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An Overview of Operations, Administration, and Maintenance (OAM) Mechanisms
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Abstract

Operations, Administration, and Maintenance (OAM) is a general term that refers to detecting and reporting link failures. OAM mechanisms have been defined for various layers in the protocol stack, and are used with a variety of protocols.

This document presents an overview of the OAM mechanisms that have been defined and are currently being defined by the IETF, as well as a comparison to other OAM mechanisms that have been defined by the IEEE and ITU-T.

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1. Introduction

OAM is a general term that refers to detecting and reporting link failures and defects. The term OAM has been used over the years in several different contexts, as discussed in [OAM Soup]. In the context of this document OAM refers to Operations, Administration, and Maintenance. OAM was originally used in the world of telephony, and has been adopted in packet based networks. OAM mechanisms are used in various layers in the protocol stack, and are applied to a variety of different protocols.

The IETF has defined OAM for several protocols, and is currently working on defining several new OAM protocols. These protocols are listed below.

o MPLS LSP Ping, as defined in [LSP Ping] is an OAM mechanism for point to point MPLS LSPs. The IETF is currently working on an extension to the LSP Ping for point to multipoint MPLS - [P2MP Ping].

o Virtual Circuit Connectivity Check (VCCV) for Pseudowires, as defined in [VCCV].

o ICMP Echo request, also known as Ping, as defined in [ICMPv4], and [ICMPv6]. ICMP Ping is a very simple and basic mechanism in failure diagnosis, and is not typically associated with OAM, but it is presented in this document for the sake of completeness, since both LSP Ping and VCCV are to some extent based on ICMP Ping.

o Bidirectional Forwarding Detection (BFD) is a family of standards that are currently being defined by the IETF. BFD is intended to be a generic OAM mechanism that can be used with various encapsulation types, and in various medium types.

o OAM for MPLS-TP is currently being defined in the MPLS workgroup.

In addition to the OAM mechanisms defined by the IETF, the IEEE and ITU-T have also defined various OAM mechanisms. These various mechanisms defined by the three standard organizations are often tightly coupled, and have had a mutual effect on each other. For example, the emerging MPLS-TP OAM is in many ways based on [ITU-T Y.1731]. The ITU-T and IETF have both defined OAM mechanisms for MPLS LSPs, [ITU-T Y.1711] and [LSP Ping]. The following OAM standards by the IEEE and ITU-T are to some extent linked to IETF OAM mechanisms listed above, and are also discussed in this document:

o OAM mechanisms for Ethernet based networks have been defined by both the ITU-T in [ITU-T Y.1731], and by the IEEE in [IEEE 802.1ag]. The IEEE 802.3 standard defines OAM for one-hop Ethernet links [IEEE 802.3ah].

o The ITU-T has defined OAM for MPLS LSPs in [ITU-T Y.1711].

This document summarizes the OAM mechanisms defined in the standards above. The focus is on OAM mechanisms defined by the IETF, compared with the relevant OAM mechanisms defined by the ITU-T and IEEE. We first present a comparison of the terminology used in various OAM

standards, and then summarize the OAM functions that each OAM standard provides.

2. Conventions used in this document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [KEYWORDS].

3. Basic Terminology

3.1. Abbreviations

AIS Alarm Indication Signal

APS Automatic Protection Switching

BDI Backward Defect Indication

BFD Bidirectional Forwarding Detection

CC Continuity Check

CCM Continuity Check Message

CV Connectivity Verification

DM Delay Measurement

DTE Data Terminal Equipment

FDI Forward Defect Indication

FFD Fast Failure Detection

ICMP Internet Control Message Protocol

L2TP Layer Two Tunneling Protocol

LCCE L2TP Control Connection Endpoint

LM Loss Measurement

LSP Label Switching Path

LSR Label Switching Router

MA   Maintenance Association

ME   Maintenance Entity

MEG   Maintenance Entity Group

MEP   Maintenance End Point

MIP   Maintenance Intermediate Point

MP   Maintenance Point

MPLS   Multiprotocol Label Switching

MPLS-TP MPLS Transport Profile

OAM   Operations, Administration, and Maintenance

PE   Provider Edge

PW   Pseudowire

PWE3   Pseudowire Emulation Edge-to-Edge

RDI   Remote Defect Indication

TTSI   Trail Termination Source Identifier

VCCV   Virtual Circuit Connectivity Verification

3.2. Terminology used in OAM Standards

3.2.1. General Terms

A wide variety of terms is used in various OAM standards. Each of the OAM standards listed in the reference section includes a section that defines the relevant terms. A thesaurus of terminology for MPLS-TP terms is presented in [MPLS-TP Term], and provides a good summary of some of the OAM related terminology.

This section presents a comparison of the terms used in various OAM standards, without fully quoting the definition of each term. For a formal definition of each term, refer to the references at the end of this document. The comparison focuses on three basic terms, and is summarized in section 3   ..2.5.

3.2.2. OAM Maintenance Entities

A Maintenance Entity (ME) can be either a point-to-point or a point-to-multipoint relationship between two or more Maintenance Points. The connectivity between these Maintenance Points is mangaged and monitored by the OAM protocol.

The term Maintenance Entity (ME) is defined in ITU-T standards (e.g. [ITU-T Y.1731]). Various terms are used to refer to an ME. For example, in MPLS terminology, an ME is simply referred to as an LSP. BFD does not explicitly use a term that is equivalent to ME, but rather uses the term "session", referring to the relationship between two nodes using a BFD protocol.

3.2.3. OAM Maintenance Points

A Maintenance Point (MP) is a node that uses an OAM protocol. A Maintenance End Point (MEP) is one of the end points of an ME. A Maintenance Intermediate Point (MIP) is a point between two MEPs, that is able to respond to OAM frames, but does not initiate them.

The terms MEP and MIP are defined in ITU-T standards (e.g. [ITU-T Y.1731]). The term Maintenance Point is a general term for MEPs and MIPs, and is used in [IEEE 802.1ag].

3.2.4. OAM Link Failures

The terms Failure, Fault, and Defect are intermittently used in the standards. In some standards, such as [IEEE 802.1ag], there is no distinction between these terms, while in other standards each of these terms refers to a different type of malfunction.

The ITU-T distinguishes between these terms in [ITU-T G.806]. The term Fault refers to an inability to perform a required action, e.g., an unsuccessful attempt to deliver a packet. The term Defect refers to an interruption in the normal operation, such as a consecutive period of time where no packets are delivered successfully. The term Failure refers to the termination of the required function. While a Defect typically refers to a limited period of time, a failure refers to a long period of time.

3.2.5. Summary of OAM Terms used in the Standards

Table 1 provides a comparison of the terminology used in different OAM standards.

	Maintenance Point Terminology	Maintenance Entity Terminology	Link Failure Terminology
ICMPv4 Ping	-Host -Gateway		
ICMPv6 Ping	Node		
BFD	System	Session	-Failure -Session is declared down
LSP Ping	LSR	LSP	-Failure -Fault = typically a local isolated failure
PW VCCV	-PE -LCCE	PW	-Failure -Fault
ITU-T Y.1711	LSR	LSP	-Fault, Defect, Failure: as defined in [ITU-T G.806]
ITU-T Y.1731	-MEP -MIP	ME	-Fault, Defect, Failure: as defined in [ITU-T G.806]
MPLS-TP OAM	-End Point -Intermediate Point	-LSP -PW -Section	-Fault, Defect, Failure: as defined in [ITU-T G.806]
IEEE 802.1ag	-MEP -MIP -MP	ME	-Failure -Fault -Defect
IEEE 802.3ah	DTE	Link	-Failure -Fault

Table 1 Summary of OAM Terms

4. OAM Functions

4.1. ICMP Ping

ICMP provides a bidirectional connectivity check for the Internet Protocol. The originator transmits an echo request packet, and the receiver replies with an echo reply. ICMP ping is defined in two variants, [ICMPv4] is used for IPv4, and [ICMPv6] is used for IPv6.

4.2. Bidirectional Forwarding Detection (BFD)

4.2.1. Overview

While multiple OAM mechanisms have been defined for various protocols in the protocol stack, Bidirectional Forwarding Detection (BFD), currently being defined by the IETF [BFD], defines a generic OAM mechanism that can be run over various encapsulating protocols, and in various medium types. The IETF is working on defining variants of the protocol for IP, for MPLS LSPs, and for PWE3.

BFD includes two main OAM functions, using two types of BFD packets: BFD Control packets, and BFD Echo packets.

4.2.2. BFD Control

BFD supports a unidirectional connectivity check, using BFD control packets. BFD control packets are be sent in one of two modes:

- o Asynchronous mode: in this mode BFD control packets are sent periodically. When the receiver detects that no BFD control packet have been received during a predetermined period of time, a failure is detected.

- o Demand mode: in this mode, BFD control packets are sent on-demand. Upon need, a system initiates a series of BFD control packets to verify the link. BFD control packets are sent independently in each direction of the link.

The transmission interval of BFD packets that are sent periodically, is a result of negotiation between the two systems. Each BFD Control packet includes the desired transmission interval, and the desired reception interval, allowing the two systems to agree on common intervals.

If no BFD Control packets are received during a fixed period of time called the Detection Time, the session is declared to be down. The detection time is a function of the negotiated transmission time, and

a parameter called Detect Mult. Detect Mult determines the number of missing BFD Control packets that cause the session to be declared as down. This parameter is included in the BFD Control packet.

The BFD Control packet also includes two fields that specify the transmitting and receiving systems, called My Discriminator and Your Discriminator, respectively.

4.2.3. BFD Echo

The echo function is a bidirectional connectivity check. A BFD echo packet is sent to a peer system, and is looped back to the originator. The echo function can be used proactively, or on-demand.

4.3. LSP Ping

The IETF defined an OAM mechanisms for MPLS LSPs in [LSP Ping]. LSP ping is used to detect data plain failures in MPLS LSPs. The transmitting LSR sends an echo request to a remote LSR, and in turn receives an echo reply. LSP ping is used in one of two modes:

- o "Ping" mode: In this mode LSP ping is used for end-to-end connectivity verification between two LSRs.

- o "Traceroute" mode: This mode is used for hop-by-hop fault localization.

4.4. PWE3 Virtual Circuit Connectivity Verification (VCCV)

VCCV, as defined in [VCCV], maintains the connectivity status of a pseudowire. VCCV is supported for both MPLS PWs and L2TPv3 PWs.

VCCV supports two possible Connectivity Verification (CV) types, i.e., two modes of operation:

- o ICMP Ping: In this mode the CV is performed using an ICMP ping packet format, as defined in [ICMPv4] or [ICMPv6].

- o LSP Ping: In this mode the LSP Ping packet format, as defined in [LSP Ping] is used for CV.

4.5. ITU-T Y.1711

4.5.1. Overview

As mentioned above (4.3.), the IETF defined LSP Ping as an OAM mechanism for MPLS. The ITU-T has also defined an OAM protocol for

MPLS, defined in [ITU-T Y.1711]. The standard defines mechanisms for connectivity verification and fast failure detection, as well as mechanism for reporting defects that have been identified in an LSP.

4.5.2. Connectivity Verification (CV)

The CV function is used to detect connectivity defects in an LSP. CV frames are sent proactively at a rate of 1 per second. Each frame contains the Trail-Termination Source Identifier (TTSI), indicating the identity of the transmitting LSR.

The CV function can detect any of the following defect conditions.

o Loss of Connectivity Verification (LOCV): A loss of connectivity is detected when no CV OAM packets are received in a period of 3 consecutive transmission periods.

o TTSI Mismatch: A TTSI mismatch is detected when a CV frame with an unexpected TTSI is received.

o TTSI Mismerge: A TTSI mismerge is detected when the CV frames received in a given LSP contain some frame with an expected TTSI, and some frames with an unexpected TTSI.

o Excess: An excess is detected when at least 5 CV frames are received during a period of 3 consecutive transmission periods.

4.5.3. Fast Failure Detection (FFD)

The FFD function is a proactive function, used for fast detection of connectivity defects. While CV is typically sufficient for path failure detection and reporting, protection switching mechanisms typically require faster detection. FFD is very similar to CV in terms of the packet format, and the possible defect conditions, but FFD allows a configurable transmission frequency. The default transmission rate of FFD frames is 20 per second, i.e., every 50 ms, allowing fast detection for protection switching applications.

4.5.4. Forward Defect Indication (FDI)

The FDI function is used by an LSR to report a defect to affected client layers, allowing them to suppress alarms about this defect. An FDI packets are sent at a rate of 1 per second.

4.5.5. Backward Defect Indication (BDI)

The BDI function is used to inform the LSR at an LSP trail termination source point about a defect condition in the forward direction of an LSP. The LSR at the LSP trail termination sink point transmits the BDI to the upstream LSR through the return path. BDI packets are sent at the same transmission rate as FDI.

4.6. ITU-T Y.1731

4.6.1. Overview

The [ITU-T Y.1731] is a protocol for Ethernet OAM. It is presented in this document as a reference point, since the OAM mechanisms that are currently being defined by the IETF for MPLS-TP are in many ways based on this standard. The standard defines various OAM functions, including unidirectional and bidirectional continuity check, and functions for performance monitoring.

4.6.2. ETH-CC

The Ethernet Continuity Check function is a proactive function that allows a MEP to detect loss of continuity with any of the other MEPs in the MEG. This function also allows detection of other defect conditions, such as unintended connectivity between two MEGs. The ETH-CC function is used for one of three possible applications: fault management, performance monitoring (see 4.6.10.), and protection switching.

Continuity Check Messages (CCM) are transmitted periodically at a constant rate. There are 7 possible transmission periods, from 3.33 ms to 10 min. When the ETH-CC function detects a defect, it reports one of the following defect conditions:

- o Loss of continuity (LOC): Occurs when at least when no CCM messages have been received from a peer MEP during a period of 3.5 times the configured transmission period.

- o Unexpected MEG level: The MEG level is a 3-bit number that defines the level of hierarchy of the MEG. This defect condition occurs when a CCM is received from a peer MEP with a MEG level that is lower than the expected MEG level.

- o Mismerge: Occurs when a CCM is received from a peer MEP with an unexpected MEG ID.

- o Unexpected MEP: Occurs when a CCM is received from a peer MEP with an unexpected transmitting MEP ID.

- o Unexpected period: Occurs when the transmission period field in the CCM does not match the expected transmission period value.

4.6.3. ETH-LB

The Ethernet loopback function verifies connectivity with a peer MEP or MIP. The loopback function is performed on-demand, by sending a loopback message (LBM) to the peer MEP or MIP. The peer node then responds with a loopback reply (LBR).

More precisely, it is used for one of two purposes:

- o Bidirectional connectivity test.

- o Bidirectional in-service / out-of-service test. The in-service mode refers to a test that is run under traffic, while the out-of-service test requires other traffic to be halted.

4.6.4. ETH-TST

The test function is very similar to the loopback function, but is unidirectional, i.e., the ETH-TST PDUs are terminated by the receiver rather than being looped back to the sender.

4.6.5. ETH-LT

The Ethernet linktrace is an on-demand function that is used for path discovery to a given target, or for locating a failure in a broken path.

4.6.6. ETH-AIS

The Alarm Indication Signal indicates that a MEG should suppress alarms about a defect condition at a lower MEG level, i.e., since a defect has occurred in a lower hierarchy in the network, it should not be reported by the current node.

A MEP that detects a failure periodically sends AIS messages to higher hierarchies. AIS messages are sent periodically at a recommended rate of 1 packet per second, until the defect condition is resolved.

4.6.7. ETH-LCK

The lock function is used for administrative locking. A MEP can initiate administrative locking, resulting in interruption of data, e.g., for out-of-service ETH-LB or ETH-TST.

A MEP that initiates an administrative locking notifies its peer MEPs to halt all relevant traffic until administrative/diagnostic condition is removed. ETH-LCK frames are used to report to higher MEG levels about the lock. The LCK frame, much like an AIS frame, indicates to the receiving MEP that it should suppress alarms about the locked link.

4.6.8. ETH-RDI

The Remote Defect Indication allows the sender to indicate that it encountered a defect conditions. The receiving MEPs are then aware that there is a defect condition in the MEG.

4.6.9. ETH-APS

The Y.1731 standard defines the frame format for Automatic Protection Switching frames. The protection switching operations are defined in other ITU-T standards.

4.6.10. ETH-LM

The loss measurement function allows a MEP to measure the packet loss rate from/to a given MEP in the MEG. Each MEP maintains counters of transmitted and received in-profile packets to/from each of its peer MEPs. These counters are incorporated in the ETH-LM frames, allowing the MEPs to compute the packet loss rate.

The ETH-LM function measures the far-end loss, referring to traffic FROM the MEP to its peer, as well as the near-end loss, referring to traffic from the peer MEP TO the local MEP.

ETH-LM is performed in one of two possible modes:

o Single-ended LM: in this mode loss measurement is performed on-demand. The initiator sends an LM message (LMM) to its peer MEP, and the peer responds with an LM reply (LMR).

o Dual-ended LM: in this mode loss measurement is performed proactively. The continuity check message (CCM) is used for proactive LM. The LM counters are piggy-backed into the CCM, and allow proactive loss measurement.

4.6.11. ETH-DM

The delay measurement function is an on-demand function that allows a MEP to measure the frame delay and frame delay variation to a peer MEP.

ETH-DM can be performed in one of two modes of operation:

- One-way DM: in this mode, a MEP transmits a 1DM frame containing the time of its transmission, TxTimeStampf. The receiving MEP receives the 1DM frame and records the time of reception, RxTimef. The receiving MEP can then compute the one-way delay by: RxTimef - TxTimeStampf.

- Two-way DM: in this mode, a MEP transmits a delay measurement message (DMM) containing its transmission time, TxTimeStampf. The peer MEP receives the DMM and responds with a delay measurement reply (DMR). Upon receiving the DMR, the initiating MEP records the time of its reception, RxTimef, and computes the round trip delay by: RxTimef - TxTimeStampf.

Each MEP maintains a time-of-day clock that is used for timestamping delay measurement frames. It should be noted that in one-way DM it is implicitly assumed that the clocks of the two peer MEPs are synchronized by a time synchronization protocol.

4.7. IEEE 802.1ag

4.7.1. Overview

While the [ITU-T Y.1731] was defined in the ITU-T, the IEEE defined the [IEEE 802.1ag] as a standard for connectivity fault management in Ethernet based networks. While the two standards are to some extent overlapping, they can also be viewed as two complementary parts of a single Ethernet OAM picture. The two standards use a common packet format. There are a few differences between the two standards in terms of terminology: the term MEG level, used in Y.1731, as referred to as Maintenance Domain level in 802.1ag; the Y.1731 standard uses the term MEG, while the 802.1ag equivalent is Maintenance Association (MA).

While Y.1731 defines multiple OAM functions (see section 4.6), the 802.1ag standard focuses on three main OAM functions: continuity check, loopback, and linktrace, and defines them with great detail.

4.7.2. Continuity Check

See 4.6.2.

4.7.3. Loopback

See 4.6.3.

4.7.4. Linktrace

See 4.6.5.

4.8. IEEE 802.3ah

4.8.1. Overview

The [IEEE 802.3ah] defines an Ethernet link-layer OAM, for single-hop Ethernet links. The OAM functions in this standard are described below.

4.8.2. Remote Failure Indication

This function allows a node to notify a peer about a defect in the receive path. Some physical interfaces allow unidirectional traffic, where even if one direction of the link fails, the reverse direction can still be used to convey the remote failure indication.

4.8.3. Remote Loopback

The remote loopback function provides a diagnostic mode that is used to verify the link connectivity, and to measure the packet loss rate. When a bridge interface is configured to loopback mode, all incoming traffic through the interface is looped and sent back to the originator.

4.8.4. Link Monitoring

Link monitoring provides an event notification function, allowing peer devices to communicate defect conditions and diagnostic information.

4.9. MPLS-TP OAM

4.9.1. Overview

The MPLS-TP is currently working on defining the OAM requirements and mechanisms for MPLS-TP. The requirements of MPLS-TP OAM are defined in [MPLS-TP OAM], and are described below. It is noted that these requirements are in many ways similar to the requirement of Ethernet OAM, as defined in [ITU-T Y.1731].

4.9.2. Continuity Checks

The continuity check is a proactive function that allows an End Point to determine whether or not it receives traffic from its peer End Points.

4.9.3. Connectivity Verification

The connectivity verification is a function that allows an End Point to verify its connectivity to a peer node. The connectivity check is performed by sending a connectivity verification PDU to the peer node, and receiving a reply within an expected time frame. This function can be performed proactively or on-demand.

4.9.4. Diagnostic Tests

This function allows an End Point to perform an on-demand test, e.g., for bandwidth measurement.

4.9.5. Route Tracing

This on-demand function is used for path discovery and for locating link failures.

4.9.6. Lock Instruct

The lock instruct function allows an End Point to instruct its peers to enter an administrative status where all traffic is halted except the test traffic and OAM PDUs.

4.9.7. Lock Reporting

This function allows an Intermediate Point to report to an End Point about a lock condition.

4.9.8. Alarm Reporting

This function allows an Intermediate Point to report to an End Point about a defect condition.

4.9.9. Remote Defect Indication

This is a proactive function that allows the sender to indicate that it encountered a defect conditions.

4.9.10. Client Failure Indication

This function allows the MPLS-TP network to relay information about a fault condition in a client network, allowing the failure indication to propagate from end to end over the MPLS-TP network.

4.9.11. Packet Loss Measurement

This function measures the packet loss ratio between two peer End Points. It can be performed proactively or on-demand.

4.9.12. Packet Delay Measurement

This function measures the frame delay between two peer End Points. Two modes of operation are supported, one-way DM, and two-way DM.

4.10. Summary of OAM Functions

Table 2 summarizes the OAM functions that are supported in each of the standards that were analyzed in this section.

Standard	Unidirectional Connectivity Check	Bidirectional Connectivity Check	Path Discovery	Defect Indications	Performance Monitoring	Other Functions
ICMP Ping		Echo				
BFD	BFD Control	BFD Echo				
LSP Ping		"Ping" mode	"Traceroute" mode			
PW VCCV		VCCV				

ITU-T Y.1711	-CV -FFD					
ITU-T Y.1731	ETH-CC	ETH-LB	ETH-LT	-ETH-RDI -ETH-AIS	-ETH-LM -ETH-DM	-ETH-LCK -ETH-APS -ETH-TST
IEEE 802.1ag	CC	Loopback	Linktrace			
IEEE 802.3ah		Remote Loopback		-Remote Failure Indication -Link Monitoring		
MPLS-TP OAM	CC	CV	Route Tracing	-Alarm Reporting -Client Failure Indication -Remote Defect Indication	-LM -DM	-Diagnostic Tests -Lock

Table 2 Summary of OAM Functions

4.11. Summary of Unidirectional Connectivity Check Mechanisms

A key element in some of the OAM standards that are analyzed in this document is the unidirectional connectivity check. It is thus interesting to present a more detailed comparison of the connectivity check mechanisms defined in OAM standards. Table 3 can be viewed as an extension of Table 2, but is presented separately for convenience. The table compares the OAM standards that support a unidirectional connectivity check. MPLS-TP is not included in the comparison, as the continuity check mechanism in MPLS-TP has not yet been defined.

The "Tx Interval" column in the table specifies the period between two consequent message transmissions, while the "Source Identifier" column specifies the name of the field in the OAM packet that is used as the identifier of the transmitter. The "Error Codes" column specifies the possible error codes when the unidirectional connectivity check detects a failure.

	Mechanism	Tx Interval	UC/MC	Source Identifier	Error Codes
BFD	BFD Control	Negotiated during session	UC	My Discriminator	Control Detection Time Expired
ITU-T Y.1711	CV FFD	CV: 1s FFD: parameter, default: 50 ms	UC	TTSI	-Loss of CV (LOCV) -TTSI Mismatch -TTSI Mismerge -Excess
ITU-T Y.1731 / IEEE 802.1ag	CC	7 possible periods: 3 1/3 ms 10 ms 100 ms 1 s 10 s 1 min 10 min	UC/MC	MEP ID	-Loss of Continuity(LOC) -Unexpected MEG level -Mismerge -Unexpected MEP -Unexpected period

Table 3 Summary of OAM Terms

5. Security Considerations

There are no security implications imposed by this document.

6. IANA Considerations

There are no new IANA considerations implied by this document.

7. Acknowledgments

This document was prepared using 2-Word-v2.0.template.dot.

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