

Internet Area Working Group  
Internet-Draft  
Intended status: Standards Track  
Expires: 28 August 2026

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24 February 2026

ICMP extension to include underlay information  
draft-jags-intarea-icmp-ext-underlay-info-04

## Abstract

Network operators managing overlay networks require visibility into underlay network hops during traceroute operations from overlay endpoints. This document defines an ICMP extension object, the Underlay Information Object (UIO), which allows underlay head-end nodes to encapsulate underlay error information within ICMP error messages. This mechanism provides overlay operators with crucial visibility into underlay network paths for troubleshooting.

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## 1. Introduction

The mechanism for ICMP messages to carry additional information is defined in [RFC4884]. ICMP message extensions that enable ICMP messages to carry additional information about the system where an error occurred are defined in [RFC5837], [RFC8335], and [RFC8883]. These extensions transmit enhanced diagnostic information to the source node.

Network operators who manage both overlay and underlay networks, such as those operating VPN segments connected through an SRv6 core network, require the ability to trace paths through the underlay infrastructure. Currently, when performing traceroute operations from an overlay endpoint, operators lack visibility into the underlay path and cannot identify the specific underlay node where a failure occurred. For instance, imagine a VPN service (overlay) running over an SRv6 network (underlay). If a packet gets dropped within the SRv6 network, the VPN operator currently has no direct way to pinpoint the exact underlay node causing the issue.

The Underlay Information Object (UIO) defined in this document addresses this operational requirement by enabling underlay head-end nodes to include underlay-specific diagnostic information in ICMP error messages sent to overlay endpoints, thereby providing crucial visibility for troubleshooting.

### 1.1. ICMP Error Message Origination and UIO

The mechanism described in this document, where an underlay head-end node encapsulates underlay error information into a new ICMP error message destined for an overlay endpoint, deviates from existing ICMP error message origination rules. Specifically, [RFC4443], Section 2.4, Rule (e.1) states that "An ICMPv6 error message MUST NOT be originated as a result of receiving the following: (e.1) An ICMPv6 error message." A similar restriction exists for ICMPv4 in [RFC792].

This document defines a specific exception to this rule for the purpose of the Underlay Information Object (UIO). The UIO mechanism is designed to provide critical diagnostic visibility into underlay network failures for overlay operators, a function not adequately served by existing ICMP mechanisms. The underlay head-end node acts as an intermediary, translating an underlay error into a new error message containing encapsulated UIO information for the overlay, rather than simply forwarding the original error message. This controlled origination of a new ICMP error message, triggered by an underlay ICMP error message, is essential for the UIO's intended troubleshooting workflow. Therefore, this document updates [RFC4443] to accommodate this specific behavior.

However, permitting this exception introduces new challenges that must be carefully addressed. Because UIO creates an intentional pathway for underlay diagnostic information to cross into the overlay domain, it raises the following concerns:

- \* Information Leakage: Unrestricted encapsulation could expose underlay topology, routing state, or configuration details beyond what is necessary for troubleshooting.
- \* Amplification and Abuse: Without constraints, a small probe could trigger disproportionately large ICMP responses containing UIO, enabling amplification attacks or reconnaissance of underlay infrastructure.
- \* Recursive Error Loops: An underlay head-end node generating a new ICMP error in response to a received ICMP error that itself contains a UIO could create infinite error loops.
- \* Content Integrity: Aggregating information from multiple underlay sources into a single UIO could produce misleading diagnostic data.

To mitigate these risks, this document defines strict content restrictions (Section 3.3) that constrain which ICMP message types and extension objects may be encapsulated within a UIO, enforce message size limits, prevent loops and recursion, and ensure each UIO originates from a single underlay source. These restrictions are essential to making the error origination exception safe for deployment.

## 2. Conventions and Definitions

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

This document uses the following terms:

**Overlay Network:** A virtual network built on top of an existing underlying network infrastructure, often providing services like VPNs or tunnels.

**Underlay Network:** The physical or logical network infrastructure over which an overlay network operates, responsible for forwarding packets between overlay endpoints.

**Overlay Endpoint:** A device or system that terminates an overlay network segment and originates or receives traffic for the overlay.

**Underlay Head-End Node:** The node in the underlay network responsible for encapsulating overlay traffic and often the first point of contact for an overlay packet entering the underlay.

### 3. Underlay Information Object

This section defines a new ICMP extension object called Underlay Information Object (UIO) that is encoded as part of ICMP extension message. A new Class-Num value TBA (To Be Assigned) is assigned to identify the UIO. As per [RFC4884], this object MAY be appended to one of the following ICMP messages:

- \* ICMPv4 Time Exceeded
- \* ICMPv4 Destination Unreachable
- \* ICMPv4 Parameter Problem
- \* ICMPv6 Time Exceeded
- \* ICMPv6 Destination Unreachable

#### 3.1. UIO Object Format

The UIO ICMP extension object has the following format:

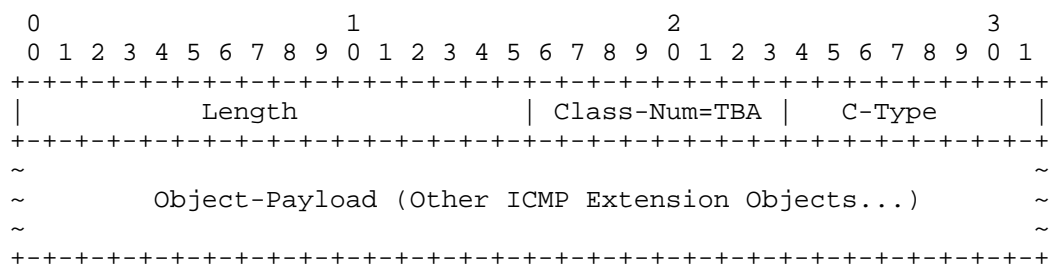


Figure 1: Underlay Information Object Format

**Length (16 bits):** The length of this object, measured in octets, including the object header and object payload. The length MUST be a multiple of 4 octets and MUST be at least 8 octets.

**Class-Num (8 bits):** The ICMP extension object class number that

identifies this as a UIO object. IANA is requested to assign a value from the "ICMP Extension Object Classes and Class Sub-types" registry (see Section 5).

C-Type (8 bits): The object sub-type. This document defines C-Type value 0. Additional C-Type values may be defined in future documents. Implementations MUST set this field to 0 and SHOULD ignore the value upon receipt.

Object-Payload (variable length): Contains one or more ICMP Extension Objects that provide information about underlay nodes. The payload MUST contain at least one ICMP extension object. Each encapsulated ICMP extension object MUST be formatted according to [RFC4884] and the specifications for that particular object class.

This ICMP extension object acts as an envelope to carry other ICMP extension objects related to the underlay. Primarily, the UIO ICMP extension object is encoded in the ICMP extension message by the underlay head-end when it receives an ICMP error message from one of its intermediate nodes.

This UIO ICMP extension object can encapsulate one or more relevant ICMP extension objects that are related to the underlay node. When the underlay head-end encodes its ICMP extension object, the first object MUST contain the ICMP extension object that carries IP address or the hostname of the node where the initial ICMP error was generated. The ICMP extension objects encoded within the UIO ICMP extension objects can belong to any address family, irrespective of the address family of the source node that decapsulates the UIO ICMP extension objects, as opposed to what is stated in Section 4.2 of [RFC5837].

If the node decoding the ICMP extension header does not recognize the UIO ICMP extension object, it SHOULD ignore this object and continue processing the other objects.

### 3.2. Underlay Information Object Encoding Process

When an underlay head-end node receives an ICMP error message from an underlay node and needs to forward information about this error to an overlay endpoint, it follows this process:

1. The underlay head-end node constructs an ICMP error message destined for the overlay endpoint.
2. The node appends a UIO ICMP extension object to this ICMP error message according to the procedures defined in [RFC4884].

3. Within the UIO object payload, the node includes one or more ICMP extension objects that carry information about the underlay node where the original error occurred.
4. The first ICMP extension object within the UIO payload MUST contain addressing information (e.g., using the Interface Information Object defined in [RFC5837]) that identifies the underlay node that generated the original error. This ensures that the most critical diagnostic information for pinpointing the failure source is immediately available.
5. Additional ICMP extension objects MAY be included to provide supplementary diagnostic information about the underlay path.
6. The encapsulated ICMP extension objects within the UIO may belong to any address family, regardless of the address family used between the underlay head-end and the overlay endpoint.
7. The total length of the ICMP message, including all extensions, MUST NOT exceed 576 octets for IPv4 or 1280 octets for IPv6 (the minimum reassembly buffer sizes defined in [RFC791] and [RFC8200], respectively).

Implementations SHOULD provide configuration options to control which underlay information is included in UIO objects, considering security and privacy implications discussed in Section 4.

### 3.3. Content Restrictions and Filtering

The Underlay Information Object crosses administrative domain boundaries between overlay and underlay networks. To prevent confusion, information leakage, and potential abuse, strict restrictions apply to the content that can be encapsulated within a UIO.

#### 3.3.1. Permitted ICMP Message Types

An underlay head-end node MUST only encapsulate ICMP error messages that indicate packet forwarding failures in the underlay network.

The following ICMP message types MAY be encapsulated:

- \* ICMPv4 Type 11 (Time Exceeded)
- \* ICMPv4 Type 3 (Destination Unreachable)
- \* ICMPv6 Type 1 (Destination Unreachable)

- \* ICMPv6 Type 2 (Packet Too Big)

- \* ICMPv6 Type 3 (Time Exceeded)

Other ICMP messages MUST NOT be included under UIO envelope. The overlay host that receives the UIO messages other than the listed above MUST be dropped.

### 3.3.2. Permitted Extension Objects

The UIO object payload SHOULD contain only ICMP extension objects that provide diagnostic information about the underlay node that generated the original ICMP error message.

The following extension object classes are RECOMMENDED for inclusion:

- \* Interface Information Object (Class-Num 2) [RFC5837]

- \* Node Identification Object (Class-Num 5)  
[I-D.ietf-intarea-extended-icmp-nodeid]

- \* MPLS Label Stack Object (Class-Num 1) [RFC4950]

Future IETF standards-track ICMP extension objects with diagnostic purpose MAY be included, subject to the restrictions below.

Other ICMP extension objects MUST NOT be included under UIO envelope. The overlay host that receives the UIO messages other than the listed above MUST be dropped.

### 3.3.3. Size Constraints

The total size of an ICMP message containing a UIO object MUST NOT exceed the minimum reassembly buffer size for the IP version being used:

- \* 576 octets for IPv4 [RFC791]

- \* 1280 octets for IPv6 [RFC8200]

To ensure sufficient space for the ICMP header, original packet excerpt (128 octets as per [RFC4884]), and potential additional extension objects outside the UIO, implementations SHOULD limit the UIO object payload to a maximum of 512 octets.

If the underlay ICMP error message contains extension objects that would cause the UIO payload to exceed this limit, the underlay head-end node SHOULD:



1. Include the most critical diagnostic information first (per Section 3.2, the Node Identification Object SHOULD be first)
2. Truncate or omit less critical extension objects
3. NOT fragment the ICMP message

#### 3.3.4. Loop and Recursion Prevention

An underlay head-end node MUST NOT generate an ICMP error message in response to receiving an ICMP error message that contains a UIO object in its extension structure.

This applies regardless of whether the underlay head-end node would normally generate an error (e.g., due to TTL expiration, routing failure, etc.). The packet MUST be silently discarded.

Additionally, as specified in Section 3.3.2, nested UIO objects (a UIO containing another UIO in its payload) MUST NOT be created.

#### 3.3.5. Single Source Principle

Each UIO object MUST contain ICMP extension objects from exactly one underlay node (the node that generated the original ICMP error message received by the underlay head-end).

An underlay head-end node MUST NOT aggregate ICMP extension objects from multiple underlay nodes into a single UIO object, even if multiple errors were encountered for related packets.

If the underlay head-end needs to communicate errors from multiple underlay nodes, it MUST generate separate ICMP messages, each with its own UIO object.

### 4. Security Considerations

The UIO extension introduces several security considerations that implementations and operators must address:

#### 4.1. Information Disclosure

The UIO extension reveals information about the underlay network topology and addressing to overlay endpoints. In many deployments, the overlay and underlay networks are operated by different administrative entities, and underlay topology information may be considered sensitive.

Implementations MUST provide configuration options to control the generation of UIO extensions. The default configuration MUST disable UIO generation. Operators SHOULD enable UIO only for authenticated and authorized overlay endpoints or networks. The specific mechanisms for such authentication and authorization are outside the scope of this document but are crucial for secure deployment.

#### 4.2. Privacy Considerations

Underlay information may reveal details about network architecture, capacity, and routing that could be exploited for reconnaissance or targeted attacks. Operators SHOULD carefully consider which underlay information to expose through UIO extensions.

#### 4.3. Message Size and Amplification

Including UIO extensions increases ICMP message size. Implementations MUST enforce the message size limits specified in Section 3.2 to prevent fragmentation issues and potential amplification attacks.

#### 4.4. Spoofing and Forgery

As with all ICMP messages, UIO extensions are subject to spoofing attacks. The authenticity and integrity of UIO information cannot be guaranteed without additional security mechanisms. Implementations and operators SHOULD NOT use UIO information for security-critical decisions.

#### 4.5. Intended Use

The extensions defined in this document are intended exclusively for administrative debugging and troubleshooting purposes. They provide diagnostic information in ICMP responses and are not designed for use in production protocols, automation systems, or non-debugging applications.

#### 4.6. Rate Limiting

Implementations SHOULD apply rate limiting to the generation of ICMP messages containing UIO extensions to prevent resource exhaustion and potential denial-of-service conditions.

#### 4.7. Content Filtering and Sanitization

The UIO mechanism crosses administrative domain boundaries between overlay and underlay networks. This "crossing of streams" creates potential security and operational risks if content is not carefully filtered.

##### 4.7.1. Information Disclosure Risks

Including inappropriate ICMP message types or extension objects in UIO could disclose:

- \* Underlay network topology beyond what is necessary for troubleshooting
- \* Underlay routing information (e.g., via redirect messages)
- \* Underlay control plane state (e.g., via router discovery)
- \* Proprietary or sensitive configuration details

The content restrictions in Section 3.3 are designed to limit information disclosure to what is necessary for diagnosing forwarding failures. Implementations **MUST** enforce these restrictions as security boundaries.

Operators **SHOULD NOT** enable UIO for destinations outside their administrative control without careful consideration of what information will be disclosed.

##### 4.7.2. Amplification and Abuse Risks

Without content and rate restrictions, UIO could be abused for:

- \* Amplification attacks (small query triggers large UIO response)
- \* Reconnaissance of underlay infrastructure
- \* Resource exhaustion at underlay head-end nodes
- \* Information gathering about overlay-underlay relationships

The following mechanisms mitigate these risks:

- \* Size limits (Section 3.3.3) prevent excessive amplification
- \* Content restrictions (Section 3.3.1, Section 3.3.2) limit reconnaissance value

- \* Loop prevention (Section 3.3.4) prevents recursive amplification
- \* Rate limiting (Section 4.6) prevents resource exhaustion

Implementations MUST enforce these protections and MUST NOT provide configuration options that bypass them (e.g., removing size limits or allowing nested UIO).

#### 4.8. Operational Security

Network operators deploying UIO should:

- \* Start with UIO disabled and enable only for specific, authorized overlay destinations
- \* Monitor UIO generation rates and investigate anomalies
- \* Regularly review what information is being disclosed via UIO
- \* Coordinate with overlay operators to understand their diagnostic needs and security requirements
- \* Document the security implications of UIO in their deployment (e.g., what underlay information is visible to overlay operators)

In multi-tenant environments, operators should carefully consider whether underlay diagnostic information should be visible to all tenants or restricted based on tenant relationships and SLAs.

### 5. IANA Considerations

#### 5.1. ICMP Extension Object Class

IANA is requested to assign a new value from the "ICMP Extension Object Classes and Class Sub-types" registry (<https://www.iana.org/assignments/icmp-parameters/>) for the Underlay Information Object (UIO) as follows:

Class Value	Class Name	Reference
TBA	Underlay Information Object	[This RFC]

Table 1

## 5.2. C-Type Values

IANA is requested to establish a new sub-registry titled "Underlay Information Object C-Types" under the "ICMP Extension Object Classes and Class Sub-types" registry.

Initial values for this registry are as follows:

C-Type Value	Description	Reference
0	Reserved/Unspecified	[This RFC]
1-246	Unassigned	
247-255	Reserved for Private or Experimental Use	[This RFC]

Table 2

The registration procedure for values 1-246 is Standards Action or IESG Approval as defined in [RFC8126].

## 6. Operational Considerations

### 6.1. Configuration

Operators SHOULD carefully configure which overlay endpoints or networks are authorized to receive UIO information. To effectively manage the security and operational aspects of UIO, implementations SHOULD provide configuration options, including but not limited to:

- \* Enable/disable UIO generation (default: disabled)
- \* Whitelist of authorized overlay prefixes
- \* Maximum UIO object payload size
- \* Rate limiting parameters

### 6.2. Troubleshooting Workflow

The intended use case for UIO is as follows:

1. An overlay operator performs traceroute from an overlay endpoint.
2. The traceroute reveals a failure point in the path.

3. ICMP error messages include UIO extensions with underlay details.
4. The overlay operator uses this information to coordinate with the underlay operator for problem resolution.

### 6.3. Multi-Vendor Interoperability

Implementations SHOULD be tested for interoperability, particularly when overlay and underlay equipment are from different vendors.

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### 7.1. Normative References

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- [IANA.address-family-numbers]  
IANA, "Address Family Numbers", <<http://www.iana.org/assignments/address-family-numbers>>.

## Appendix A. Appendix

### A.1. UIO ICMP Extension Message Examples

This section lists examples of UIO encoding.

#### A.1.1. UIO carrying IPv6 information to the IPv4 source

In this example, a host receives an IPv4 ICMPv4 Time Exceeded error message in response to an ICMP Echo Request as part of the traceroute application. It also contains a UIO ICMP extension object with IPv6 interface address information as follows.

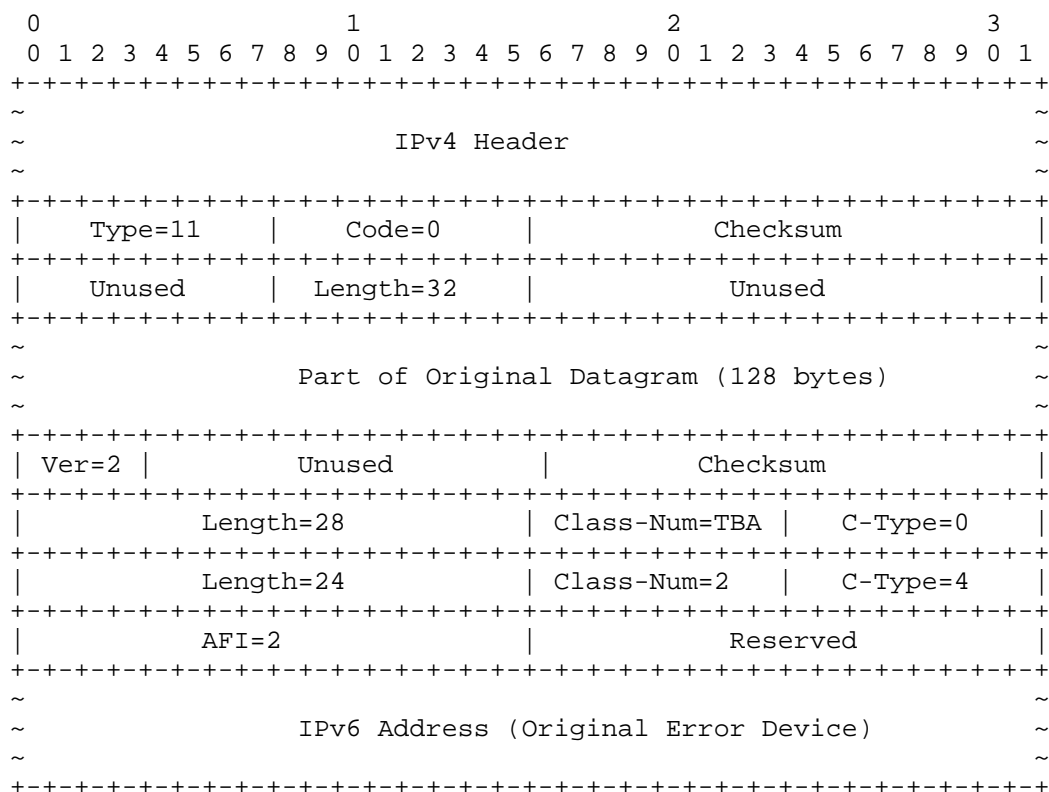


Figure 2: ICMPv4 packet carrying UIO ICMP extension

The traceroute application displays the IPv6 Address in the UIO to allow an administrator to trace the underlay path of the route being traced.

#### A.1.2. UIO carrying IPv4 information to the IPv6 source

In this example, a host receives an IPv6 ICMPv6 Time Exceeded error message in response to an ICMP Echo Request as part of the traceroute application. It contains a UIO ICMP extension object with IPv4 interface address information as follows.



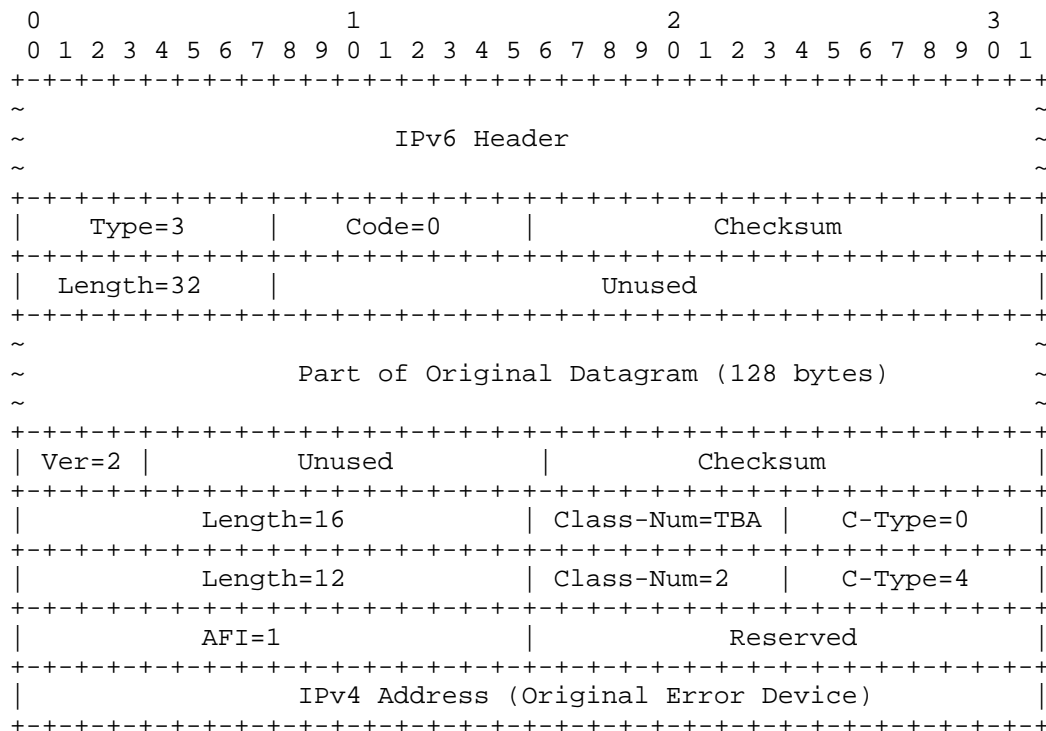


Figure 3: UIO carrying IPv4 information to the IPv6 source

The traceroute application displays the IPv4 Address in the UIO to allow an administrator to trace the underlay path of the route being traced.

#### Acknowledgments

The authors thank the contributors listed below for their substantial input and review.

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