG	**e, d, i**
ETSI	F5G ISG	**a, e, i**
ETSI	TC INT & TC MTS Joint Work on "AI in Test Systems, and Testing AI Models"	**h, k**
ITU-T	SG11 & Focus Group FG-TBFxG	**h**
ETSI & IPv6 Forum	IP6 ISG	**g**
GSMA	Telco Operating Platform	**a, b, e, i**
GSMA	Future Networks Project & Autonomous Networks	**c, d, e, i**
IEEE	The IEEE Global Initiative on Ethics of Autonomous and Intelligent Systems	**a, c, i, j**
IEEE	IEEE Future Networks Standardization	**a, c, h, i, j**
IEEE	5G related Standardization	**a**
IETF/IRTF	Various groups on IETF Protocols (mainly IP based Protocols) required in 5G & Future Networks	**g**
ITU-T	SG13 and SG11	**a, b, c, d, e, i, h**
ITU-T	Focus group on ML For Future Networks	**d**
MEF	Network Automation & Service Orchestration	**b, e, i**
NGMN	E2E 5G Architecture	**a, b, c, d e, i**
NIST	AI Standards	**d**
OMG	Metamodeling Tools; and Model-Driven Information Networking for Networks & Models for Knowledge Representation	**f, j**
ONF	SDN, and Intent based management	**b, e, i**
3GPP	SA5 WG5 Intent Based Networking (IBN)	**a, b, e, d, i**
3GPP	SA2 & SA5: Self-Organizing Networks(SON)	**a, b, c, i**
TM Forum	Autonomous Networks (ANs)	**a, c, d, f, i, j**
TM Forum	AI Program	**d**
TM Forum	Open Digital Architecture (ODA)	**a, b, c, e, d, i**
CEN/CENELEC	Focus Group on Artificial Intelligence	**d**

5GPPP Consortium	5G Experimentation Platform	**h**
European Commission (EC) funded StandICT Project's Standards Watch Portal	Standards Watch Repository for Tracking Standards Outputs & Roadmaps	**m**

Legend:

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

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

4. Future State (2032)

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 IEEE 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.

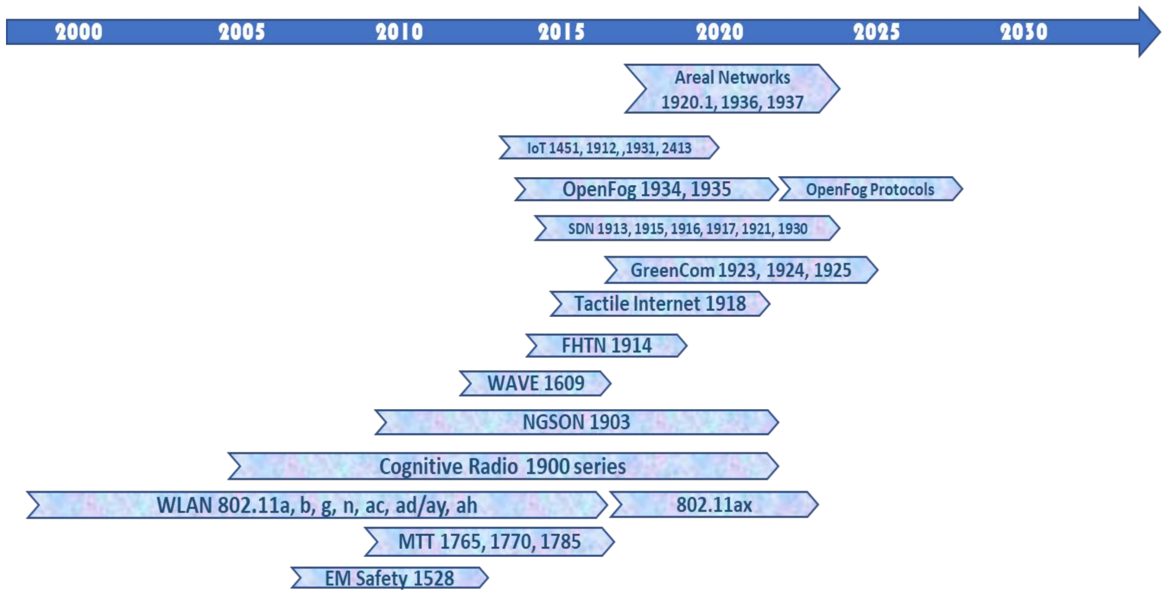

Figure 6. 5G and Future Networks Related IEEE Standards Timeline

- IEEE 1900.1- 2019—Standard Definitions and Concepts for Dynamic Spectrum Access: Terminology Relating to Emerging Wireless Networks, System Functionality, and Spectrum Management
- IEEE 1900.5.1- 2020—Standard Policy Language for Dynamic Spectrum Access Systems
- IEEE 1900.5.2- 2017 - Standards for Methods for Modeling Spectrum Consumption
- IEEE 1900.6 -2011—Standard for Spectrum Sensing Interfaces and Data Structures for Dynamic Spectrum Access and other Advanced Radio Communication Systems.
- P1913—Software-Defined Quantum Communication
- P1916.1—Standard for Software-Defined Networking and Network Function Virtualization Performance
- P1930.1—Recommended Practice for Software Defined Networking (SDN) based Middleware for Control and Management of Wireless Networks
- P1922.1— Standard for a method for calculating anticipated emissions caused by virtual machine migration and placement
- IEEE 1922.2- 2019—Standard for a method to calculate near real-time emissions of information and communication technology infrastructure
- IEEE 1923.1-2021—Standard for 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—Standard for Energy Efficient Dynamic Line Rate Transmission System

- P1926.1—Standard for 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—Standard for a Mechanism for Energy Efficient Virtual Machine Placement
- P1929.1—Standard for an Architectural Framework for Energy Efficient Content Distribution
- IEEE 1914.1-2019—Standard for Packet-based Fronthaul Transport Networks
- IEEE 1914.3 - 2018—Standard for Radio Over Ethernet Encapsulations and Mappings
- P1918.1— Standard for Tactile Internet: Application Scenarios, Definitions and Terminology, Architecture, Functions, and Technical Assumptions
- P1918.1.1—Standard for Haptic Codecs for the Tactile Internet
- P1920.1—Standard for Aerial Communications and Networking Standards
- P1920.2: Standard for Vehicle-to-Vehicle Communications for Unmanned Aircraft Systems
- P1931.1—Standard for an Architectural Framework for Real-time Onsite Operations Facilitation (ROOF) for the Internet of Things
- P1932.1— Standard for Licensed/Unlicensed Spectrum Interoperability in Wireless Mobile Networks
- IEEE 1906.1-2015— Standard for Nanoscale and Molecular Communication Framework
- IEEE 2410-2017— Standard for Biometrics Open Protocol Standard
- P1912— Standard for Privacy and Security Architecture for Consumer Wireless Devices
- IEEE 1906.1.1-2020—Standard Data Model for Nanoscale Communication Systems
- IEEE 1934- 2018— Standard for OpenFog Reference Architecture for Fog Computing
- P1934.1 – Nomenclature and Taxonomy for Distributing Computing, Communications And Networking along the Things - Cloud Continuum
- IEEE 1904.1 – 2017 - Standard for Service Interoperability in Ethernet Passive Optical Networks (SIPON)
- IEEE 1904.2 - 2021— Standard for Control and Management of Virtual Links in Ethernet-Based Subscriber Access Networks
- IEEE 1910.1- 2020 — Standard for Meshed Tree Bridging with Loop-Free Forwarding
- IEEE 2413 - 2019—Standard for an Architectural Framework for the Internet of Things (IoT)
- 802.11 series of standards
- P1765— Recommended Practice for Estimating the Uncertainty in Error Vector Magnitude of Measured Digitally Modulated Signals for Wireless Communications

- IEEE1770-2021— Recommended Practice for the Usage of Terms Commonly Employed in the Field of Large-Signal Vector Network Analysis
- IEEE 1785.1-2012—Standard for Rectangular Metallic Waveguides and Their Interfaces for Frequencies of 110 GHz and Above
- IEEE 1528.7-2020—Guide for EMF Exposure Assessment of Internet of Things (IoT) Technologies and Devices

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, Computing in the Network Research Group (coinrg) 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 coinrg 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.

Inspired by ETSI's GANA, the IETF's anima ("Autonomic Networking Integrated Model and Approach") Working Group (https://datatracker.ietf.org/wg/anima/about/) has since developed multiple RFCs (e.g., RFCs 8990-8995) with many more Internet-Drafts about autonomic networking in the pipeline.

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 future networks beyond 5G.
- NextG 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 IoT 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.
- 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. Moreover, O-RAN Alliance has defined a set of use cases that has been categorized into two phases. Naturally, the use cases of phase I correspond to the immediate and the high priority items that should be developed earlier by operators or service providers and will be the foundation of phase II use cases. Accordingly, phase I use cases are mostly generic scenarios such as white box hardware design, traffic steering, QoS/QoE optimization, and massive MIMO. On the other hand, Phase II is devoted to more specialized applications such as V2X, UAV, and RAN sharing.

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 open-source projects.

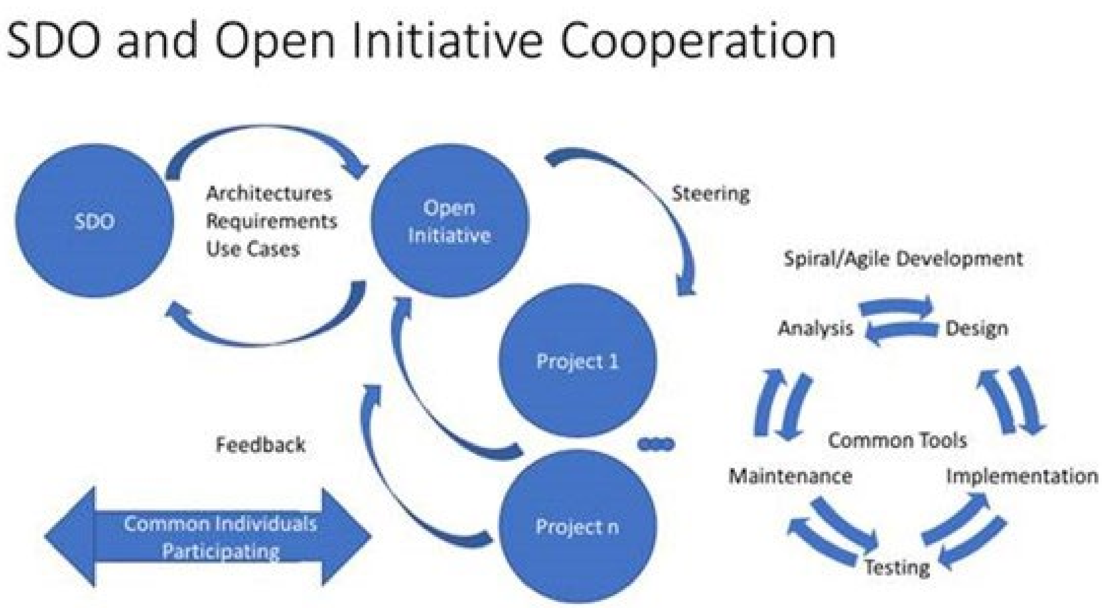

Figure 7. Cooperation among SDOs and Open-Source Initiatives

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 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).

- **O-RAN Software Community -** The O-RAN work involves several players. In particular, O-RAN Alliance relies on the 3GPP reference design architecture of the RAN (e.g., CU, DU) and defines the open interfaces (e.g., E2, A1) and the nodes (e.g., both RICs, the SMO). ONF's SD-RAN builds upon the aforementioned architectural focus of the O-RAN Alliance and leverages the underlying specifications to build an exemplar and open-source compliant O-RAN comprising a RIC and a set xApps. The objective is to allow various vendors and operators to emulate and experiment with various combinations for the sake of interoperability. O-RAN Alliance join forces with Linux Foundation to create the O-RAN Software Community (OSC) that aims at creating an open-source software reference design for the whole O-RAN.

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 SDOs/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. Figure 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, Figure 9 illustrates harmonization efforts by the BBF and 3GPP.

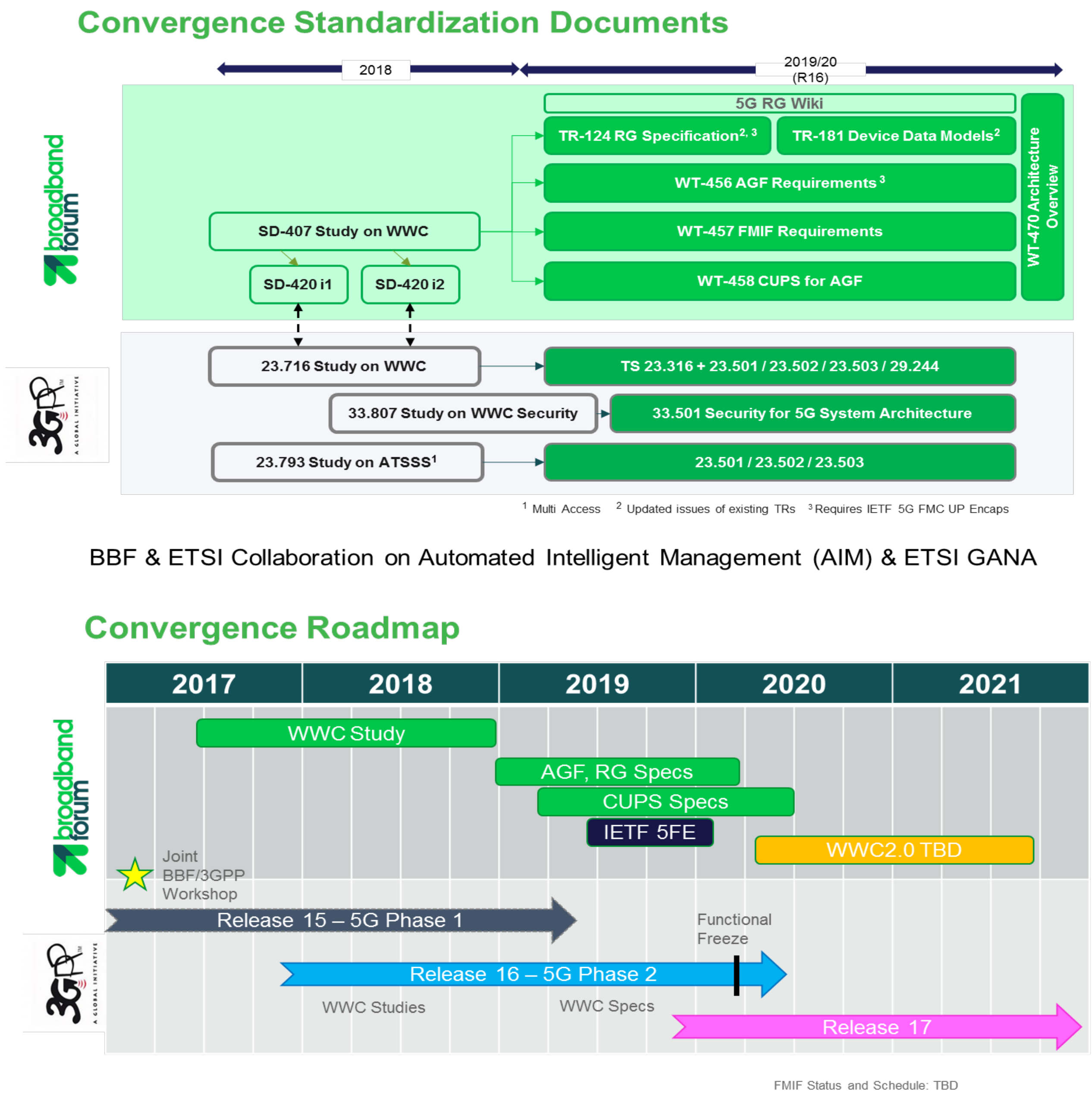

Figure 9. BBF Collaborations with 3GPP, IETF, ETSI, and other Groups

5.3.3. Harmonization of Autonomic Management & Control (AMC) and Autonomic/Autonomous Networking (ANs) Standards

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.

Figure 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.

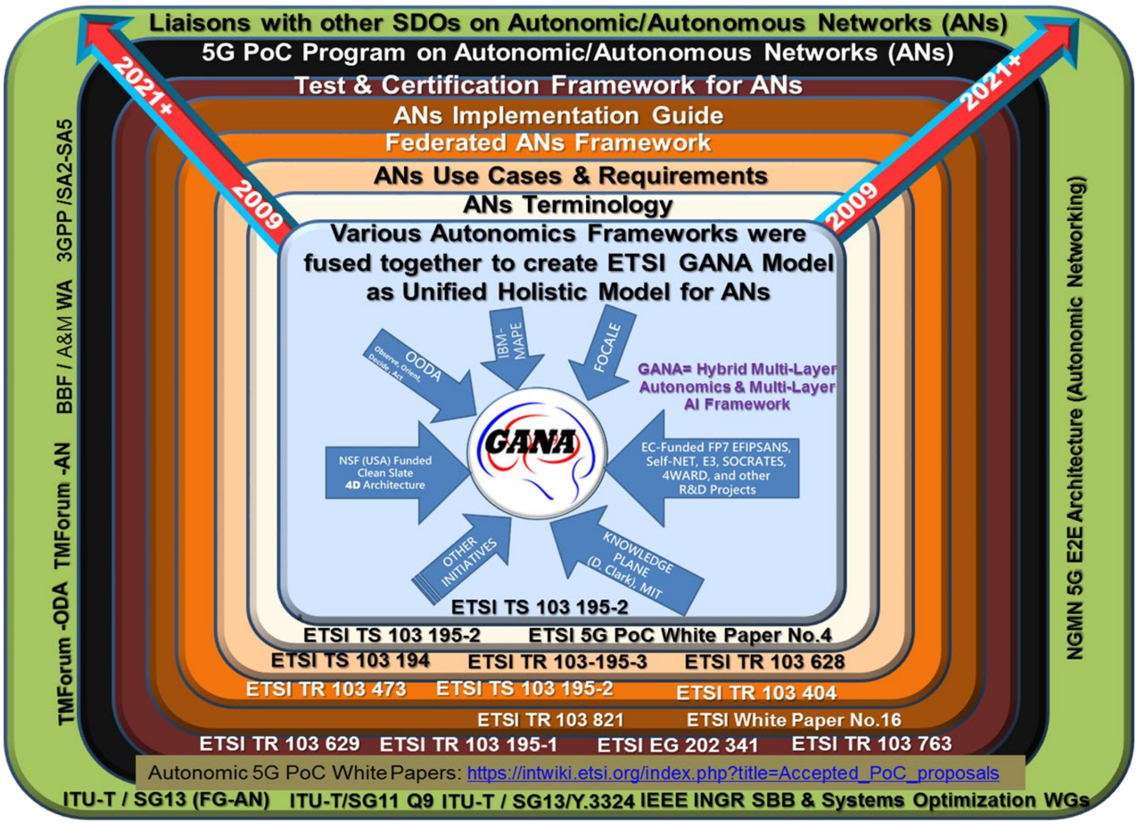

Figure 10. Historical Background on Standardization Efforts for Autonomic/Autonomous Networking Frameworks, and Ecosystem on ETSI Collaboration with other SDOs/Fora on the Topic

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, IETF[2] and

[2] Inspired by GANA, IETF's *anima* ("Autonomic Networking Integrated Model and Approach") Working Group, has since developed multiple RFCs (e.g., RFCs 8990-8995) with many more Internet-Drafts in the pipeline on the subject of autonomic networking.

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.

Recently, an initiative called "Multi-SDO Collaboration on Autonomous Networking (ANs)" was formed under the auspices of the TM Forum as host for the initiative (dubbed "Multi SDO Autonomous Network coordination"). The Initiative is intended to bring various SDOs/Fora that are working on AN-related topics to come together in discussing and exchanging information on their scope on ANs to reduce duplication work, avoid standards collisions, and identify gaps that need to be closed in standardization on ANs. The SDOs/Fora and Open Source involved in the multi-SDO include ETSI, GSMA, ONAP, NGNM, 3GPP SA5, CCSA, IEEE, IETF, ITU-T.

What is immediately needed is the development of a standardized blueprint of common operational principles for Autonomic/Autonomous Networks (ANs). Figure 11 illustrates a potential solution for implementing this blueprint.

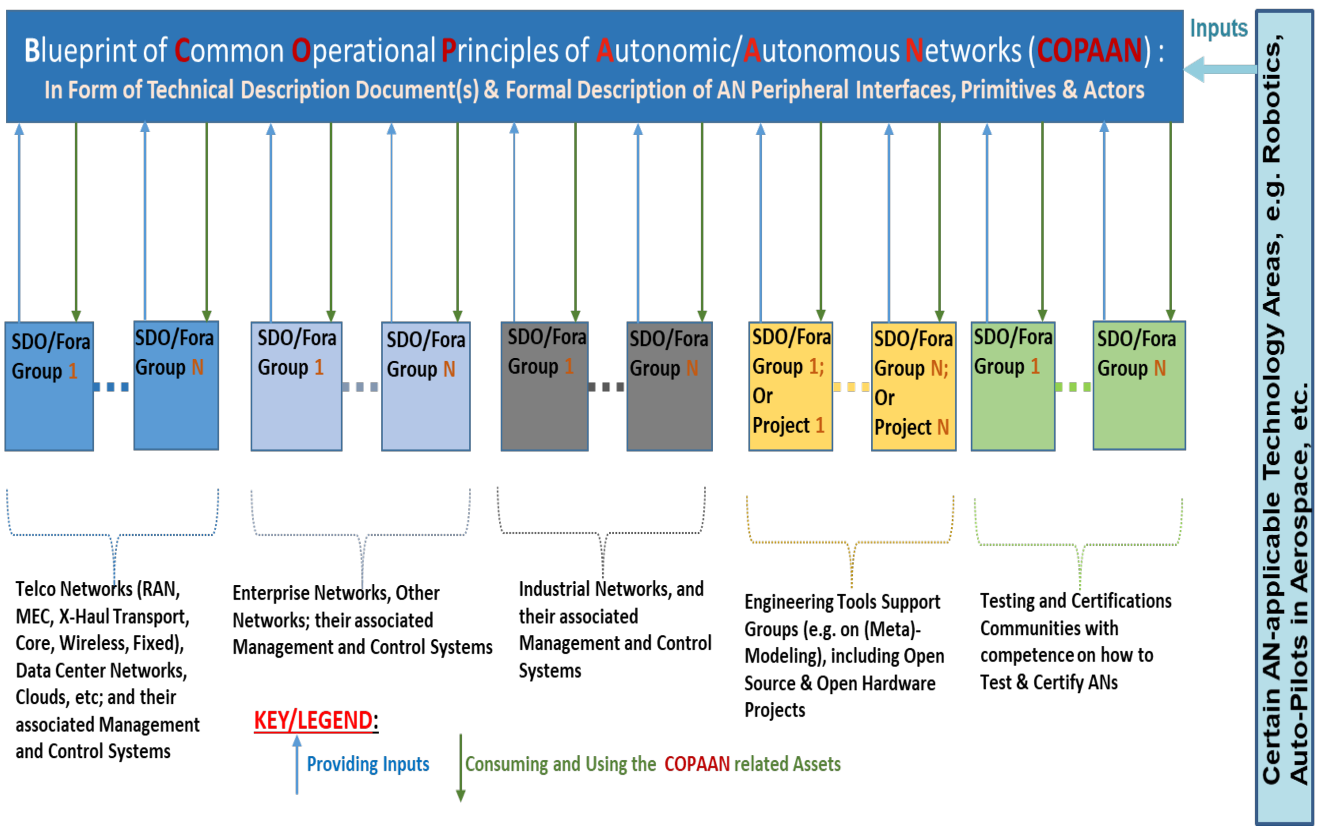

Figure 11: A vision on "How to Build the Blueprint (COPAAN), the kinds of Inputs required for Developing the COPAAN, and the Outputs that should then be consumed by SDOs/Fora working on ANs".

5.3.3.1. Inter-System Coordination for Exchanging Network Service Level Assurance Information

There is another coordination need when multiple networks, independently operated by different communications services providers, offer seamless communications services to their subscribers. There must be a coordinated way for these autonomous systems to exchange network service level assurance information that may allow neighboring autonomous systems to plan and adapt ahead of time to deal with networkwide events detected or predicted by the originating autonomous system.

As a matter of practical deployment, it is not uncommon to have end-users of communications services in a common geographical area to be served by multiple networks independently operated by different communications services providers. Figure 12 depicts such a possible scenario.

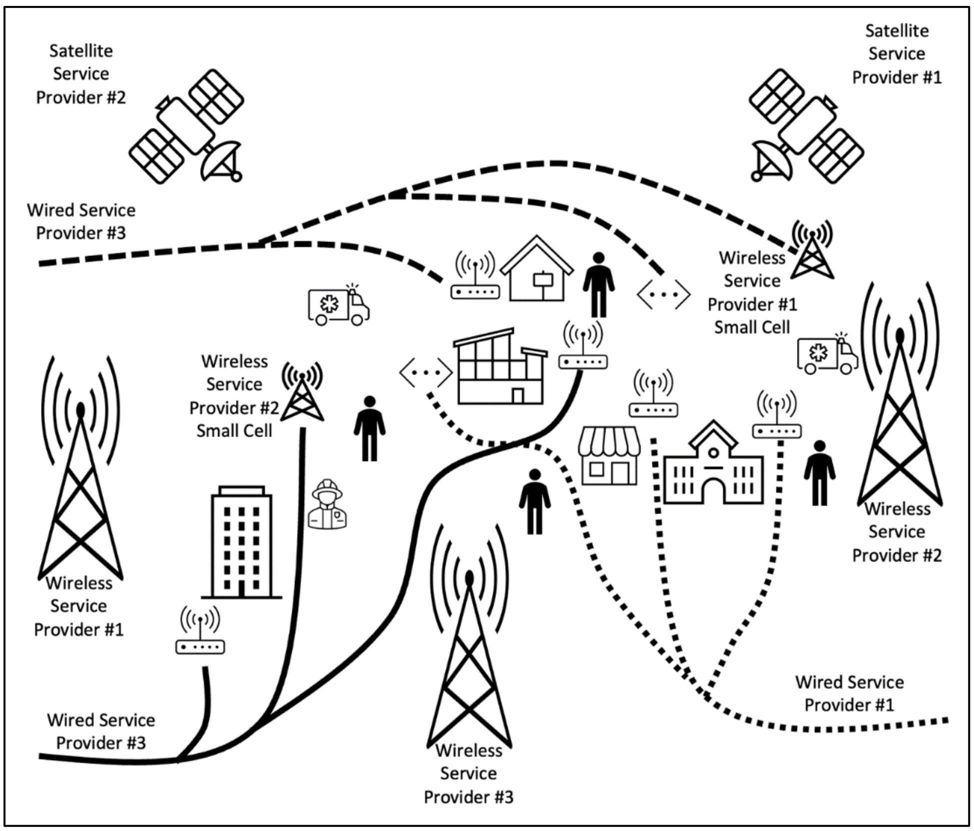

Figure 12. Example of a plausible deployment scenario where one geographic area is served by multiple networks

Figure 12 shows, as an example of a plausible deployment scenario, the following:

- A geographical area with end-users; these end-users may be pedestrians, residents in houses and multi-dwelling units (MDUs), businesses, schools, government institutions, public safety assets, transportation hubs, Internet-of-Things (IoT) devices, base stations, etc.
- These end-users are in a common geographical area with communications services provided by:
    - Three wired service providers (e.g., cable, fiber, DSL, and/or metro Ethernet operators)

    - Three wireless service providers (e.g., 2G/3G/4G/LTE/5G cellular, WiMAX, fixed and/or mobile)
    - Two satellite service providers
- Also note the possibility of one service provider having a dependency on another service provider, such as a small cell operated by Wireless Service Provider #2 depending on the wired backhaul provided by Service Provider #3.

An end-user may subscribe or otherwise have access to more than one communications service. For example, a typical consumer is quite likely to subscribe to a wireless mobile cellular service and a wired Internet service for his residence. Furthermore, the same consumer may have additional accesses through his employer or his institution's communications networks, perhaps also to temporary complementary accesses furnished by hospitality businesses and transportation hubs.

For individual end-users, it is natural that when one service does not work well (for any reason), the end-user switches to another service for which he has access. Such switching may happen automatically without the end-user having to take any explicit action to initiate the switch.

Businesses and institutions, more so than individuals, are even more likely to maintain multiple accesses to communications networks. For example, a business or institution may deploy dual-WAN or multi-WAN routers that automatically load-balance or switch data traffic between two or more wireline access services, perhaps also with one or more wireless backhauls as backups (may be cellular, satellite, or combinations of both).

Service providers, each on their own, deploy increasingly sophisticated operational management of their networks. They collect increasingly rich and detailed telemetry and analytics data (e.g., as evidenced by the Broadband Forum's ever-expanding TR-181 device data model, or through open-source efforts such as the OpenSync software[3]). Many increasingly adopt various Software-Defined Networking (SDN), Self-Organizing/Self-Optimizing Networking (SON), cloud computing, and elastic computing technologies to make their networks adapt more numbly to changes in operating conditions. Some even adopt Artificial Intelligence technologies (AI), with Machine Learning (ML) leveraging the increasingly rich set of analytics they collect, to further enhance and automate much of their operations.

At the level of individual connection or individual session switching access from one network to another, some standards exist to facilitate such switching in manners that preserve the individual connections or sessions. For example, 3GPP has standardized some aspects of inter-technology mobility to allow the user equipment to move across 3GPP and non-3GPP technologies (e.g., 3GPP TS 23.402, 23.502) while maintaining connectivity. Standards certainly exist to facilitate "handovers" and "roaming" across different cellular networks operated by different service providers, as end-users have long enjoyed the benefits of such capabilities as a matter of course. At the level of individual routes, standard protocols also exist for networks to signal to each other the availability of individual routes.

Yet, at the aggregate network level, there are scant standards to facilitate automatic coordination across autonomous systems on gross resourcing or gross performance levels.

Viewed from the lens of the end-users (be they individuals, businesses, or institutions), rationally, each will seek out another usable access when whichever access they were using becomes sufficiently

[3] Reference https://www.opensync.io/

degraded. Collectively, when one service provider experiences service issues, the end-users will switch over to other usable services, e.g., refer to Figure 12, if services by Wired Service Provider #3 were to become unavailable, then all the end-users who were on Wi-Fi or Ethernet or small cell that rely on Wired Service Provider #3 will switch to using services by other providers, such as cellular services by Wireless Service Providers #1 and #3, Wi-Fi or Ethernet services by Wired Service Provider #1 and #3, perhaps even to the Satellite Service Providers.

In short, when the network services provided by one autonomous system become significantly degraded in a geographic area, neighboring network services operated by other autonomous systems in the same region will likely experience a "surge" in usage as the impacted end-users seek out and migrate to other available network services. These "surges" may, in turn, have the potential to degrade or destabilize the neighboring networks if not handled appropriately.

While the neighboring networks and autonomous systems may each handle these "surges" by overprovisioning in general, or perhaps even through combinations of AI/ML, SDN, and elastic computing techniques (where AI/ML detects or even predicts the "surge" just by looking at analytics within its autonomous system, then automatically adapts its network with SDN and elastic computing techniques), in the quest for greater efficiency in resource allocation and faster response to keep the end-users satisfied, the question could still be asked: can efficiency and response time be further improved if, when one autonomous system detects or otherwise expects degradation in a geographic area, that there is a way for that system to somehow let the other autonomous systems serving the same geographical area know that a "surge" may be coming?

In summary, there is a strong need for further study the potential for greater coordination and perhaps further standardization for autonomous systems to exchange network service level assurance information that may allow neighboring autonomous systems to plan and adapt ahead of time to deal with networkwide events detected or predicted by the originating autonomous system. This may be further generalized to facilitate the exchange of aggregate network operations knowledge in general.[4]

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

[4] The sharing of "operation knowledge" is also suggested by the TM-Forum, albeit in different contexts for different objectives. See TM Forum white paper, *Autonomous Networks: Empowering digital transformation for the telecoms industry* (Rel. 2), December 2020, p.9.

- 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.

5.3.6. SDOs/Fora Collaborations on Testbeds Federations and Associated APIs for 5G & Beyond

There is a flurry of activities in developing testbeds independently by many organizations around the world. Therefore, there is a strong need for collaboration among the industry (operator, vendor) and research communities and thus expand upon the existing testbeds towards federated development of testbeds for next-generation networks. Accordingly, there are several efforts to accomplish this collaboration as summarized below:

Recently, ETSI TC INT and ITU-T SG11 developed a Standardized Reference Model for Testbeds Federations, associated APIs, and their respective Use Cases (Q.4068 https://www.itu.int/ITU-T/recommendations/rec.aspx?rec=14765).

Furthermore, ITU-T established a new Focus Group (FG) under SG11 (FG-TBFxG) (https://www.itu.int/en/ITU-T/focusgroups/tbfxg/Pages/default.aspx). The vision of the newly established Focus Group is to bring together various relevant Stakeholders (including SDOs/Fora) to work together in creating Interoperable and Harmonized Standards for Testbeds Federations for 5G and Beyond, based on the Reference Model mentioned above, and jointly share the burden on developing and Standardizing interoperable APIs for Testbeds Federations for 5G & Beyond. An interesting business model that is to be enabled by the Reference Model and its instantiations is “Testbed-as-a-Service”.

In March 2021, ITU SG11, ETSI TC INT, and IEEE INGR Future Networks Testbeds WG ran a Joint SDOs brainstorming workshop on Testbeds Federations for 5G and beyond while focusing on interoperability, standardization, reference models, and APIs (https://www.itu.int/en/ITU-T/Workshops-and-Seminars/20210316). This workshop laid the foundation and groundwork for joint work in this area of Testbeds Federations for 5G and Beyond.

IEEE INGR Future Networks Testbeds WG is very active in Testbeds (and Federations) for future networks. Although this WG is not a standard developing group, nevertheless it has been collaborating with the industry and research communities towards federated development of testbeds for next-generation networks. The Group is also curating a directory of available 5G and beyond networking testbeds for use by both academic and industry research groups. Such a directory will also identify gaps in availability and capabilities. NOTE: Such a Directory can be one of the very important enablers for building Federated Testbeds and associated Standards.

The topic of Federated Testbeds is expected to be explored further and build on the Reference Model jointly developed by ITU-T SG11 and ETSI TC INT (and published by ITU), while collaborating with the other SDOs and players from industry and academia, to derive and produce standardizable contributions to the established Focus Group in ITU (FG-TBFxG). Such joint and collaborative efforts in this area by the various stakeholders shall benefit the industry and other stakeholders.

5.4. Standardization of Emerging Technologies

5.4.1. Advanced Standardization of Emerging Technologies

New technologies appear due to innovation and research in Academia and Industry. Initially, new technologies are socialized in closed circles of experts and with time get exposed to a wider audience via public workshops and conference presentations, and eventually publications in magazines and journals.

Often technologies are born and socialized at about the same timeframe in various geographic places and research communities. Different approaches to the naming and characterization of new technologies are common.

Standards traditionally play a significant role in enabling markets for products and services. This is a well-established industry practice. However, standards also can have a role in enabling technology evolution from conception to maturity.

Scientific and technical research communities need to establish common taxonomy and frameworks for technology research. Lack of common frameworks, terminology, and accepted architectures often confuse and slow down the technology evolution

Advanced standardization allows to build consensus among industrial and academic researchers at least on the taxonomy and eventually on the frameworks and functional architectures for the emerging technologies, if and when appropriate, and thus can help the technology evolution, as illustrated in Figure 13.

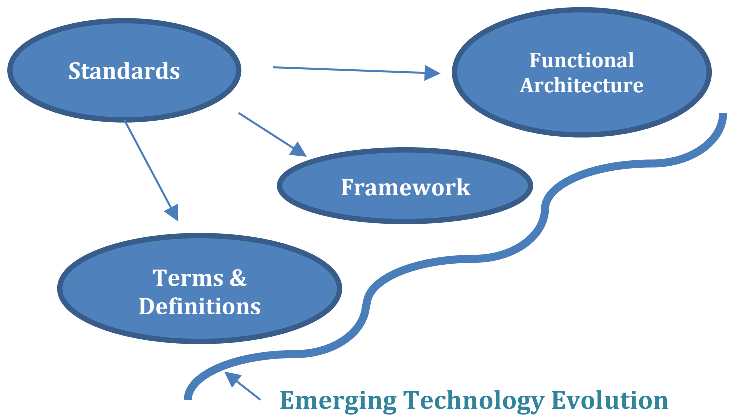

Figure 13. Technology Evolution and Standards

The order, timing, and nature of emerging technology standards vary with the technology and due to many other factors. Industrial and academic researchers often feel intimidated by the notion of standards slowing down innovation. Properly formulated and modularized standards projects should not be an obstacle to innovation and should not cast in iron ideas and concepts, that in any way restrict innovation.

Often emerging technologies have a supporting role, serve as enablers for other technologies, or can be only deployed in a system and their deployment and implementation are completely dependent on the application. If such technology is "ahead of its time", i.e., the industry is not ready for it, the evolution of such technology and its acceptance can be accelerated by appropriate standardization. An advanced standard for new technology should not be bound by current capabilities around it, environmental or any other conditions that appear to limit deployment.

Below are some examples of advanced IEEE standards and standardization projects, created with the active participation of Industrial and Academic researchers:

- IEEE 1900.1-2019 - IEEE Standard for Definitions and Concepts for Dynamic Spectrum Access: Terminology Relating to Emerging Wireless Networks, System Functionality, and Spectrum Management
- IEEE 1906.1-2015 - IEEE Recommended Practice for Nanoscale and Molecular Communication Framework
- IEEE 1910.1-2020 - IEEE Standard for Meshed Tree Bridging with Loop-Free Forwarding
- IEEE P1913.1 - Software-Defined Quantum Communication
- IEEE P1918.1 - Tactile Internet: Application Scenarios, Definitions and Terminology, Architecture, Functions, and Technical Assumptions
- IEEE 1923.1-2021 - IEEE Standard for Computation of Energy Efficiency Upper Bound for Apparatus Processing Communication Signal Waveform
- IEEE P1924.1 - IEEE Draft Recommended Practice for Developing Energy Efficient Power-Proportional Digital Architectures
- IEEE 1934-2018 - IEEE Standard for Adoption of OpenFog Reference Architecture for Fog Computing

5.4.2. 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 (Figure 14).

Figure 14. 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 (Figure 15).

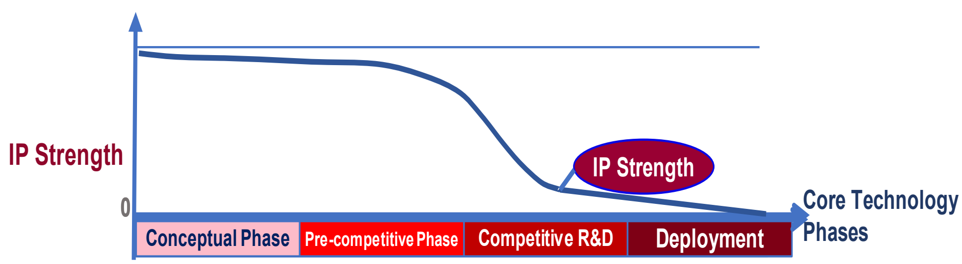

Figure 15. Diminishing Strength of the Intellectual Property

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 (Figure 16).

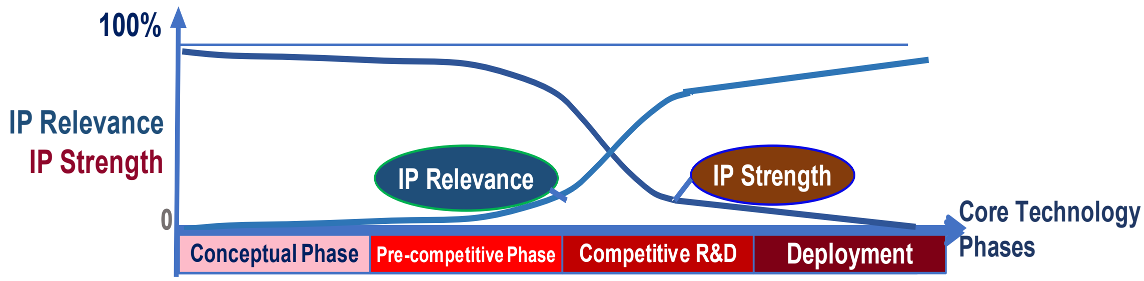

Figure 16. Strength versus Relevance of Intellectual Property

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 (Figure 17).

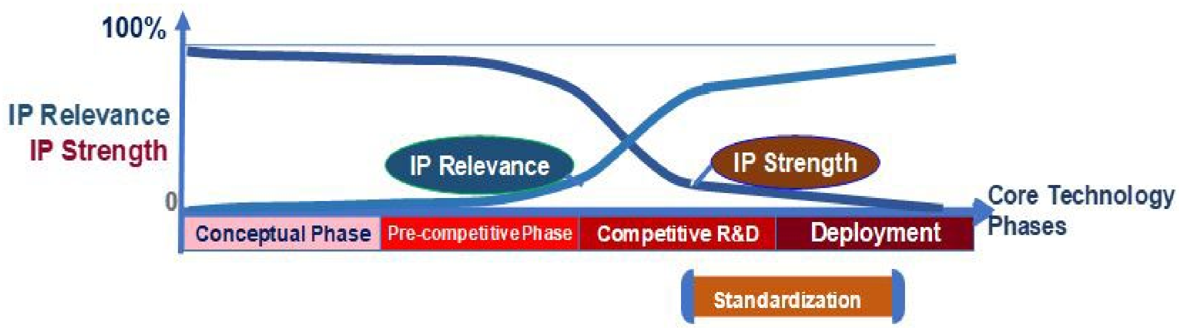

Figure 17. Typical Standardization Interval

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 18 illustrates how IEEE products are mapped to the technology evolution timeline

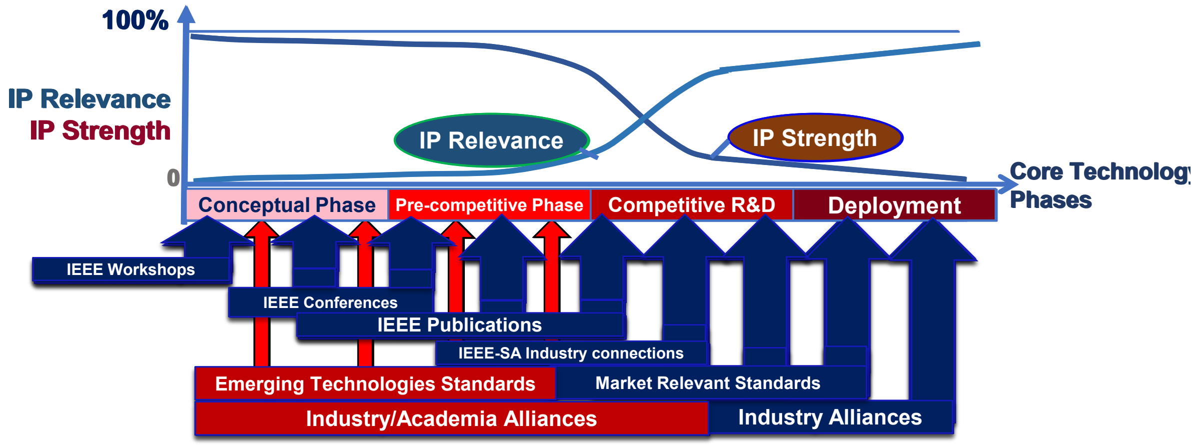

Figure 18. IEEE Products and Standardization positioned in Technology Evolution timeline

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.

5.4.3. 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 Roadmap (INGR) 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. Contributor Bios

Alexander D. Gelman is an IEEE Life Fellow. He received M.E. and Ph.D. (EE) from the City University of New York. Presently he is CTO of NETovations Consulting Group. During 1998-2007 Alex was the Chief Scientist of Panasonic Research Laboratory located in Princeton NJ and San Jose Ca; during 1984-1998 worked at Bell Communications Research (Bellcore), lastly as Director-Internet Access Architectures Research. Alex has numerous publications and several patents. He pioneered Multimedia Multi-point communications, Streaming Video over Networks, XDSL-based Internet Access. Alex co-founded eight IEEE conferences and two publications; initiated ComSoc Standards Activities; initiated ComSoc Technical Committee and standardization in Power Line Communications and IEEE standardization in the area of cognitive radio; chaired the Technical Committee on Multimedia Communications; served four terms as ComSoc Vice President, e.g. was elected as ComSoc's first Vice President-Standards Activities.Alex served two terms on IEEE SA BoG, e.g. as Vice President-Technical Innovation and Engagement; served several terms on IEEE SA Standards Board, e.g. representing TAB; chaired TAB Ad Hoc Committee on Standards in 2008 and served as the Inaugural Vice-chair of the TAB committee on Standards in 2018. Presently Alex is a chair of the IEEE Access and Core Networks Standards Committee, Vice Chair of the IEEE SA Fellow Nominations Support Committee, co-chair of the Standardization Building Blocks Working Groups of the FDC INGR Initiative. Alex is a recipient of ComSoc Donald McLellan Meritorious Service Award, IEEE SA Corporate Standards Sponsor Award and IEEE SA Standards Medallion.

Mehmet Ulema is a professor of Computer Information Systems at Manhattan College, New York. Previously, he held management and technical positions in ATT Bell Laboratories, Bellcore, and Daewoo Telecom. He has been on the editorial board of a number of journals. He is also the co-editor of the IEEE Press-Wiley book series on Network and Service Management. Dr. Ulema is the author of a book entitled "Fundamentals of Public Safety Networks and Critical Communications" published by Wiley. Mehmet was actively involved in standardization in ITU, TIA, ATIS, and IEEE. Currently, he is a member of IEEE Standards Association Board of Governors. He is also a co-chair of the IEEE Public Safety Technology Initiative. Dr. Ulema had leading roles in numerous IEEE ComSoc conferences including IEEE ICC and IEEE GLOBECOM. He is the co-founder of IEEE BlackSeaCom conference series. Dr. Ulema has received a number of awards including IEEE SA Standards Medallion award and IEEE ComSoc Harold Sobol Award. Dr. Ulema holds MS Ph.D. degrees in Computer Science at Polytechnic University (now the New York University Tandon School of Engineering. He also received BS MS degrees at Istanbul Technical University.

Abdelaali Chaoub is an Associate Professor in Telecommunications, appointed at the Institut National des Postes et Télécommunications (INPT) of Morocco in 2015. He obtained an engineering degree of telecommunication from INPT in 2007 with the highest honors and received his Ph.D. degree from Mohammed V-Agdal University in 2013. His research interests are related to remote/rural connectivity solutions for B5G/6G networks, design and optimization of IoT-enabled smart environments, dynamic spectrum access and cognitive radio networks, adaptive multimedia streaming in wireless networks and mitigation of DoS attacks in cellular networks. Prof A. Chaoub is an IEEE Senior Member. A member of the professional online network: Elsevier Innovation Panel (the former Elsevier's Innovation Explorers). Member of the following Working Groups within IEEE SA: P1950.1, P1900.1 and P1941.1.

Member of the following Working Groups within the IEEE INGR: Standardization Building Blocks and Systems Optimization. Member of Connecting the Unconnected (CTU) initiative driven by IEEE Future Networks. Member of two teams within the 6G Flagship project: Connectivity for Remote Areas and RF & Spectrum. He is also an active member of the Moroccan Association of Information and Communications Technologies (AMTIC). Prof A. Chaoub has accumulated intersectoral skills through work experience both in academia and industry as a Senior VoIP solutions Consultant/Architect at Alcatel-Lucent (2007 -- 2015), where he has been involved in many projects for implementing voice over IP in large structures.

Ranganai Chaparadza Dr.-Ing./PhD, is a Senior Capgemini Engineering Technical & Technology Consultant for Vodafone (and for other Telecommunications Network Operators as well) and Solutions Design Architect, while also supporting in the Standardization of Autonomic/Autonomous Networking in ETSI TC INT AFI WG. He is also IPv6 Forum Fellow representative in ETSI TC INT AFI WG to bring perspectives of IPv6 enablers for autonomic network setup and operation. He actively supports Network Operators in various aspects: Vendor Management and Solutions Selections on SDN/NFV and E2E Service Assurance Solutions for Telco Networks and Data Center (DC) Network Services; Business Development with Emerging ICT Technologies and Future Networks; Standardization Expert (ETSI, BBF, ITU-T, NGMN, TMF, 3GPP, IEEE, IETF, ONF, MEF); R&D; RFIs/RFQs/RFPs Processes and Solution Supplier Selection; SDN/NFV TCO (Total Cost of Ownership); Building Optimal Commercial Models for Transport SDN and NFV; Procurement Transformation in the Era of SDN/NFV; Products Innovation with SDN, NFV and AMC (Autonomic Management & Control) for Network Automation using ETSI GANA oriented Standards; ETSI 5G PoC on E2E Closed-Loop (Autonomic) Service Assurance and E2E Autonomic Security Assurance for 5G Network Slices. He is also actively involved in E2E Architecture for Disaggregated 5G Networks; and ETSI Framework on E2E Autonomic 5G Networks powered by ETSI GANA Multi-Layer Autonomics & AI and IPv6. He is also contributor to IEEE INGR Future Networks Standardization Building Blocks (SBB) Roadmap WG, IEEE INGR Systems Optimization WG, and IEEE INGR Testbeds WG.

Baw Chng is a technologist, inventor, and author who consults in the wireless networking and telecommunications industry. Baw Chng has been awarded multiple patents in such areas as network and system architecture, network planning, security and authentication, mobility, system selection, service provisioning, access control, user interface and user experience, and network management. Baw Chng has published papers on computer networking, computer architecture, and magnetic recording in peer reviewed publications. Through his consulting practice at BAWMAN LLC, Baw Chng offers technology consulting, standards consulting, and business strategy consulting services in the networking and communications industry. Baw Chng has extensive experience working with large Tier-1 communications service providers, their strategic technology vendors, technology start-ups, as well as various standards development organizations in the industry. Baw Chng has done pioneering work on femtocell and small cell technologies and his body of work spans across a broad array of critical technologies including Wi-Fi (mesh and infrastructure), cellular communications, Internet-of-Things (IoT), low-power wide-area network (LPWAN), network function virtualization (NFV), software defined networking (SDN), self-organizing and self-optimizing network (SON), cloud computing, plastic optical fiber (POF), optical networking, quality of service (QoS), and fair queueing.

Muslim Elkotob (M.Sc. TU München, Germany 2003, PhD LTU, Sweden 2010) is a Principal Solutions Architect at Vodafone with a lead design and business development role and end-to-end responsibility in the Enterprise Business Line. He works on driving innovation and standardizing architectures in the areas of SDN/NFV, Autonomics, Slicing and Security in 5G and IoT. He is an IPv6-Forum Fellow and delegate with lead roles in various SDOs including ETSI, TMForum, ITU-T and IEEE. Dr. Elkotob is Vice-Chairman of ITU-T Focus Group on Testbeds Federations for IMT-2020 and beyond (FG-TBFxG). Having a career background with vendors, service providers and R&D, he has spent the last eight years strengthening Vodafone's role in the enterprise Value Chain as a global player with a powerful infrastructure and autonomic IT services on top.

Reinhard Schrage is a senior consultant at SchrageConsult, Germany. He studied Pure Mathematics, Stochastics and Theoretical Computer Science at USC, Los Angeles and Leibniz University of Hannover, Germany, where he received his MSc in Mathematics. His work expertise includes the (a) calculation of nuclear fallout areas for the German Army, (b) customer specific design, creation and implementation of financial application software for the Treasury in New Zealand, (c) customer specific adaptation of LAN protocol software for New Zealand Parliament, (d) support for strategic Northern Telecom customers, like Deutsche Telekom and Telefonica in Madrid, Spain, (e) European Customer Service Manager at UK based Cable and Wireless, managing a team of 18 people of 13 nationalities, (f) planning and management responsibility for the global financial services network of British Telecom in London, (g) Resident Nortel Networks Engineer at Volkswagen Headquarters and (h) stochastic performance analysis of smartphone clusters. He is contributing member to several IEEE standardization workgroups like (a) IEEE 1903 Next Generation Service Overlay Network, (b) vice chair for 1910.1 Standard for Meshed Tree Bridging with Loop Free Forwarding, (c) vice chair for 1900.1 Standard for Definitions and Concepts for Dynamic Spectrum Access, (d) Editor of the 1900.5.1 Standard Policy Language for Dynamic Spectrum Access Systems as well as (e) contributing member to RFC 6349 Framework for TCP Throughput Testing.

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

8. 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

Antitrust 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/wp-content/uploads/2022/02/antitrust.pdf