
**Information technology —
Telecommunications and information
exchange between systems — Local and
metropolitan area networks — Specific
requirements**

**Part 1AX:
Link Aggregation**

*Technologies de l'information — Télécommunications et échange
d'information entre systèmes — Réseaux locaux et métropolitains —
Exigences spécifiques —*

Partie 1AX: Agrégation de lien





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IEEE Standard for Local and metropolitan area networks— Link Aggregation

IEEE Computer Society

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(Revision of
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IEEE Standard for Local and metropolitan area networks— Link Aggregation

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Approved 10 December 2014

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Abstract: MAC-independent Link Aggregation capability and general information relevant to specific MAC types are defined in this standard. Link Aggregation allows parallel full-duplex point-to-point links to be used as if they were a single link and also supports the use of multiple links as a resilient load sharing interconnect between multiple nodes in two separately administered networks.

Keywords: Aggregated Link, Aggregator, Distributed Resilient Network Interconnect, DRNI, IEEE 802®, IEEE 802.1AX™, interconnect, Link Aggregation, Link Aggregation Group, local area network, management, Network-Network Interface, NNI

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This standard contains state-of-the-art material. The area covered by this standard is undergoing evolution. Revisions are anticipated within the next few years to clarify existing material, to correct possible errors, and to incorporate new related material. Information on the current revision state of this and other IEEE 802® standards can be obtained from:

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IEEE Standard for Local and metropolitan area networks— Link Aggregation

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1. Overview

1.1 Scope

Link Aggregation provides protocols, procedures, and managed objects that allow the following:

- One or more parallel instances of full-duplex point-to-point links to be aggregated together to form a Link Aggregation Group (LAG), such that a MAC Client can treat the LAG as if it were a single link.
- A resilient interconnect using multiple full-duplex point-to-point links among one to three nodes in a network and one to three nodes in another, separately administered, network, along with a means to ensure that frames belonging to any given service will use the same physical path in both directions between the two networks.

This standard defines the MAC-independent Link Aggregation capability and general information relevant to specific MAC types that support Link Aggregation. The capabilities defined are compatible with previous versions of this standard.

1.2 Purpose

Link Aggregation allows the establishment of full-duplex point-to-point links that have a higher aggregate bandwidth than the individual links that form the aggregation, and the use of multiple systems at each end of the aggregation. This allows improved utilization of available links in bridged local area network (LAN) environments, along with improved resilience in the face of failure of individual links or systems. In

applications connecting separately administered networks, the networks are isolated from each other's fault recovery events.

1.3 State diagram conventions

This document uses the state diagram conventions of IEEE Std 802.1Q™-2011, Annex E.¹

Should a conflict exist between a state diagram and either the corresponding global transition tables or the textual description associated with the state machine, the state diagram takes precedence.

¹Information on references can be found in Clause 2.

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.

IEEE Std 802[®], IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture.^{2, 3}

IEEE Std 802.1AC[™], IEEE Standard for Local and Metropolitan Area Networks Media Access Control (MAC) Service Definition.

IEEE Std 802.1D[™], IEEE Standard for Local and metropolitan area networks Media Access Control (MAC) Bridges.

IEEE Std 802.1Q[™]-2011, IEEE Standard for Local and metropolitan area networks: Media Access Control (MAC) Bridges and Virtual Bridged Local Area Networks.

IEEE Std 802.3[™]-2012, IEEE Standard for Ethernet.

IETF RFC 1213 (IETF STD 17), Management Information Base for Network Management of TCP/IP-based internets: MIB-II, McCloghrie K., and M. Rose, Editors, March 1991.⁴

IETF RFC 1321, The MD5 Message-Digest Algorithm, R. Rivest. April 1992.

IETF RFC 2578 (STD 58), Structure of Management Information Version 2 (SMIv2), K. McCloghrie, D. Perkins, J. Schoenwaelder. April 1999.

IETF RFC 2579 (STD 58), Textual Conventions for SMIv2, McCloghrie, K., Perkins, D., Schoenwaelder, J., Case, J., Rose, M. and S. Waldbusser, April 1999.

IETF RFC 2580 (STD 58), Conformance Statements for SMIv2, McCloghrie, K., Perkins, D., Schoenwaelder, J., Case, J., Rose, M. and S. Waldbusser, April 1999.

IETF RFC 2863, The Interfaces Group MIB, K. McCloghrie, F. Kastenholz, June 2000.

IETF RFC 3410, Introduction and Applicability Statements for Internet-Standard Management Framework, J. Case, R. Mundy, D. Partain, B. Stewart. December 2002.

IETF RFC 3414 (STD 62), User-based Security Model (USM) for Version 3 of the Simple Network Management Protocol (SNMPv3), U. Blumenthal, B. Wijnen. December 2002.

IETF RFC 3415 (STD 62), View-based Access Control Model (VACM) for the Simple Network Management Protocol (SNMP), B. Wijnen, R. Presuhn, K. McCloghrie, December 2002.

ISO/IEC 10165-4:1992, Information technology—Open Systems Interconnection—Structure of management information—Part 4: Guidelines for the definition of managed objects.⁵

²IEEE publications are available from The Institute of Electrical and Electronics Engineers (<http://standards.ieee.org/>).

³The IEEE standards or products referred to in this clause are trademarks of The Institute of Electrical and Electronics Engineers, Inc.

⁴IETF documents (i.e., RFCs) are available for download at <http://www.rfc-archive.org/>.

⁵ISO/IEC publications are available from the ISO Central Secretariat (<http://www.iso.org/>). ISO publications are also available in the United States from the American National Standards Institute (<http://www.ansi.org/>).