



IEEE Standard for Tactile Internet—Application Scenarios, Definitions and Terminology, Architecture, Functions, and Technical Assumptions

IEEE Communications Society

Developed by the
Mobile Communication Networks Standards
Committee

IEEE Std 1918.1™-2024

STANDARDS

IEEE Standard for Tactile Internet—Application Scenarios, Definitions and Terminology, Architecture, Functions, and Technical Assumptions

Developed by the

Mobile Communication Networks Standards Committee
of the
IEEE Communications Society

Approved 26 September 2024

IEEE SA Standards Board

Abstract: A framework for the Tactile Internet, including descriptions of various application scenarios, definitions and terminology, functions, and technical assumptions, is defined by this standard. Also included prominently in this framework is a reference architecture, which defines common architectural entities, interfaces between those entities, and the mapping of functions to those entities. Mission critical applications (e.g., manufacturing, transportation, healthcare, and mobility) and noncritical applications (e.g., edutainment and events) are encompassed by the Tactile Internet.

Keywords: 5G, 6G, B5G, beyond 5G, digital twins, extended reality, haptic communication, human-in-the-loop, IEEE 1918.1™, IoT, massive machine-type communications, mMTC, Tactile Internet, URLLC, XR

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

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Published 23 January 2026. Printed in the United States of America.

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PDF: ISBN 979-8-8557-1481-4 STD27501
Print: ISBN 979-8-8557-1482-1 STDPD27501

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Introduction

This introduction is not part of IEEE Std 1918.1-2024, IEEE Standard for Tactile Internet—Application Scenarios, Definitions and Terminology, Architecture, Functions, and Technical Assumptions.

This standard covers the application scenarios, definitions and terminology, architecture, functions, and technical assumptions of the Tactile Internet (TI), which is defined as: A network or network of networks for remotely accessing, perceiving, manipulating or controlling real or virtual objects or processes in perceived real time by humans or machines.

- a) This standard presents the TI architecture, which encompasses different variations of interactions between TI entities. It captures different types of end-to-end bootstrapping between tactile devices and how the infrastructure can adapt to varying performance requirements. This involves both humans and machines operating at the tactile edge.
- b) On each tactile edge, the architecture is designed to integrate the operation of sensors, actuators, controllers, and support engines to enable TI operation of both humans or machines, operating and/or interacting with either real or virtual objects.
- c) This standard is the baseline for future contributions that build on the TI architecture, such as the IEEE 1918.1.1™ haptic codecs standard which, while standalone, was designed to help ensure compatibility and operational synergy with the baseline standard.
- d) The TI architecture is built on ultra-reliable and low-latency capabilities of 5G and beyond networks. The architecture is so developed to capture scenarios with less stringent requirements on latency and/or reliability.
- e) Nine use cases are presented in [Annex A](#) to highlight different scenarios and applications of the TI.
- f) [Annex B](#) details a mapping of the TI standard on a medical use case to further clarify the interaction of different components of the TI architecture.

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IEEE Standard for Tactile Internet—Application Scenarios, Definitions and Terminology, Architecture, Functions, and Technical Assumptions

1. Overview

1.1 Scope

This standard defines a framework for the Tactile Internet (TI), including descriptions of various application scenarios, definitions and terminology, functions, and technical assumptions. This framework prominently also includes a reference architecture, which defines common architectural entities, interfaces between those entities, and the mapping of functions to those entities. The Tactile Internet encompasses mission critical applications (e.g., manufacturing, transportation, healthcare, and mobility), as well as noncritical applications (e.g., edutainment and events).

1.2 Purpose

This standard facilitates the rapid realization of the Tactile Internet as a 5G and beyond application, across a range of different user groups. Additionally, this standard provides the groundwork upon which the Tactile Internet will be formed. To this end, this standard provides a baseline for a pioneering range of further standards that will be created under this working group realizing the key necessary technical capabilities of the Tactile Internet.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall equals is required to*).^{6,7}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should equals is recommended that*).

⁶ The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

⁷ The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

There are no normative references in this standard.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. *The IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.⁸

actuator: A device that performs actuation functions without having a networking module.

actuator gateway (AG): A gateway that provides a generic interface to connect to third party actuation devices and another interface compliant with the standard to connect to actuator nodes (ANs). *See also:* **actuator node (AN)**.

actuator node (AN): A device that performs actuation functions and includes the standard's air interface network connectivity module.

application service providers (ASP): Provider that offers application services.

control plane entities (CPE): Entities performing control plane functionalities.

controller node (CN): Node that runs control algorithms for handling the operation of a system of sensor nodes (SNs) and actuator nodes (ANs). *See also:* **sensor node (SN)**; **actuator node (AN)**.

device application controller (DAC): Controller that adapts configurable parameters based on inputs from the device application monitor (DAM) to meet target performance quality. *See also:* **device application monitor (DAM)**.

device application monitor (DAM): Monitors the application-level end-to-end quality between the communicating tactile devices (TDs). *See also:* **tactile device (TD)**.

gateway node (GN): Node that is configured to serve as a gateway for a domain.

gateway node controller (GNC): A central node that facilitates interoperability with various network domain options.

haptic handshake protocol: The exchange of haptic control data in a Tactile Internet (TI) session, to enable haptic communication among tactile devices (TDs). *See also:* **tactile device (TD)**; **Tactile Internet (TI)**.

⁸*IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the *dictionary sign-in page*.

haptic information: Describes information pertinent to haptic communication in a Tactile Internet (TI) session, such as number of degrees of freedom, ranges of displayable force and torque, and/or position resolution. *See also:* **Tactile Internet (TI)**.

network controller (NC): Node that handles the operation of the tactile edge. *See also:* **tactile edge**.

network monitor: Node that monitors the performance of the network or networks between various nodes, for example gateway nodes (GNs) and tactile devices (TDs). *See also:* **gateway node (GN)**; **tactile device (TD)**.

rendezvous point: A device in the tactile edge that would take over setting up a latching point under the hybrid model. *See also:* **tactile edge (TE)**.

sensor: A device that performs sensing functions without having a networking module.

sensor gateway (SG): A gateway that provides a generic interface to connect to third party sensing devices and another interface compliant with the standard to connect to sensor nodes (SNs). *See also:* **sensor node (SN)**.

sensor node (SN): A device that performs sensing functions and includes the standard's air interface network connectivity module.

support engine: An engine that provides computing and storage resources for improving the performance of the tactile edges. *See also:* **tactile edge (TE)**.

tactile device (TD): A physical or virtual entity which communicates tactile information.

tactile device application manager (TDAM): Entity that monitors the end-to-end performance of the tactile device (TD) and adapts its application-layer configurable parameters. *See also:* **tactile device (TD)**.

tactile device network manager (TDNM): Entity that monitors the performance of the local network between the tactile device (TD) and the gateway node (GN) or among peer TDs and adapts connectivity-related configurable parameters accordingly. *See also:* **gateway node (GN)**; **tactile device (TD)**.

tactile edge (TE): Consists of physical tactile devices (TDs), or a virtual implementation that emulates the functions and interfaces of TDs, which may include a gateway node controller (GNC) and/or a support engine. *See also:* **gateway node controller (GNC)**; **tactile device (TD)**.

Tactile Internet (TI): A network or network of networks for remotely accessing, perceiving, manipulating, or controlling real or virtual objects or processes in perceived real time by humans or machines.

Tactile Internet metadata (TIM): Control information that is used in the haptic handshaking phase.

Tactile Internet session (TIS): Defines the session in which a Tactile Internet (TI) communication between two or more tactile devices (TDs) takes place, spanning the duration from its start (with the bootstrapping process) until its termination. *See also:* **tactile device (TDs)**; **Tactile Internet (TI)**.

tactile network manager (TNM): Entity responsible for control plane processing and intelligence.

tactile service manager (TSM): Entity that defines the characteristics and requirements of the Tactile Internet service between the two tactile edges and distributes this information to key entities in the tactile edges and network domains. *See also:* **tactile edge (TE)**; **Tactile Internet (TI)**.

user plane entities (UPE): Entities performing user plane functionalities.

3.2 Acronyms and abbreviations

A	actuator
AG	actuator gateway
AN	actuator node
ASP	application service providers
CPE	control plane entities
CN	controller node
DAC	device application controller
DAM	device application monitor
DNC	device network controller
DNM	device network monitor
GN	gateway node
GNC	gateway node controller
S	sensor
SG	sensor gateway
SN	sensor node
SE	support engine
TD	tactile device
TDAM	tactile device application manager
TDNM	tactile device network manager
TE	tactile edge
TI	Tactile Internet
TIM	Tactile Internet metadata
TIS	Tactile Internet session
TNM	tactile network manager
TSM	tactile service manager
UPE	user plane entities

4. Tactile Internet (TI) architecture and components

4.1 Introduction

This specification describes the Tactile Internet (TI) architecture, which covers the various system components and inter-network domains. The architecture is based on the following principles and concepts:

- Should be generic, modular, and scalable to support different TI use cases.
- Support interoperability with various network interconnectivity options, including wired and wireless in addition to dedicated and shared network technologies.

- Provide operation and management functionalities in order to meet the end-to-end quality of experience requirements.
- Enable integration with external application service providers.
- Should enable TI communication between tactile devices (TDs), which may be physical or virtual.

The reference architecture is shown in [Figure 1](#). It covers the various modes of interconnectivity network domains between two tactile edges. Each tactile edge consists of one or multiple TDs (T. Yang et al. [B55]⁹), where TDs in tactile edge A communicate tactile/haptic information with TDs in tactile edge B through a network domain. A tactile edge shall consist of physical TDs or a virtual implementation that emulates the functions and interfaces of TDs. The network domain should be able to provide an adequate level of performance under certain conditions in order to meet end-to-end requirements. The network domain can be any, or a combination, of the following:

- Shared wireless network (e.g., cellular 5G radio access and core networks)
- Shared wired network (e.g., Internet core network)
- Dedicated wireless network (e.g., point-to-point microwave or millimeter wave links)
- Dedicated wired network (e.g., point-to-point leased line or fiber-optic links)

The TI reference architecture is composed of the following entities with the listed functionalities in 4.2 and 4.3.

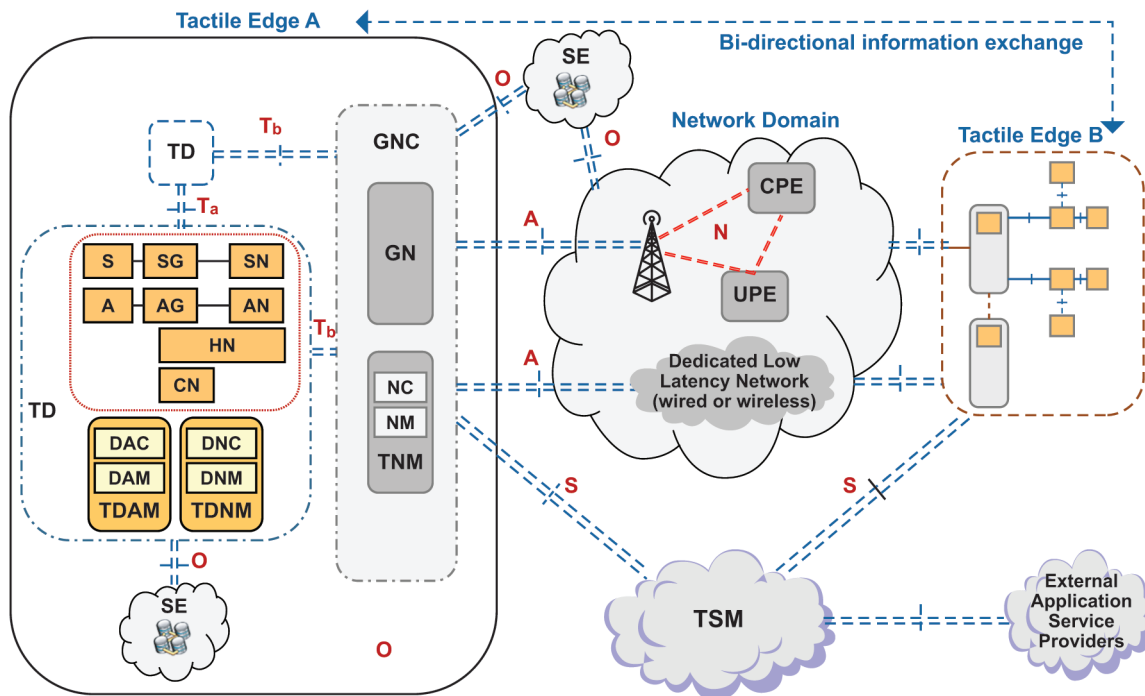


Figure 1—TI Reference Architecture

⁹ The numbers in brackets correspond to those of the bibliography in [Annex C](#).

4.2 Tactile device (TD)

A TD supports one or more of the following functions: sensing, actuation, haptic feedback, or control via one or multiple corresponding entities (R. Stone [B50]). These functions may also be realized via a virtual implementation.

In order to connect sensor (S) to sensor node (SN) or actuator (A) to actuator node (AN), a sensor gateway (SG) or actuator gateway (AG) shall be used, respectively. These gateways provide a generic interface to connect to third-party sensing and actuation devices and another interface compliant with the standard to connect to SNs and ANs.

That is, a TD may consist of sensors and/or actuators to collect data and/or to execute tasks. Further, sensors or actuators can be equipped with network interfaces, which then act as sensor nodes or actuator nodes, directly communicating within the tactile edge. If sensors or actuators have no communication capabilities, they should be connected to a sensor gateway or actuator gateway.

A TD can also serve as a human system interface node (HN), which can convert human input into haptic output, or as a controller node (CN), which runs control algorithms for handling the operation of a system of SNs and ANs, with the necessary air interface network connectivity module.

In terms of monitoring, management, and control functionalities, the TD includes a tactile device application manager (TDAM) and a tactile device network manager (TDNM).

The TDAM monitors the TD's end-to-end performance and adapts its application-layer configurable parameters by communicating with its peer TD in the destination tactile edge. The TDAM consists of device application monitor (DAM) and device application controller (DAC) subentities, which are as follows:

- The DAM monitors the application-level end-to-end quality between the communicating TDs.
- The DAC incorporates algorithms to adapt configurable parameters based on inputs from the DAM to meet the target performance quality.

The TDNM monitors the performance of the local network between the TD and the gateway node (GN) or among peer TDs, and it adapts connectivity-related configurable parameters accordingly. The TDNM consists of device network monitor (DNM) and device network controller (DNC), which are as follows:

- The DNM monitors the performance of the (local) edge network from the TD to the GN.
- The DNC incorporates algorithms to adapt parameters, such as the communications interface technology or parameters in the network stack, based on inputs from the DNM to attain the target performance quality.

4.3 Gateway node controller (GNC)

The gateway node controller (GNC) is a central node as it facilitates interoperability with various network domain options; this is essential for compatibility between the TI standard and other emerging radio standards. To offer more flexibility in implementation, the GNC may be implemented at the tactile edge or in the network domain. In the latter case, the modified architecture is reflected in [Figure 2](#).

The GNC is composed of two entities: the gateway node (GN) and the tactile network manager (TNM).

The GN has enhanced networking capabilities that reside at the interface between a tactile edge and a network domain and is mainly responsible for user plane data forwarding.

The TNM is responsible for control plane processing and intelligence. It is composed of two subentities: the network monitor (NM) and the network controller (NC). They are as follows:

- The NM monitors the performance of the network or networks (in case of multiple connectivity options) between the GN and TDs, between the GN and the network domain, and among peer GNs in different tactile edges.
- The NC handles the operation of the tactile edge by incorporating algorithms to adapt configurable parameters at the various layers of the protocol stack for one or multiple communication interfaces based on inputs from the NM to attain the target performance quality. This can also include intelligence for admission and congestion control, service provisioning, resource management and optimization, connection management, network interface selection, and so forth.

The GNC may alternatively reside in the network domain side if the network domain technology supports TI functionalities and requirements. In this case, the reference architecture is modified as shown in Figure 2. The network domain is generically composed of a radio access point or base station connected logically to control plane entities (CPEs) and user plane entities (UPEs).

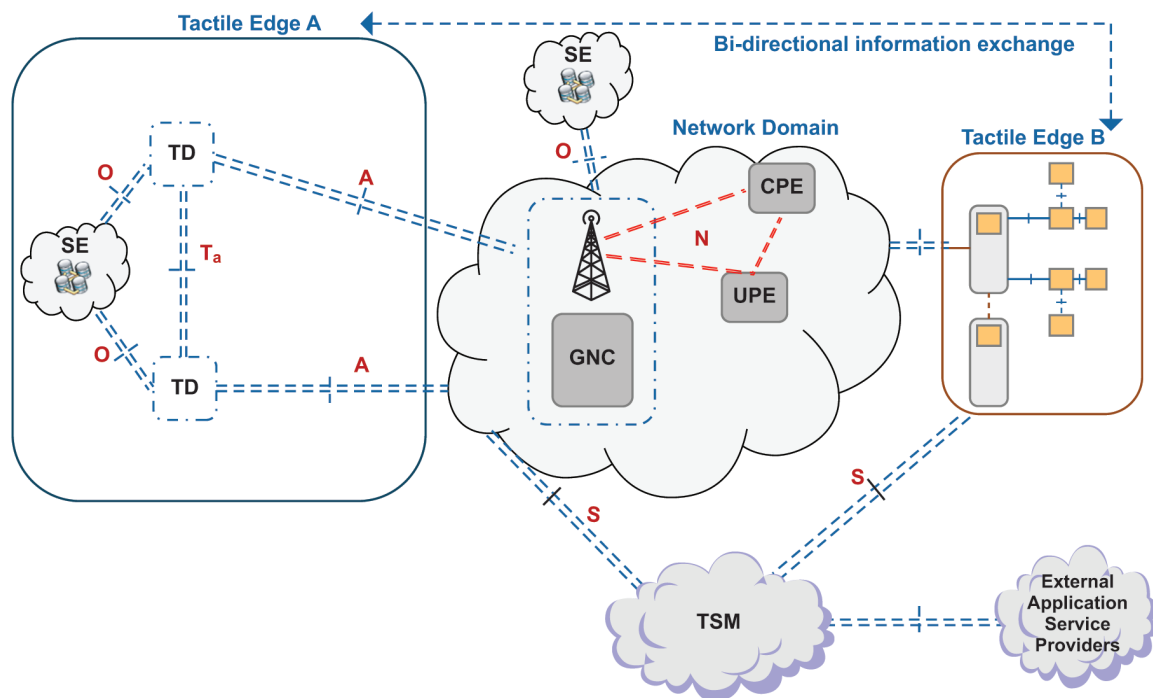


Figure 2—Modified TI reference architecture with the GNC residing in the network domain

Each tactile edge may include multiple TDs that can communicate/cooperate among each other. This can include TD-to-TD direct communication without going through the GNC or the network domain, for example, in use cases that require information sharing among nearby TDs. This can also include cooperation in the form of relaying, whereby, for example, a TD that is close to the GNC can act as a relay to another remote TD to reduce transmission delays, or in the form of distributed computing to reduce processing delays. This TD-to-TD connectivity is reflected in the architecture via a defined interface and would be managed by the GNC node to provide the needed coordination and management.

4.4 Support engine (SE)

The support engine (SE) provides both computing and storage resources for improving the performance of the tactile edges in order to meet the delay and reliability requirements of the end-to-end communication. The SE can run advanced algorithms, employing artificial intelligence (AI) techniques (Maier and Ebrahimzadeh [B42]), among others, to offload processing operations that are too resource or energy intensive to be done in the TD (e.g., haptic rendering, motion-trajectory prediction, and sensory compensation) or the GNC (e.g., prediction and forecast related to traffic, load, quality, and security).

A main goal of the SE is to enable the perception of real-time connectivity using predictive analytics while overcoming the challenges and uncertainties along the path between source and destination TDs, to dynamically predict network load and rate variations over time to optimize resource utilization, and to allow sharing of learned experience about environments among different TDs.

The SE can also provide intelligent caching (D. Liu et al. [B39]) capabilities to reduce the end-to-end traffic load and data transmission delays. The SE can reside locally within the tactile edge to enhance the response rate for requests from TDs or GNC or reside remotely in the public/private cloud or network domain while providing services to the tactile edges and network domain entities.

SEs can function either in centralized or distributed modes with the possibility for multiple SE resource coordination and aggregation.

4.5 Tactile service manager (TSM)

The tactile service manager (TSM) defines the characteristics and requirements of the TI service between the two tactile edges and distributes this information to key entities in the tactile edges and network domains. Communication between the two tactile edges can be unidirectional or bidirectional and can be either based on client-server or peer-to-peer models (R. Maly [B43]).

The TSM can also support functions such as registration and authentication and provides an interface to external TI application service providers (ASPs). TDs may need to subscribe and authenticate with external servers in order to be able run the corresponding applications and initiate end-to-end connections.

In terms of scalability, the reference architecture supports more than two tactile edges communicating among each other over a common network domain or simultaneously over multiple network domains to achieve the target performance requirements discussed in 5.7.

5. Communication interfaces

5.1 Introduction

Interfaces between the TI components that enable the interaction between the architecture entities are described in this section.

This standard distinguishes between the two different scenarios in the architecture depending on where the GNC resides. Figure 1 depicts the architecture when the GNC resides at the tactile edge, whereas Figure 2 depicts the architecture when the GNC resides in the network domain side in which case the network domain should support TD functionalities and requirements. The scenario depicted in Figure 1 will also be referred to as the first scenario; similarly, the second scenario is depicted in Figure 2.

The identified key physical interfaces are as discussed in 5.2, 5.3, 5.4, 5.5, and 5.6.