Appendix A: Reference architecture comparison: functions of standards in knowledge-intensive industries

TABLE 1 | **Functions of standards**
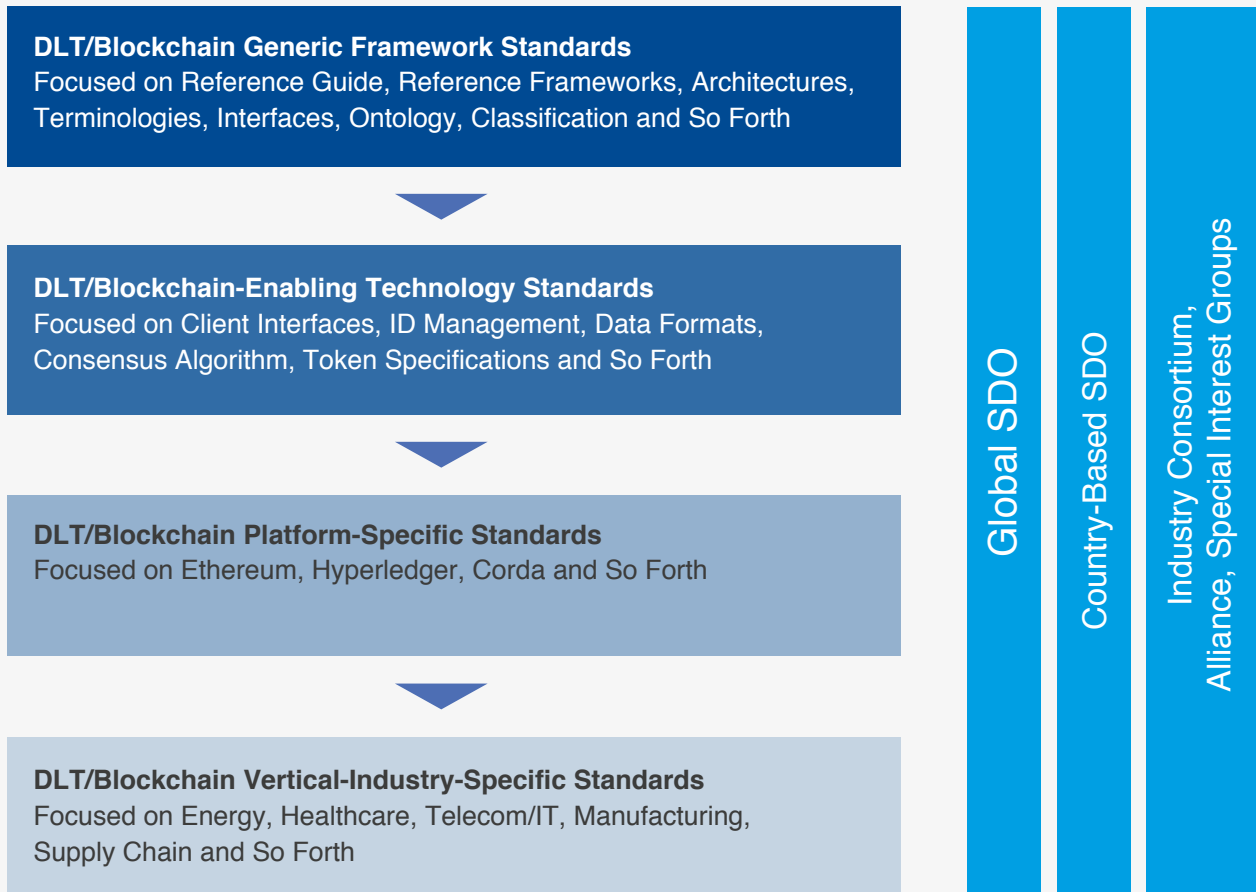
Function	Types of standard	Examples	Economic impacts
1. Enable variety reduction among designs and functions of product elements	−Design, component and architecture configurations −Standard data file formats	−Computer keyboards −Microprocessor architecture, size of silicon wafers	−Achieve economies of scale and/or network externalities
2. Specify quality and reliability of product and process technologies	−Performance metrics, such as minimum quality levels −Equipment calibration methods and data	−Building codes and regulations −Minimum quality levels for motor oils −Equipment calibrations for semiconductor process equipment	−Achieve economies of scale and/or network externalities
3. Provide performance-related information on characteristics of resources and actual products and processes	−Measurement and testing methods −Critically evaluated data, standard reference materials −Product performance	−Standard reference data for advanced ceramic materials −Terminology for nanotechnology	−Increased research efficiency −Higher productivity through better process control −Reduced transaction costs and hence lower prices for new products
4. Assure interoperability for hardware and software components for technology-based systems	−Interconnections among system components −Portability across implementations of a product technology system	−Efficient integration of computer hardware and software components −Portability of software across computer systems, data-format standards	−Achieve network externalities and thereby expand value/cost ratios Facilitate open systems and thereby enable more competition at component and subsystem levels

Appendix B:
Reference architecture comparison

FIGURE 1,2 | **IEEE**

| DLT/Blockchain Generic Framework Standards |
| Focused on Reference Guide, Reference Frameworks, Architectures, Terminologies, Interfaces, Ontology, Classification and So Forth |

DLT/Blockchain-Enabling Technology Standards
Focused on Client Interfaces, ID Management, Data Formats, Consensus Algorithm, Token Specifications and So Forth

DLT/Blockchain Platform-Specific Standards
Focused on Ethereum, Hyperledger, Corda and So Forth

DLT/Blockchain Vertical-Industry-Specific Standards
Focused on Energy, Healthcare, Telecom/IT, Manufacturing, Supply Chain and So Forth

Global SDO

Country-Based SDO

Industry Consortium, Alliance, Special Interest Groups

Note: The figures use the notation for class diagrams defined in IEEE 42010.

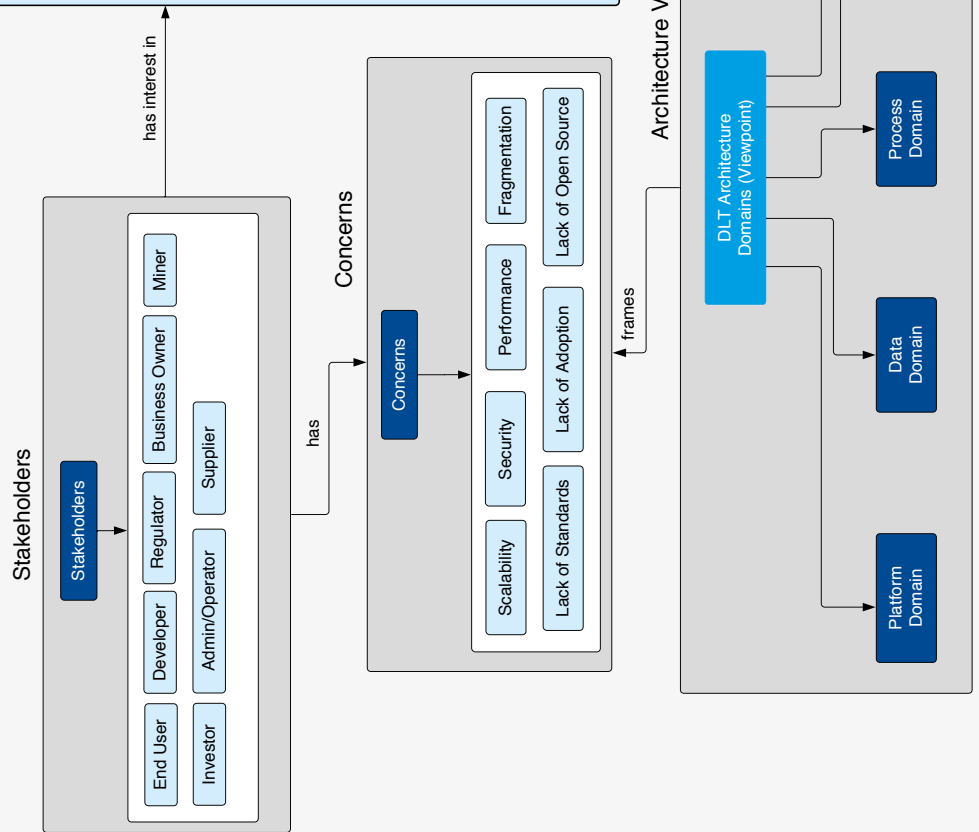**Source**: Lima, C. "Developing Open and Interoperable DLTVBlockchain Standards [Standards]" in Computer, vol. 51, no. 11, 2018, 106–111. https://doi.ieeecomputersociety.org/10.1109/MC.2018.2876184

DLT/Blockchain System of Interest

Proof-of-X

Proof of Stake	Proof of Work
Proof of Burn	Proof of Activity
Proof of Importance	Proof of Valuation
Proof of Authority	Proof of Capacity
Stellar Consensus	Ripple Consensus
Proof of Elapsed Time	Delegated Proof of Stake
Proof of Storage	Proof of Space

- Data Blocks
- Chain Structure — UTXO / Traditional
- Transaction Model
- Binary / Patricia
- Cryptographic Protocol
- Merkle Tree
- On Chain / Off Chain
- Block Header
- Datasets
- Hash Function
- Distributed Hash Table
- Digital Signature
- Data Scope

Nodes — Full / Thin
- Peer to Peer (P2P)
- Relay Network
- Local Servers

Consensus Protocol

Process Domain

Data Domain

Network Domain

DLT
- BlockDAG
- HashGraph
- Others

Blockchain
- On Chain / Off Chain
  - Processing / Messaging
  - Storage
  - Cloud / On Premise
  - Cache / P2P Node
- Permissionless / Permissioned
  - Public / Private
  - Consortium/Community

has interest in

Stakeholders

Miner	Business Owner
Regulator	Supplier
Developer	Admin/Operator
End User	Investor

has

Concerns

Fragmentation	Lack of Open Source
Performance	Lack of Adoption
Security	Lack of Standards
Scalability	

frames

Architecture Viewpoints

DLT Architecture Domains (Viewpoint)
- Applications Domain
- Services Domain
- Process Domain
- Data Domain
- Platform Domain

Architecture Description

Purpose of the Architecture: This architecture framework defines the basis of the blockchain IoT architecture. It uses IEEE 42010 as a reference model to map the key stakeholders, concerns, architecture viewpoints and description into a cohesive solution.

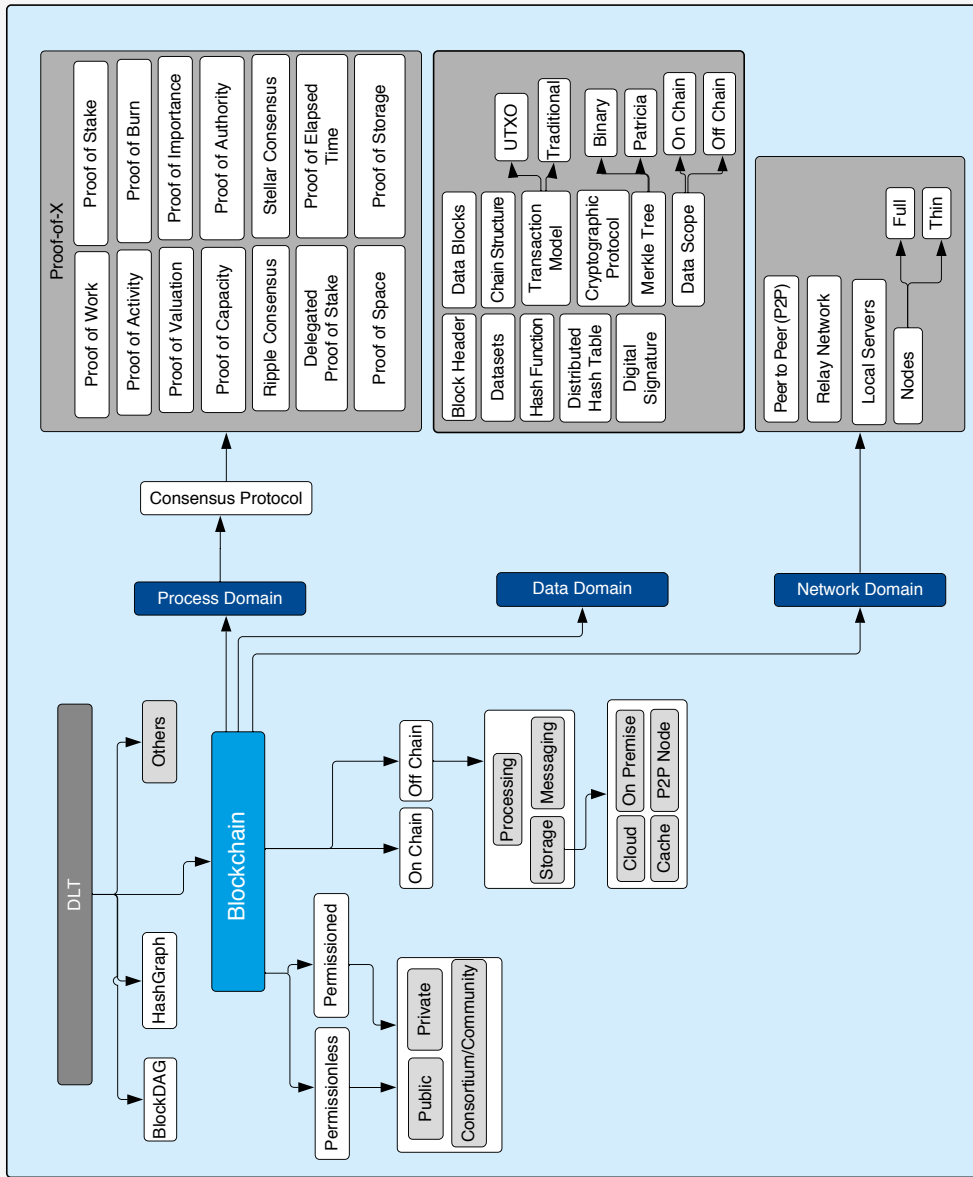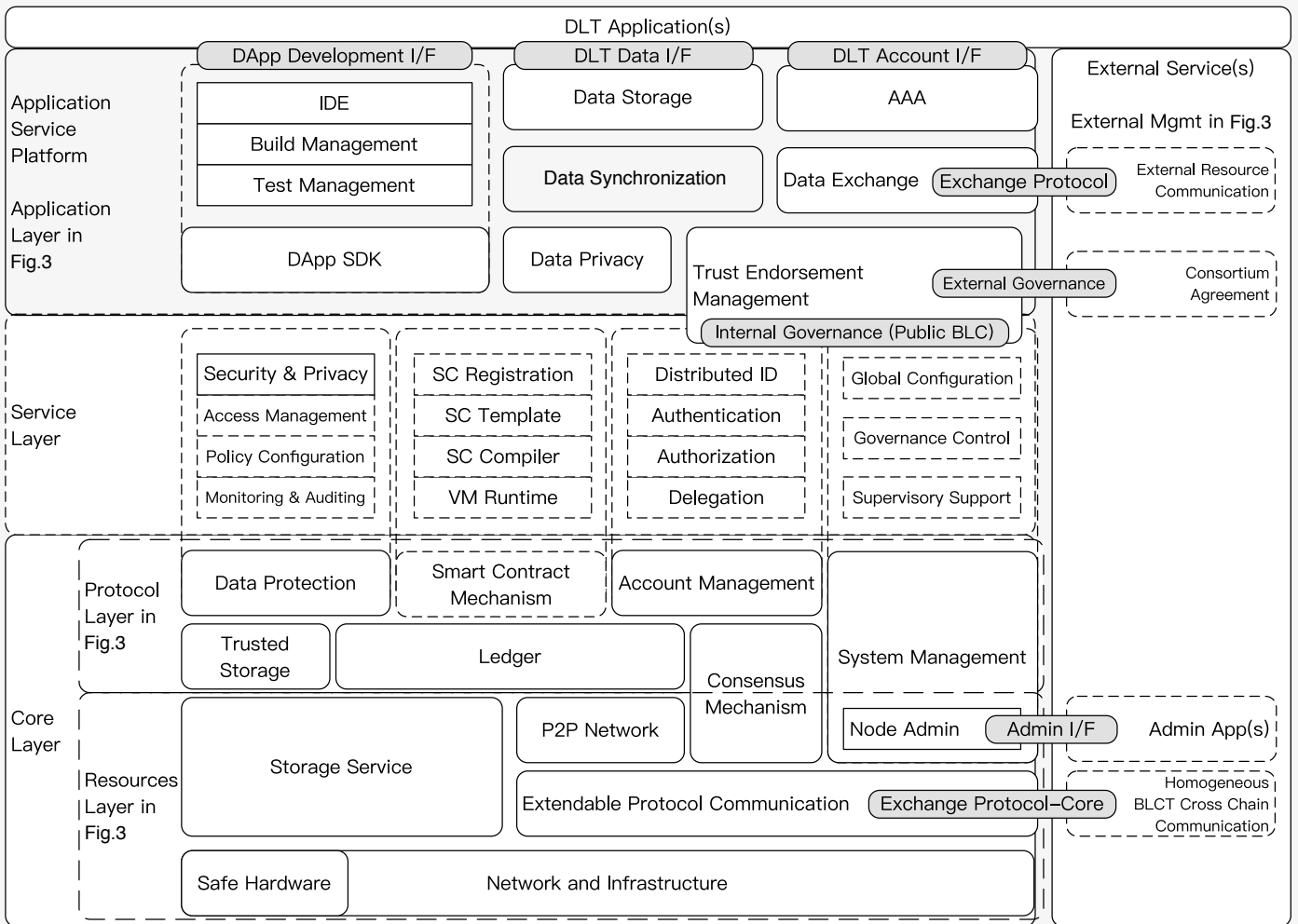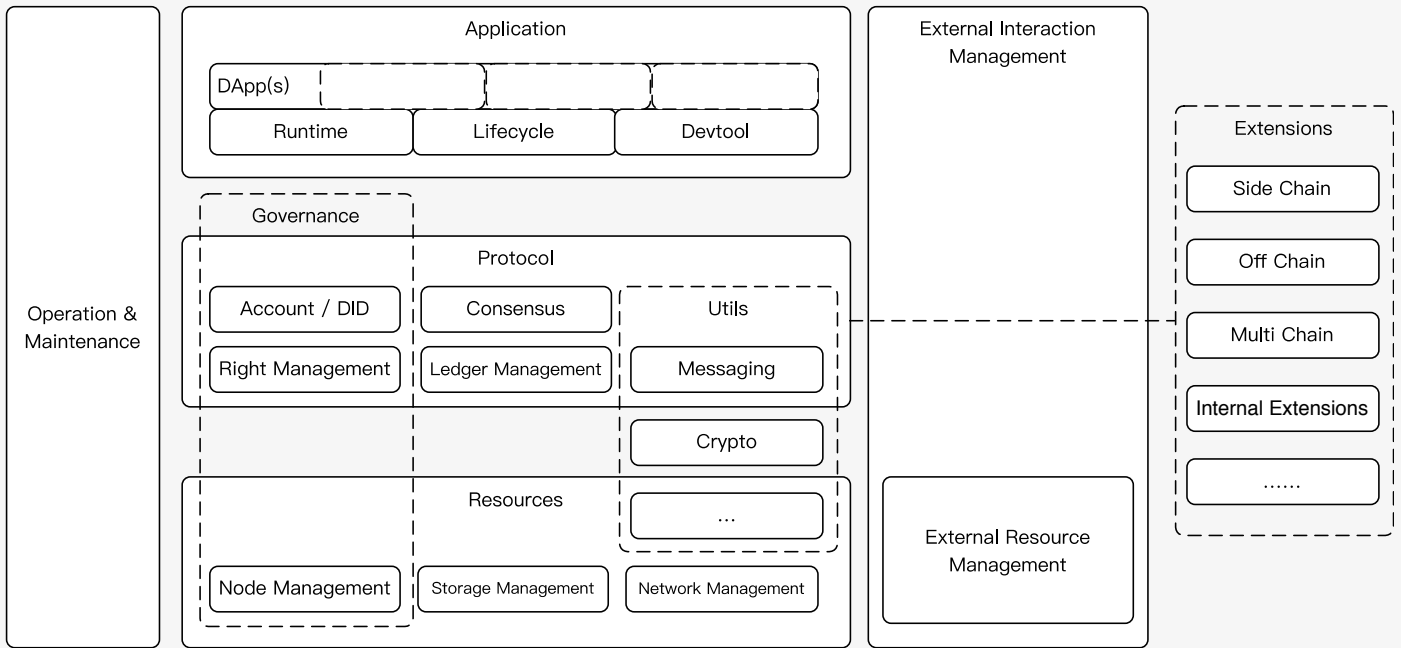**Note:** The figures use the notation for class diagrams defined in IEEE 42010.

Source: Lima, C. "Developing Open and Interoperable DLTV Blockchain Standards [Standards]" in Computer, vol. 51, no. 11, 2018, 106–111. https://doi.ieeecomputersociety.org/10.1109/MC.2018.2876184

Appendix C:
Additional information about standards-setting initiatives

Institute of Electrical and Electronics Engineers (IEEE) Blockchain Initiative

Background. The formation of the IEEE Blockchain Initiative (BLK) was approved by the IEEE Future Directions Committee, effective 1 January 2018. The BLK is the hub for all IEEE blockchain projects and activities. The BLK encompasses a comprehensive set of projects and activities supported by the following core subcommittees: Pre/Standards, Education, Conferences and Events, Community Development and Outreach, Publications, Special Projects.

Standards. IEEE aims to develop standards for blockchain with the aim of supporting the adoption of blockchain. The IEEE Standards Association (IEEE SA) pursues blockchain standardization through activities in multiple industries. The BLK and the IEEE SA collaborate to further develop and progress blockchain standards. The BLK focuses on a wide topic of blockchain-related standards, including cryptocurrency payments, identity management and the internet of things (IoT).

International Organization for Standardization (ISO)

Background. The ISO is an independent, non-governmental international organization with a membership of 164 national standards bodies. One of these standards bodies is the ISO/TC (technical committee) 307, which focuses on blockchain and distributed ledger technologies and has existed since April 2016.

Standards. The standardization efforts of the ISO/TC 307 are divided into the following seven working groups:

– ISO/TC 307/WG1 – Foundations

– ISO/TC 307/WG2 – Security, privacy and identity

– ISO/TC 307/WG3 – Smart contracts and their applications

– ISO/TC 307/JWG4 – Joint ISO/TC 307 – ISO/IEC JTC 1/SC 27 WG: Blockchain and distributed ledger technologies and IT security techniques

– ISO/TC 307/WG5 – Governance

– ISO/TC 307/WG6 – Use cases

– ISO/TC 307/SG7 – Interoperability of blockchain and distributed ledger technology systems

In addition, four ISO advisory working groups have been established

– ISO/TC 307/AG 1 – SBP Review Advisory Group

– ISO/TC 307/AG 2 – Liaison Advisory Group

– ISO/TC 307/AHG 2– Guidance for Auditing DLT Systems

– ISO/TC 307/CAG 1 – Convenors' Coordination Group

Furthermore, the ISO is exploring the need for additional standards or the improvement of existing standards where DLT is a driver for this exploration. For example, the impact of DLT on ISO/IEC 10918, standardization of the image format JPEG, is being explored.

World Wide Web Consortium (W3C)

Background. The W3C Blockchain Community Group (BCG) was launched in March 2016. Its mission is to generate message format standards of blockchain based on ISO20022 and to generate guidelines for usage of storage, including torrent, public blockchain, private blockchain, side chain and content delivery network (CDN).

Standards. The BCG drafted the Web Ledger Protocol 1.0, which is currently considered a specification and not a standard. This specification outlines a data model and syntax for expressing a set of ordered events in a decentralized system in a way that can be cryptographically verified.

Furthermore, the W3C Verifiable Credentials Working Group published the Verifiable Credentials Data Model 1.0 Report. Also, the W3C Credentials Community Group published several reports related to identity management credentials. These reports may be relevant for use cases that entail both blockchain and identity management.

Internet Research Task Force (IRTF) – Decentralized Internet Infrastructure Research Group (DINRG)

Background. The aim of the DINRG, which was established in July 2017, is to investigate open research issues in decentralizing infrastructure services such as trust management, identity management, name resolution, resource/asset ownership management and resource discovery.

Standards. The DINRG has not yet published any standards.

International Electrotechnical Commission (IEC) – ISO/IEC JTC 1/SC 41 – ahG 18 Study Group on Integration of IoT and Blockchain

Background. The ISO/IEC JTC 1/SC 41 serves as a proponent of JTC 1's standardization programme on the internet of things (IoT), and provides guidance to JTC 1, IEC, ISO on developing IoT-related applications.

Standards. The ahG 18 study group aims to analyse the field of IoT and blockchain by identifying standardization gaps within the scope of ISO/IEC JTC 1/SC 41, study the requirements for IoT use cases and blockchain, and study the requirements of interoperability between IoT and blockchain. Currently (January 2020), the working group focuses on a preliminary work item called Integration of IoT and DLT/Blockchain: use cases.

Enterprise Ethereum Alliance (EEA)

Background. Since the EEA's formation in 2017, its standards have aimed to drive interoperability, making standards key to scaling the enterprise blockchain ecosystem. The EEA is developing a certification test for vendors of enterprise blockchain solutions to pass. This test validates vendor products that comply with EEA specifications.

Standards. The EEA has developed the Enterprise Ethereum Architecture Stack (EEAS), a conceptual framework that summarizes the components from the Ethereum ecosystem. The stack comprises five main components: 1) application; 2) tooling; 3) privacy/scaling; 4) core blockchain; and 5) network. Furthermore, token standards have been developed such as ERC-20 or ERC-223.

The Hyperledger project

Background. Started in 2015, the Hyperledger project was launched by the Linux Foundation as an umbrella project of open-source blockchains and related tools.

Standards. The Hyperledger project and the EEA cooperate in developing open standards. The community creates and integrates standards on a ledger or use-case specific basis.

Internet Engineering Task Force (IETF)

Background. Founded in January 1986, the IETF is an open-standards organization that develops and promotes internet standards. As blockchain relies heavily on the interconnectivity of the internet, in particular permissionless blockchains, it becomes important to take these standards into consideration.

Standards. In addition to internet standards, the IETF specified the Interledger Protocol (ILP). The ILP provides the functions necessary to deliver a payment from a source to a destination over an interconnected system of ledgers.

Additionally, the IETF drafted the "blockchain transaction protocol for constraint nodes", enabling generation of transactions by nodes with limited storage and processing capacity.

International Telecommunication Union Telecommunication Standardization Sector (ITU-T) – Focus Group on Application of Distributed Ledger Technology (FG DLT)

Background. The FG DLT was established in May 2017. It aims to:

– Identify and analyse DLT-based applications and services

– Draw up best practices and guidance

– Propose a way forward for related standardization work in ITU-T study groups.

Standards. Several specifications and reports have been made available through the FG DLT, such as DLT terms and definitions, DLT use cases and assessment criteria for DLT platforms. Next to the FG DLT, ITU-T consists of several study groups focusing on a specific topic together with DLT. These study groups are:

– ITU-T Study Group 13: Future networks, with focus on IMT-2020, cloud computing and trusted network infrastructures

– ITU-T Study Group 17: Security

– ITU-T Study Group 16: Multimedia coding, systems and applications

– ITU-T Study Group 20: Internet of things (IoT) and smart cities and communities (SC&C)

– ITU-T Focus Group on Digital Currency including Digital Fiat Currency (FG DFC)

– ITU-T Focus Group on Data Processing and Management to support IoT and Smart Cities and Communities (FG-DPM)

– ITU-T Focus Group on Environmental Efficiency for Artificial Intelligence and Other Emerging Technologies (FG-AI4EE)

– ITU-T Focus Group on Digital Financial Services (FG DFS)

British Standards Institution (BSI)

Background. Founded in 1901, the BSI is the national standards body of the United Kingdom. It produces standards of a technical nature, including a wide range of products and services.

Standards. The BSI website points to several ISO standards but the BSI does not itself currently publish any standards related to blockchain.

An overview report was published in May 2017 called *Distributed Ledger Technologies/Blockchain: Challenges, opportunities and the prospects for standards*.

European Committee for Standardization (CEN) and European Committee for Electrotechnical Standardization (CENELEC) – Focus Group on Blockchain and Distributed Ledger Technologies (FG-BDLT)

Background. Founded in 1961, the CEN develops European Standards (ENs) for various sectors, whereas the CENELEC develops standards in the area of electrical engineering. In 2017 the CEN and the CENELEC together established a focus group, FG-BDLT, to identify European needs and requirements for the implementation of DLT in Europe. The aim of this group is to map these needs against the publications of the ISO/TC 307. Other objectives of FG-BDLT are the identification of European needs for blockchain and DLT standardization, and to encourage further European participation in ISO/TC 307.

In line with this, the European Commission launched the European Blockchain Partnership in April 2018: 22 European countries agreed through a joint declaration to cooperate in the establishment of a European blockchain services infrastructure. The aim of this infrastructure is to support the delivery of cross-border public services through interoperability and open interfaces and with the highest standards of security. The EC engages and follows both the ISO TC 307 and the ITU-T Focus Group on Application of DLT.

Standards. The CEN and the CENELEC published a white paper in October 2018 entitled *Recommendations for Successful Adoption in Europe of Emerging Technical Standards on Distributed Ledger/Blockchain Technologies*. This white paper identifies specific European needs on blockchain and DLT.

Standards Australia

Background. Founded in 1922, Standards Australia is the principal non-government standards development body in Australia. It developed a roadmap for blockchain standardization that is designed to:

1. Identify the various technical issues associated with developing, governing and using DLT

2. Identify DLT use cases relevant to Australia

3. Prioritize the order of standards development activities that could be undertaken by ISO TC 307

In April 2016, Standards Australia proposed a New Field of Activity (NFTA) to the International Organization for Standardization (ISO). This resulted in the creation of the ISO TC 307. Furthermore, Standards Australia established the IT-041 Blockchain and Distributed Ledger Technologies committee to provide input to the ISO TC 307.

Standards. Standards Australia has so far largely contributed to the ISO TC 307.

World Intellectual Property Organization (WIPO)

Background. Founded in July 1967, the WIPO is a specialized agency of the United Nations. The WIPO was established to encourage creative activity and to promote the protection of IP throughout the world. The WIPO is currently exploring the application of blockchain to intellectual property datasets, and the WIPO Standards Workshop on Blockchain was held in April 2019.

Standards. The WIPO has not currently developed any blockchain-related standards.

European Telecommunications Standards Institute (ETSI)

Background. The ETSI is a not-for-profit standardization organization in the telecommunications industry in Europe. Founded in 1988, the ETSI is tasked with the standardization of information and communication technologies (ICT) in Europe. The ETSI established an Industry Specification Group for Permissioned Distributed Ledger (ISG PDL).

Standards. Currently the ETSI has proposed two initial drafts on PDL.

Standardization Administration of China (SAC)

Background. The SAC has set up a national standards committee for blockchain technology (SCBT).

Standards. Currently no standards have been developed.

Blockchain Industry Group (BIG)

Background. The BIG aims to develop and promote blockchain standards, education, certification and collaboration.

Standards. The BIG has published several opinion blog posts, but has not yet published any standards.

Other blockchain standardization-interested bodies

In this section we list organizations that discuss standardization of blockchain within a specific application domain, or that are specifically related to blockchain standardization.

– As most DLT heavily relies on cryptography, the National Institute of Standards and Technology (NIST) should play a prominent role in DLT standardization. Although NIST does not develop DLT standards itself, it does provide a wide set of cryptographic standards.

– Peerplays Blockchain Standards Association supports the development of provably fair gaming on the Peerplays blockchain. It aims to develop provably fair standards for its own blockchain. Currently, no such standards have been published.

– The vision of Mobility Open Blockchain Initiative (MOBI) – Vehicle Identity Working Group (VIWG) is to use DLT to make mobility safer, greener, cheaper and more accessible. MOBI is divided into six working groups: 1) Vehicle Identity; 2) Usage-Based Insurance; 3) Electric Vehicle Grid Integration; 4) Connected Mobility and Data Marketplace; 5) Supply Chain and Finance; and 6) Securitization and Smart Contracts. So far only the VIWG has published a draft standard titled Vehicle Identity Standard.

– The Blockchain Engineering Task Force (BETF) is designed to be a standard-setting task force similar to the IETF. Given the lack of public activity in the past two years, this project seems to have been abandoned.

– The Global Blockchain Business Council (GBBC) aims to bring together innovators and thought leaders to further adoption of DLT by engaging and educating regulators, business leaders and lawmakers. The GBBC does not develop any standards by itself.

– The International Association of Trusted Blockchain Applications (INATBA) aims to develop a framework that supports DLT to be mainstreamed and scaled up across multiple sectors of industry. INATBA does not itself publish standards.

– Global Standards One (GS1) maintains global standards for business communication. Its best-known example is the barcode. GS1 promotes the use of its open standards for the standardized exchange of data and item-level tracking on DLT.

– The International Chamber of Commerce (ICC) aims to establish a working group called Digital Standards Initiative (DSI). The purpose of DSI will be to promote and maintain standards-based interoperability (between blockchain and non-blockchain consortia and networks) in global trade.