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Datagram PLPMTUD for UDP Options

Abstract

This document specifies how a UDP Options sender implements Datagram Packetization Layer Path Maximum Transmission Unit Discovery (DPLPMTUD) as a robust method for Path Maximum Transmission Unit discovery. This method uses the UDP Options packetization layer. It allows an application to discover the largest size of datagram that can be sent across the network path. It also provides a way to allow the application to periodically verify the current maximum packet size supported by a path and to update this when required.

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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This Internet-Draft will expire on 4 January 2024.

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1. Introduction

The User Datagram Protocol [RFC0768] offers a minimal transport service on top of IP and is frequently used as a substrate for other protocols. Section 3.5 of UDP Guidelines [RFC8085] recommends that applications implement some form of Path MTU discovery to avoid the generation of IP fragments:

"Consequently, an application SHOULD either use the path MTU information provided by the IP layer or implement Path MTU Discovery (PMTUD)".

The UDP API [RFC8304] offers calls for applications to receive ICMP Packet Too Big (PTB) messages and to control the maximum size of datagrams that are sent, but it does not offer any automated mechanisms for an application to discover the maximum packet size

supported by a path. Upper Layer protocols, which includes applications, can implement mechanisms for Path MTU discovery above the UDP API.

Packetization Layer Path MTU Discovery (PLPMTUD) [RFC4821] describes a method for a Packetization Layer (PL) to search for the largest Packetization Layer PMTU (PLPMTU) supported on a path. Datagram PLPMTUD (DPLPMTUD) [RFC8899] specifies this support for datagram transports. PLPMTUD and DPLPMTUD gain robustness by using a probing mechanism that does not solely rely on ICMP PTB messages and works on paths that drop ICMP PTB messages.

UDP Options [I-D.ietf-tsvwg-udp-options] supplies functionality that can be used to implement DPLPMTUD within the transport service or in an Upper Layer protocol (including an application) that uses UDP Options. This document specifies how DPLPMTUD using UDP Options is implemented (Section 6.1 of [RFC8899]).

Implementing DPLPMTUD within the transport service above UDP Options avoids the need for each Upper Layer protocol to implement the DPLPMTUD method. It provides a standard method for applications to discover the current maximum packet size for a path and to detect when this changes.

2. Terminology

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 terms defined for DPLPMTUD (Sections 2 and 5 of [RFC8899]).

3. DPLPMTUD for UDP Options

A UDP Options sender implementing DPLPMTUD uses the method specified in [RFC8899]. In this specification, this is realised using a pair of UDP Options: the Request (REQ) Option and the Response (RES) Option [I-D.ietf-tsvwg-udp-options]. The method also uses the the End of Options List (EOL) Option [I-D.ietf-tsvwg-udp-options] to introduce padding to set the size of a probe packet.

Use of DPLPMTUD MUST be explicitly enabled by the application, for instance once an application has established connectivity and is ready to exchange data with the remote Upper Layer protocol. Similarly, a receiver SHOULD NOT respond to a REQ Option until DPLPMTUD has been enabled.

Probe packets consume network capacity and incur endpoint processing (Section 4.1 of [RFC8899]). Implementations ought to send a probe packet with a REQ Option only when required by their local DPLPMTUD state machine, i.e., when confirming the base PMTU for the path, probing to increase the PLPMTU, or to confirm the current PLPMTU.

There are two designs for using DPLPMTUD over UDP Options:

- Implementation within the UDP transport service;

- By an Upper Layer protocol (or application) that uses UDP Options.

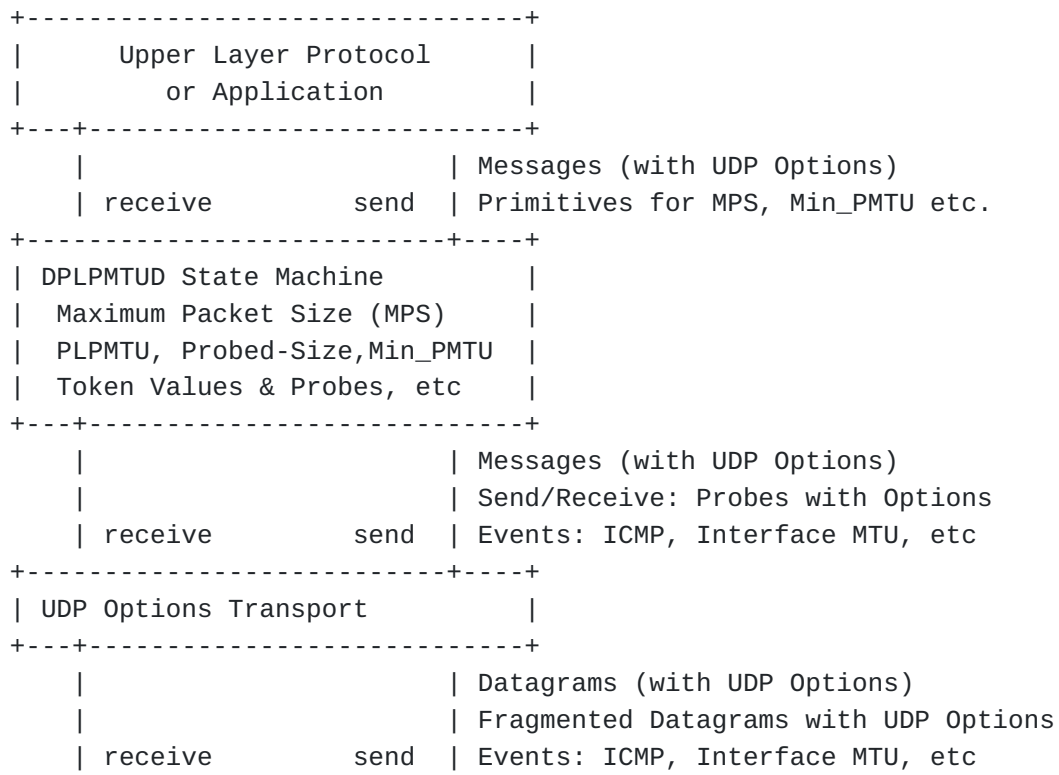
When DPLPMTUD is within the UDP transport service, the DPLPMTUD state machine is responsible for sending probe packets to determine a PLPMTU, as described in this document. The Upper Layer protocol is responsible for deciding at what point in a session DPLPMTUD should be enabled. Similarly a DPLPMTUD receiver ought to not respond to a REQ Option until this option is enabled.

The discovered PLPMTU can be used to either:

- set the maximum datagram size for the current path;

- set the maximum fragment size when a sender uses the UDP Fragmentation Option to divide a datagram into multiple UDP fragments for transmission. The size of each UDP fragment is then less than the size of the discovered largest IP packet that can be received across the current path.

The figure below shows an implementation of DPLPMTUD within the UDP transport service. It illustrates key interactions between the layers. This design REQUIRES an API primitive to allow the application to control whether the DPLPMTUD state machine is enabled for a specific UDP port. By default, this API MUST disable DPLPMTUD processing.



Note: UDP allows an Upper Layer Protocol to send datagrams with or without payload data (with or without UDP Options). These are delivered across the network to the remote Upper Layer. When DPLPMTUD is implemented within the UDP transport service, DPLPMTUD can be permitted to generate probe packets with no UDP payload, and these include a REQ or RES UDP Option. In this case, these probe packets were not generated by the sending application and therefore the corresponding datagrams are not delivered to the remote application.

When DPLPMTUD is instead implemented by an Upper Layer protocol, the format and content of probe packets are determined by the Upper Layer protocol. This design is also permitted to use the REQ and RES Options provided by UDP Options.

If DPLPMTUD is active at more than one layer, then the values of the tokens used in REQ Options need to be coordinated with any values used for other DPLPMTUD probe packets to ensure that each probe packet can be identified by a unique token. When configurable, a design ought to avoid performing such discovery within UDP Options and also by upper protocol layers (that send and receive probe packets via UDP Options).

Section 6.1 of [RFC8899] recommends that "An application SHOULD avoid using DPLPMTUD when the underlying transport system provides this capability".

3.1. Packet Formats

The UDP Options used in this document are described in [I-D.ietf-tsvwg-udp-options] and are used in the following way:

- The REQ Option is set by a sending PL to solicit a response from a remote receiver. A four-byte token identifies each request.

- A sending PL can use the EOL option together with a minimum datagram length to pad probe packets.

- The RES Option is sent by a UDP Options receiver in response to a previously received REQ Option. Each RES Option echoes the last received four-byte token.

- Reception of a RES Option by the sender confirms that a specific probe packet has been received by the remote UDP Options receiver.

The token allows a UDP Options sender to distinguish between acknowledgements for initial probe packets and acknowledgements confirming receipt of subsequent probe packets (e.g., travelling along alternate paths with a larger round-trip time). Each probe packet MUST be uniquely identifiable by the UDP Options sender within the Maximum Segment Lifetime (MSL). The UDP Options sender MUST NOT reuse a token value within the MSL. A four byte value for the token field provides sufficient space for multiple unique probe packets to be made within the MSL. Since UDP Options operates over UDP, the token values only need to be unique for the specific 5-tuple over which it is operating.

The value of the four-byte token field SHOULD be initialised to a randomised value to enhance protection from off-path attacks, as described in Section 5.1 of [RFC8085].

3.2. Sending Probe Packets with the Request Option

DPLPMTUD relies upon sending a probe packet with a specific size. Each probe packet includes the UDP Options area containing a REQ Option and any other required options concluded with an EOL Option (Section 9.1 of [I-D.ietf-tsvwg-udp-options]) followed by any padding needed to inflate to the required probe size.

A probe packet can therefore be of size up to the maximum for the size supported by the local interface. [RFC8899] (Section 3, item 2) requires the network interface below DPLPMTUD to provide a way to

transmit a probe packet that is larger than the current PLPMTU. The size of this probe packet MUST NOT be constrained by the maximum PMTU set by network layer mechanisms (such as discovered by PMTUD [RFC1191][RFC8201] or the PMTU size held in the IP-layer cache), as noted in bullet 2 of Section 3 in [RFC8899]).

UDP datagrams used as DPLPMTUD probe packets, as described in this document, MUST NOT be fragmented at the UDP layer.

3.3. Receiving UDP-Options Probe Packets and sending the RES Option

When DPLPMTUD is enabled, a UDP Options receiver responds by sending a UDP datagram with the RES Option when it receives a UDP Options datagram with the REQ Option.

The operation of DPLPMTUD can depend on the support at the remote UDP Options endpoint, the way in which DPLPMTUD is implemented and in some cases the application data that is exchanged over the UDP transport service. When UDP Options is not supported by the remote receiver, DPLPMTUD will be unable to confirm the path or to discover the PLPMTU. This will result in the minimum configured PLPMTU (MIN_PLPMTU). More explanation of usage is provided in Section 6.

Note: A receiver that only responds when there is a datagram queued for transmission by the Upper Layer could potentially receive multiple datagrams with a REQ Option before it can respond. When sent, the RES Option will only acknowledge the latest received token value. A sender would then conclude that any earlier REQ Options were not successfully received. However, DPLPMTUD does not normally send more than one probe packet per timeout interval, and a delay in responding will already have been treated as a failed probe attempt. Therefore, this does not significantly impact performance, although a more prompt response would have resulted in DPLPMTUD recording reception of all probe packets.

4. DPLPMTUD Sender Procedures for UDP Options

DPLPMTUD utilises three types of probe. These are described in the following sections:

*Probes to confirm the path can support the BASE_PLPMTU (Section 5.1.4 of [RFC8899]).

*Probes to detect whether the path can support a larger PLPMTU.

*Probes to validate the path supports the current PLPMTU.

4.1. Confirmation of Connectivity across a Path

The DPLPMTUD method requires a PL to confirm connectivity over the path (Section 5.1.4 of [RFC8899]), but UDP itself does not offer a mechanism for this.

UDP Options can provide this required functionality. A UDP Options sender implementing this specification MUST elicit a positive confirmation of connectivity for the path, by sending a probe packet, padded to size BASE_PLPMTU. This confirmation probe MUST include the REQ UDP option to elicit a response from the remote DPLPMTUD. Reception of a datagram with the corresponding RES Option confirms the reception of a packet of the probed size that has successfully traversed the path to the receiver. This also confirms that the remote endpoint supports the RES Option.

4.2. Sending Probe Packets to Increase the PLPMTU

From time to time, DPLPMTUD enters the SEARCHING state, described in Section 5.2 of [RFC8899], (e.g., after expiry of the PMTU_RAISE_TIMER) to detect whether the current path can support a larger PLPMTU. When the remote endpoint advertises a UDP Maximum Segment Size (MSS) option, this value MAY be used as a hint to initialise this search to increase the PLPMTU.

Probe packets seeking to increase the PLPMTU SHOULD NOT carry application data ("Probing using padding data" in Section 4.1 of [RFC8899]), since they will be lost whenever their size exceeds the actual PMTU. A probe packet needs to elicit a positive acknowledgment that the path has delivered a datagram of the specific probed size and, therefore, MUST include the REQ Option.

At the receiver, a received probe packet that does not carry application data does not form a part of the end-to-end transport data and is not delivered to the Upper Layer protocol (i.e., application or protocol layered above UDP).

4.3. Validating the Path with UDP Options

A PL using DPLPMTUD needs to validate that a path continues to support the PLPMTU discovered in a previous search for a suitable PLPMTU value (Section 6.1.4 of [RFC8899]). This validation sends probe packets in the DPLPMTUD SEARCH_COMPLETE state to detect black-holing of data (Section 5.2 of [RFC8899], Section 4.3 of [RFC8899] defines a DPLPMTUD black-hole).

Path validation can be implemented within UDP Options by generating a probe packet of size PLPMTU, which MUST include a REQ Option to elicit a positive confirmation that the path has delivered this probe packet. A probe packet used to validate the path MAY use

either "Probing using padding data" to construct a probe packet that does not carry any application data, as described in a previous section, or "Probing using application data and padding data", see Section 4.1 of [RFC8899]. When using "Probing using padding data", the API does not indicate receipt of the zero-length probe packet, see Section 4.4.

4.4. Probe Packets that do not include Application Data

A simple implementation of the method might be designed to only use probe packets in a UDP datagram that includes no application data. The size of each probe packet is padded to the required probe size including the REQ Option. This implements "Probing using padding data" (Section 4.1 of [RFC8899]) and avoids having to retransmit application data when a probe fails. This could be achieved by setting a minimum datagram length, such that the options list ends in EOL and additional space is zero-filled as needed (Section 13 of [I-D.ietf-tsvwg-udp-options]). In this use, the probe packets do not form a part of the end-to-end transport data and a receiver does not deliver them to the Upper Layer protocol.

4.5. Probe Packets that include Application Data

An implementation always uses the format in Section 4.4 when DPLPMTUD searches to increase the PLPMTU.

An alternative format is permitted for a probe packet used to confirm connectivity or that validates the path. These probe packets are permitted to carry application data. (A UDP payload data is permitted because these probe packets perform black-hole detection and will, therefore, usually have a higher probability of successful transmission, similar to other packets sent by the Upper Layer protocol.) Section 4.1 of [RFC8899] provides a discussion of the merits and demerits of including application data. For example, this reduces the need to send additional datagrams.

This type of probe MAY utilise a control message format defined by the Upper Layer protocol, provided that the message does not need to be delivered reliably. The REQ Option MUST be included when a sending Upper Layer protocol performs DPLPMTUD. The DPLPMTUD method tracks the transmission of probe packets (using the REQ Option) and reception of the corresponding RES Options to the Upper Layer protocol.

A receiver that responds to DPLPMTUD needs to process the REQ Option and include the corresponding RES Option in an Upper Layer protocol message that it returns to the requester. DPLPMTUD can be used to manage the PLPMTU in just one direction or can be used for both

directions. Probe packets that use this format form a part of the end-to-end transport data.

5. Receiving Events from the Network

This specification does not rely upon reception of events from the network, but an implementation can utilise these events when provided.

5.1. Changes in the Path

A change in the path or the loss of a probe packet can result in DPLPMTUD updating the PLPMTU. DPLPMTUD [RFC8899] recommends that methods are robust to path changes that could have occurred since the path characteristics were last confirmed and to the possibility of inconsistent path information being received. For example, a notification that a path has changed could trigger path validation to provide black-hole protection (Section 4.3 of [RFC8899]).

An Upper Layer protocol could trigger DPLPMTUD to validate the path when it observes a high packet loss rate (or a repeated protocol timeout) [RFC8899].

Section 3 of [RFC8899] requires any methods designed to share the PLPMTU between PLs (such as updating the IP cache PMTU for an interface/destination) to be robust to the wide variety of underlying network forwarding behaviors. For example, an implementation could avoid sharing PMTU information that could potentially relate to packets sent with the same address over a different interface.

5.2. PTB Message Handling

Support for receiving ICMP PTB messages is OPTIONAL for use with DPLPMTUD. A UDP Options sender can therefore ignore received ICMP PTB messages.

When DPLPMTUD utilises ICMP PTB messages received in response to a probe packet it MUST use the ICMP quoted packet to validate the UDP port information in combination with the token contained in the UDP Option, before processing the packet using the DPLPMTUD method. Section 4.6.1 of [RFC8899] specifies this validation procedure. An implementation unable to support this validation needs to ignore received ICMP PTB messages.

6. Examples with Different Receiver Behaviors

When enabled, a DPLPMTUD endpoint that implements UDP Options normally responds with a UDP datagram with a RES Option when requested by a sender.

The following examples describe various possible receiver behaviors:

* (No DPLPMTUD receiver support) One case is when a sender supports this specification, but the remote endpoint that does not return a RES Option. In this example, the method is unable to discover the PLPMTU. This will result in using the minimum configured PLPMTU (MIN_PLPMTU). Such a remote endpoint might not process UDP Options, or might not return a datagram with a RES Option for some other reason (due to persistent packet loss, insufficient space to include the option, etc.)

* (DPLPMTUD receiver uses application datagrams) In a second case, both the sender and receiver support DPLPMTUD using the specification, and the receiver design only returns a RES Option with the next UDP datagram that is sent to the requester. In this design, the reception of a REQ Option does not systematically trigger a response. The design allows DPLPMTUD to operate when there is a flow of datagrams in both directions, providing there is periodic feedback (e.g., one acknowledgment packet per RTT). This also requires the PLPMTU at the receiver to be sufficiently large that the RES option can be added to the feedback packets that are sent in the return direction. This is a simple method that also avoids opportunities to misuse the method as a DoS attack. However, when there is a low rate of transmission (or no datagrams are sent) in the return direction, this will prevent prompt delivery of the RES Option. At the DPLPMTUD sender this results in probe packets failing to be acknowledged in time, and will result in a smaller PLPMTU than is actually supported by the path, or in using the minimum configured PLPMTU (MIN_PLPMTU).

* (Uni-directional transfer) Another case is where an application only transfers data in one direction (or predominantly in one direction). In this case the wait at the receiver for a datagram to be queued before returning a RES Option could easily result in a probe timeout at the DPLPMTUD sender. In this case, DPLPMTUD could allow exchanging datagrams without a payload (as discussed in earlier sections) to return the RES Option.

* (DPLPMTUD Receiver permitted to send responses in UDP datagrams with no payload) A DPLPMTUD receiver can generate a datagram (e.g., with zero payload data) solely to return a RES Option (e.g., when no other datagrams are queued for transmission). This design allows a UDP Options endpoint to probe the set of open UDP ports using DPLPMTUD probe packets. It results in some additional traffic overhead but has the advantage that it can ensure timely progress of DPLPMTUD. If a UDP Options endpoint creates and sends a datagram with a RES option solely as response to a received REQ Option, the responder MUST limit the rate of these responses (e.g., limiting each pair of ports to send 1 per RTT or 1 per

second). This rate limit is to mitigate the DoS vector, without significantly impacting the operation of DPLPMTUD.

7. Acknowledgements

Gorry Fairhurst and Tom Jones are supported by funding provided by the University of Aberdeen. The editors would like to thank Magnus Westerlund and Mohamed Boucadair for their detailed comments and also other people who contributed to completing this document.

8. IANA Considerations

This memo includes no requests to IANA.

9. Security Considerations

The security considerations for using UDP Options are described in [I-D.ietf-tsvwg-udp-options]. The method does not change the integrity protection offered by the UDP options method.

The security considerations for using DPLPMTUD are described in [RFC8899]. On path attackers could maliciously drop or modify probe packets to seek to decrease the PMTU, or to maliciously modify probe packets in an attempt to black-hole traffic.

The specification recommends that the token value in the REQ Option is initialised to a randomised value. This is designed to enhance protection from off-path attacks. If a subsequent probe packet uses a token value that is easily derived from the initial value, (e.g., incrementing the value) a misbehaving on-path observer could then determine the token values used for subsequent probe packets from that sender, even if these probe packets are not transiting via the observer. This would allow probe packets to be forged, with an impact similar to other on-path attacks against probe packets. This attack could be mitigated by using an unpredictable token value for each probe packet.

The method does not change the ICMP PTB message validation method described by DPLPMTUD: A UDP Options sender that utilises ICMP PTB messages received to a probe packet MUST use the quoted packet to validate the UDP port information in combination with the token contained in the UDP Option, before processing the packet using the DPLPMTUD method.

Upper Layer protocols or applications that employ encryption ought to perform DPLPMTUD at a layer above UDP Options, and not to enable UDP Options support for DPLPMTUD. This allows the application to control when DPLPMTUD is used to control the additional traffic that this generates. This also ensures that DPLPMTUD probe packets are encrypted.

10. References

10.1. Normative References

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[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <https://www.rfc-editor.org/info/rfc2119>.

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10.2. Informative References

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[RFC8304] Fairhurst, G. and T. Jones, "Transport Features of the User Datagram Protocol (UDP) and Lightweight UDP (UDP-

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<https://www.rfc-editor.org/info/rfc8304>.

Appendix A. Revision Notes

XXX Note to RFC-Editor: please remove this entire section prior to publication. XXX

Individual draft-00.

* This version contains a description for consideration and comment by the TSVWG.

Individual draft-01.

* Address Nits

* Change Probe Request and Probe Reponse options to Echo to align names with draft-ietf-tsvwg-udp-options

* Remove Appendix B, Informative Description of new UDP Options

* Add additional sections around Probe Packet generation

Individual draft-02.

* Address Nits

Individual draft-03.

* Referenced DPLPMTUD RFC.

* Tidied language to clarify the method.

Individual draft-04

* Reworded text on probing with data a little

* Removed paragraph on suspending ICMP PTB suspension.

Working group draft-00

* -00 First Working Group Version

* RFC8899 call search_done SEARCH_COMPLETE, fixed.

Working group draft -01

* Update to reflect new fragmentation design in UDP Options.

* Add a description of uses of DPLPMTUD with UDP Options.

*Add a description on how to form probe packets with padding.

*Say that MSS options can be used to initialise the search algorithm.

*Say that the recommended approach is to not use user data for probes.

*Attempts to clarify and improve wording throughout.

*Remove text saying you can respond to multiple probes in a single packet.

*Simplified text by removing options that don't yield benefit.

Working group draft -02

*Update to reflect comments from MED.

*More consistent description of DPLPMTUD with UDP Options.

*Clarify the nonce value (token) is intended per 5-tuple, not interface.

*BASE_PLPMTU related to RFC8899.

*Probes with user data can carry application control data.

*Added that application data uses RES and REQ nonce (token) values from the app.

*QUIC was intended as an informational reference to an example of RFC8899.

Working group draft -03

*Update to reflect more comments from MED.

*Again more consistent description of DPLPMTUD with UDP Options.

*Clarify token/nonce to use token.

*Clarify any use of application data for black-hole detection.

*Minor changes to reflect update to UDP Options base spec.

Working group draft-04.

Update for WG Last Call

Working group draft-05.

Update following WG Last Call

Working group draft-06.

Tidy text after WG Last Call, based on review by Med.

Added text after WG Last Call, based on review by Magnus.

Added text after WG Last Call, based on comments by Joe and Mike.

Restructured to integrate the WGLC new text.

Working group draft-07.

Mention of UDP-Options in Intro, from a review by Med.

Resolve typo, from review by Magnus.

Working group draft-08.

Corrections following a review by Mike Heard.

Working group draft-09.

Corrections following a review by Erik Auerswald and others.

Working group draft-10.

Corrections following a review by Erik Auerswald.

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