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Extensions for Generic UDP Encapsulation
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Abstract

This specification defines a set of the fundamental optional extensions for Generic UDP Encapsulation (GUE).

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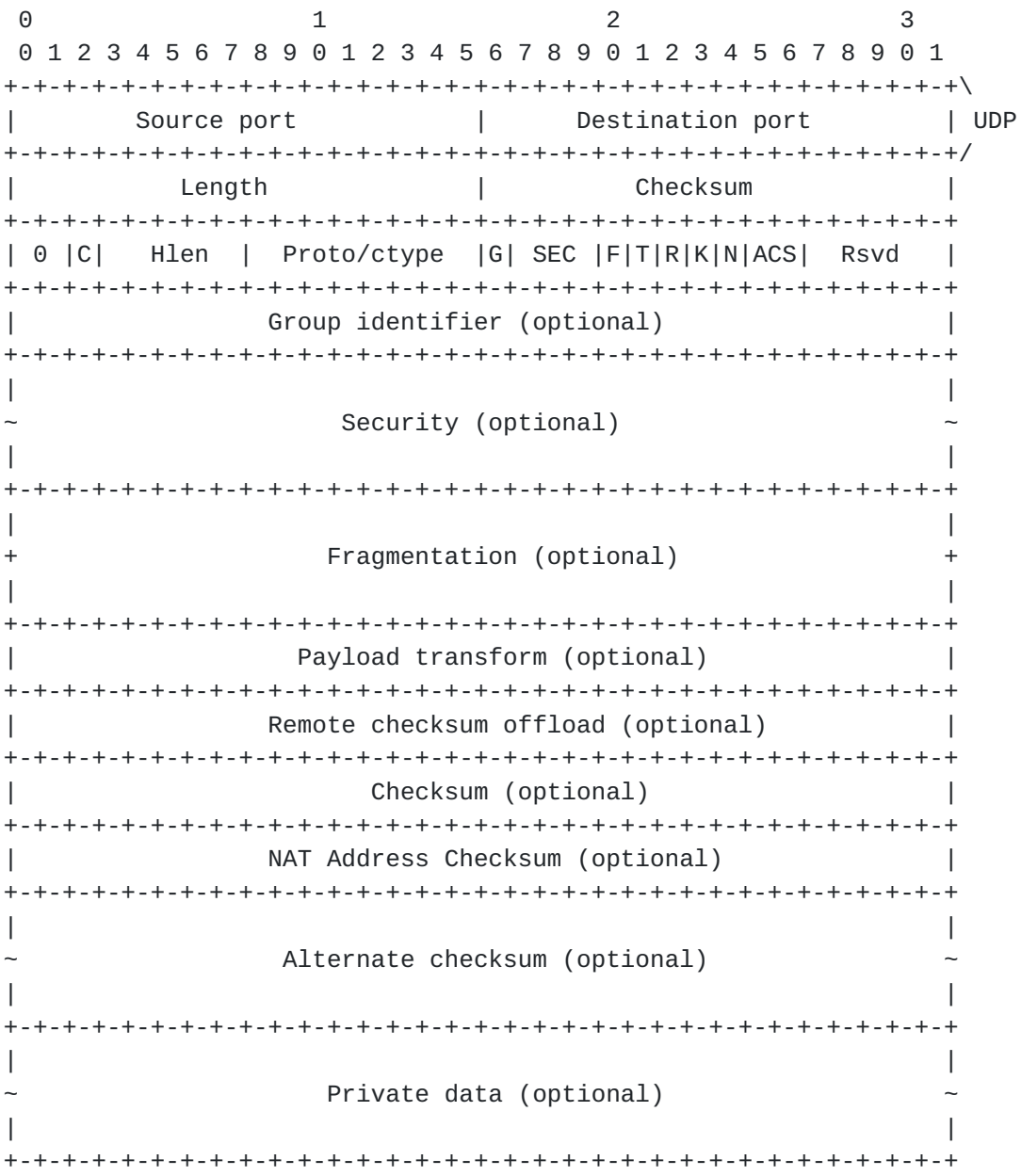
1. Introduction

Generic UDP Encapsulation (GUE) [I.D.ietf-gue] is a generic and extensible encapsulation protocol. This specification defines a fundamental set of optional extensions for version 0 of GUE. These extensions are the group identifier, security, fragmentation, payload transform, remote checksum offload, checksum, NAT address checksum, and alternate checksum.

2. GUE header format with optional extensions

The format of a version 0 GUE header with optional extensions is:



The contents of the UDP header are described in [I.D.ietf-gue].

The GUE header consists of:

- Variant: Set to 0 to indicate GUE encapsulation header. Note that variant 1 (direct IP encapsulation) does not allow options.

- C: C-bit. Indicates the GUE payload is a control message when set, a data message when not set. GUE optional extensions can be used with either control or data messages unless otherwise specified in the extension definition.

- Hlen: Length in 32-bit words of the GUE header, including optional extension fields and private data but not the first four bytes of the header. Computed as (header_len - 4) / 4. The length of the encapsulated packet is determined from the UDP length and the Hlen: encapsulated_packet_length = UDP_Length - 12 - 4*Hlen.

- Proto/ctype: If the C-bit is not set this indicates IP protocol number for the packet in the payload; if the C bit is set this is the type of control message in the payload. The next header begins at the offset provided by Hlen. When the payload transform option or fragmentation option is used this field MAY be set to protocol number 59 for a data message, or zero for a control message, to indicate no next header for the payload.

- G: Indicates the the group identifier extension field is present. The group identifier option is described in section 3.

- SEC: Indicates security extension field is present. The security option is described in section 4.

- F: Indicates fragmentation extension field is present. The fragmentation option is described in section 5.

- T: Indicates payload transform extension field is present. The payload transform option is described in section 6.

- R: Indicates the remote checksum extension field is present. The remote checksum offload option is described in section 7.

- K: Indicates checksum extension field is present. The checksum option is described in section 8.

- N: Indicates NAT address checksum field is present. The NAT address checksum option is described in section 9.

- ACS: Indicates alternative checksum field is present. The alternative checksum option is described in section 10.

- Private data is described in [I.D.ietf-gue].

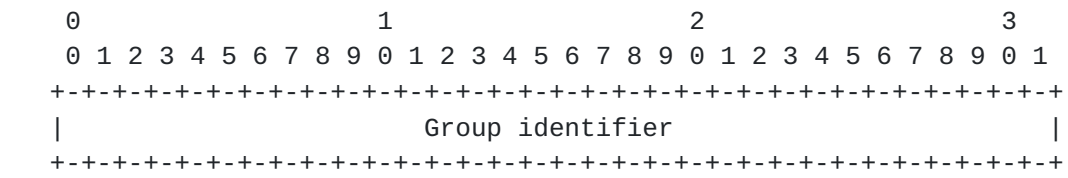
3. Group identifier option

The group identifier classifies packet that logically belong to the same group. Groups are arbitrarily defined for different purposes and their definition is shared between the communicating end nodes.

3.1. Extension field format

The presence of the GUE group identifier option is indicated in the G flag bit of the GUE header.

The format of the group identifier option is:



The fields of the option are:

- Group identifier: Identifier value of a group.

3.2. Usage

The group identifier is set by an encapsulator to indicate to the decapsulator that a packet belongs to a group. Groups may be arbitrarily defined to classify packets. Specific use cases of the group identifier may be defined in other documents ([I.D.hy-nvo3-gue-4-nvo] defines a use of this field to contain a virtual networking identifier for implementing network virtualization).

Intermediate nodes MAY apply semantics to group identifiers if group identifier information is shared and made global within a network. For instance, a firewall could block packets based on a group identifier that serves as a virtual identifier for a tenant.

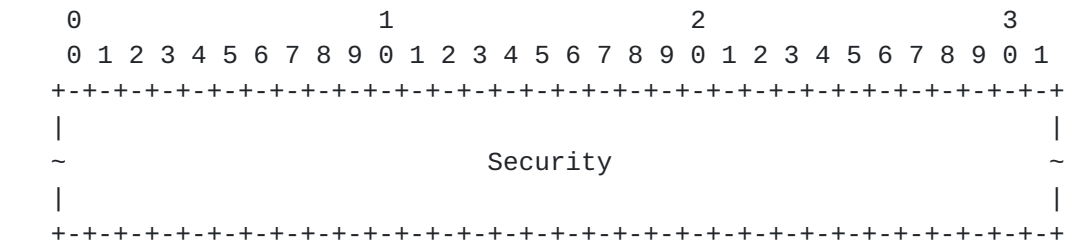
4. Security option

The GUE security option provides origin authentication and integrity protection of the GUE header at tunnel end points to guarantee isolation between tunnels and mitigate Denial of Service attacks.

4.1. Extension field format

The presence of the GUE security option is indicated in the SEC flag bits of the GUE header.

The format of the security option is:



The fields of the option are:

- Security (variable length). Contains the security information. The specific semantics and format of this field are expected to be negotiated between the two communicating nodes.

To provide security capability, the SEC flags MUST be set. Different sizes are allowed to allow different methods and extensibility. The use of the security field is expected to be negotiated out of band between two tunnel end points.

The values in the SEC flags are:

- 000b - No security field
- 001b - 64 bit security field
- 010b - 128 bit security field
- 011b - 256 bit security field
- 100b - 320 bit security field (HMAC)
- 101b, 110b, 111b - Reserved values

4.2. Usage

The GUE security option is used to provide integrity and authentication of the GUE header. Security parameters (interpretation of security field, key management, etc.) are expected to be negotiated out of band between two communicating hosts. Two security algorithms are defined below.

4.3. Cookies

The security field may be used as a cookie. This would be similar to the cookie mechanism described in L2TP [RFC3931], and the general properties should be the same. A cookie MAY be used to validate the encapsulation. The cookie is a shared value between an encapsulator and decapsulator which SHOULD be chosen randomly and MAY be changed periodically. Different cookies MAY be used for logical flows between the encapsulator and decapsulator, for instance packets sent with different VNIs in network virtualization [I.D.hy-nvo3-gue-4-nvo] might have different cookies. Cookies can be 64, 128, or 256 bits in size.

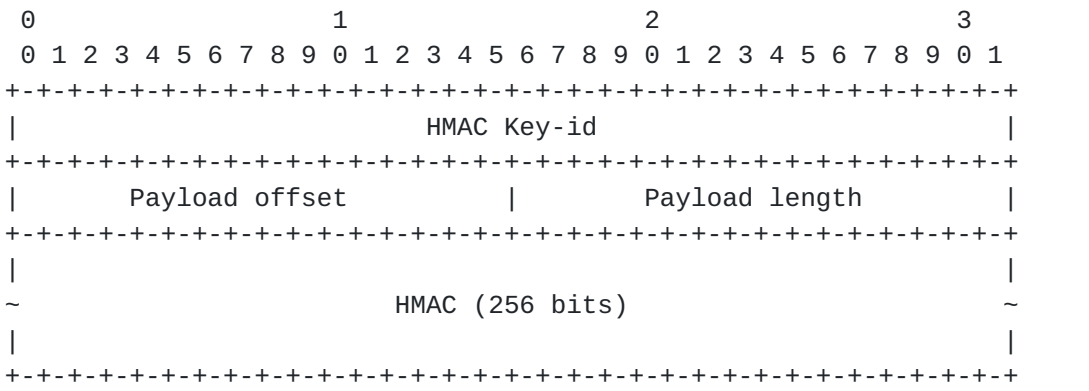
4.4. HMAC

Key-hashed message authentication code (HMAC) is a strong method of checking integrity and authentication of data. This sections defines a GUE security option for HMAC. Note that this is based on the HMAC TLV description in "IPv6 Segment Routing Header (SRH)" [I.D.previdi-6man-sr-header].

4.4.1. Extension field format

The HMAC option is a 320 bit field (40 octets). The security flags are set to 100b to indicate the presence of a 320 bit security field.

The format of the field is:



Fields are:

- HMAC Key-id: opaque field to allow multiple hash algorithms or key selection
- Payload offset: offset in payload that indicates the first octet of payload data included in the HMAC.

- Payload length: length of payload data starting from the payload offset to be included in the HMAC calculation. Zero indicates no payload data in used in the calculation.

- HMAC: Output of HMAC computation

The HMAC field is the output of the HMAC computation (per [RFC2104]) using a pre-shared key identified by HMAC Key-id and of the text which consists of the concatenation of:

- The IP addresses

- The GUE header including all optional extensions except for the security option

- Optionally some or all of GUE payload. The portion of payload covered is indicated by an offset into the payload and a length relative to the offset.

The purpose of the HMAC option is to verify the validity, the integrity and the authentication of the GUE header itself and optionally some or all of the GUE payload.

The HMAC Key-id field allows for the simultaneous existence of several hash algorithms (SHA-256, SHA3-256 ... or future ones) as well as pre-shared keys. The HMAC Key-id field is opaque, i.e., it has neither syntax nor semantic. Having an HMAC Key-id field allows for pre-shared key roll-over when two pre-shared keys are supported for a while when GUE endpoints converge to a fresher pre-shared key.

A portion of the GUE payload MAY be included in the HMAC calculation. The payload coverage is indicated in the option in the payload offset and payload length fields. If no payload data is included in the HMAC then the payload length field is set to zero. On reception, if the sum of the payload offset and the payload length is greater than the total length of the payload, then the packet MUST be dropped.

4.4.2. Selecting a hash algorithm

The HMAC field in the HMAC option is 256 bit wide. Therefore, the HMAC MUST be based on a hash function whose output is at least 256 bits. If the output of the hash function is 256 bits, then this output is simply inserted in the HMAC field. If the output of the hash function is larger than 256 bits, then the output value is truncated to 256 bits by taking the least-significant 256 bits and inserting them in the HMAC field.

GUE implementations can support multiple hash functions but MUST implement SHA-2 [FIPS180-4] in its SHA-256 variant.

4.4.3. Pre-shared key management

The field HMAC Key-id allows for:

- Key roll-over: when there is a need to change the key (the hash pre-shared secret), then multiple pre-shared keys can be used simultaneously. A decapsulator can have a table of <HMAC Key-id, pre-shared secret> for the currently active and future keys.

- Different algorithms: by extending the previous table to <HMAC Key-id, hash function, pre-shared secret>, the decapsulator can also support simultaneously several hash algorithms

The pre-shared secret distribution can be done:

- In the configuration of the endpoints

- Dynamically using a trusted key distribution such as [RFC6407]

4.5. Interaction with other optional extensions

If GUE fragmentation (section 5) is used in concert with the GUE security option, the security option processing is performed after fragmentation at the encapsulator and before reassembly at the decapsulator.

The GUE payload transform option (section 6) may be used in concert with the GUE security option. The payload transform option could be used to encrypt the GUE payload to provide privacy for an encapsulated packet during transit. The security option provides authentication and integrity for the GUE header (including the payload transform field in the header). The two functions are processed separately at tunnel end points. A GUE tunnel can use both functions or use one of them. Section 6.3 details handling for when both are used in a packet.

5. Fragmentation option

The fragmentation option allows an encapsulator to perform fragmentation of packets being ingress to a tunnel. Procedures for fragmentation and reassembly are defined in this section. This specification adapts the procedures for IP fragmentation and reassembly described in [RFC0791] and [RFC8200]. Fragmentation can be performed on both data and control messages in GUE.

5.1. Motivation

This section describes the motivation for having a fragmentation option in GUE.

MTU and fragmentation issues with In-the-Network Tunneling are described in [RFC4459]. Considerations need to be made when a packet is received at a tunnel ingress point which may be too large to traverse the path between tunnel endpoints.

There are four suggested alternatives in [RFC4459] to deal with this:

1) Fragmentation and Reassembly by the Tunnel Endpoints

2) Signaling the Lower MTU to the Sources

3) Encapsulate Only When There is Free MTU

4) Fragmentation of the Inner Packet

Many tunneling protocol implementations have assumed that fragmentation should be avoided, and in particular alternative #3 seems preferred for deployment. In this case, it is assumed that an operator can configure the MTUs of links in the paths of tunnels to ensure that they are large enough to accommodate any packets and required encapsulation overhead. This method, however, may not be feasible in certain deployments and may be prone to misconfiguration in others.

Similarly, the other alternatives have drawbacks that are described in [RFC4459]. Alternative #2 implies use of something like Path MTU Discovery which is not known to be sufficiently reliable. Alternative #4 is not permissible with IPv6 or when the DF bit is set for IPv4, and it also introduces other known issues with IP fragmentation.

For alternative #1, fragmentation and reassembly at the tunnel endpoints, there are two possibilities: encapsulate the large packet and then perform IP fragmentation, or segment the packet and then encapsulate each segment (a non-IP fragmentation approach).

Performing IP fragmentation on an encapsulated packet has the same issues as that of normal IP fragmentation. Most significant of these is that the Identification field is only sixteen bits in IPv4 which introduces problems with wraparound as described in [RFC4963].

The second possibility of alternative #1 follows the suggestion expressed in [RFC2764] and the fragmentation feature described in the AERO protocol [I.D.templin-aerolink]; that is for the tunneling

protocol itself to incorporate a segmentation and reassembly capability that operates at the tunnel level. In this method, fragmentation is part of the encapsulation and an encapsulation header contains the information for reassembly. This differs from IP fragmentation in that the IP headers of the original packet are not replicated for each fragment.

Incorporating fragmentation into the encapsulation protocol has some advantages:

- At least a 32 bit identifier can be defined to avoid issues of the 16 bit Identification in IPv4.
- Encapsulation mechanisms for security and identification, such as group identifiers, can be applied to each segment.
- This allows the possibility of using alternate fragmentation and reassembly algorithms (e.g. fragmentation with Forward Error Correction).
- Fragmentation is transparent to the underlying network so it is unlikely that fragmented packet will be unconditionally dropped as might happen with IP fragmentation.

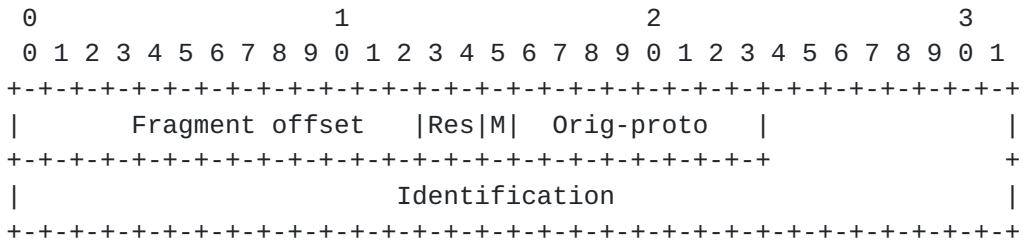
5.2. Scope

This specification describes the mechanics of fragmentation in Generic UDP Encapsulation. The operational aspects and details for higher layer implementation must be considered for deployment, but are considered out of scope for this document. The AERO protocol [I.D.templin-aerolink] defines one use case of fragmentation with encapsulation.

5.3. Extension field format

The presence of the GUE fragmentation option is indicated by the F bit in the GUE header.

The format of the fragmentation option is:



The fields of the option are:

- Fragment offset: This field indicates where in the datagram this fragment belongs. The fragment offset is measured in units of 8 octets (64 bits). The first fragment has offset zero.

- Res: Two bit reserved field. MUST be set to zero for transmission. If set to non-zero in a received packet then the packet MUST be dropped.

- M: More fragments bit. Set to 1 when there are more fragments following in the datagram, set to 0 for the last fragment.

- Orig-proto: The control type (when the C-bit in the GUE header is set) or the IP protocol (when C-bit is not set) of the fragmented packet.

- Identification: 40 bits. Identifies fragments of a fragmented packet.

Pertinent GUE header fields to fragmentation are:

- C-bit: This is set for each fragment based on the whether the original packet being fragmented is a control or data message.

- Proto/ctype - For the first fragment (fragment offset is zero) this is set to that of the original packet being fragmented (either will be a control type or IP protocol). For other fragments, this is set to zero for a control message being fragmented, or to "No next header" (protocol number 59) for a data message being fragmented.

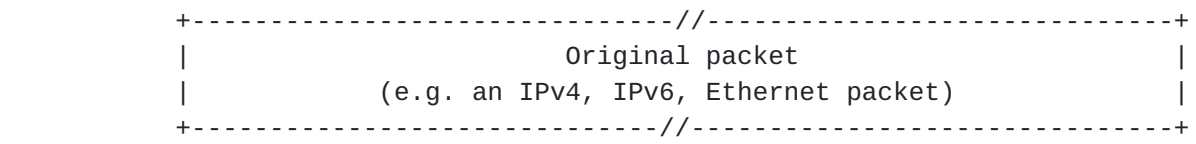
- F bit - Set to indicate presence of the fragmentation extension field.

5.4. Fragmentation procedure

If an encapsulator determines that a packet must be fragmented (eg. the packet's size exceeds the Path MTU of the tunnel) it should divide the packet into fragments and send each fragment as a separate GUE packet, to be reassembled at the decapsulator (tunnel egress).

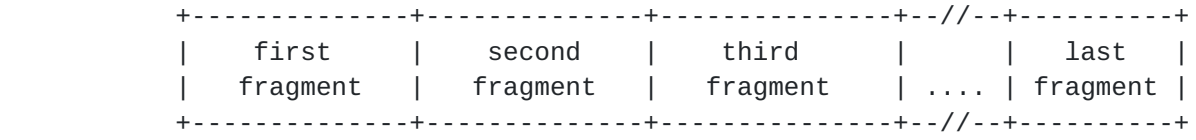
For every packet that is to be fragmented, the source node generates an Identification value. The Identification MUST be different than that of any other fragmented packet sent within the past 60 seconds (Maximum Segment Lifetime) with the same tunnel identification-- that is the same outer source and destination addresses, same UDP ports, same orig-proto, and same group identifier if present.

The initial, unfragmented, and unencapsulated packet is referred to as the "original packet". This will be a layer 2 packet, layer 3 packet, or the payload of a GUE control message:

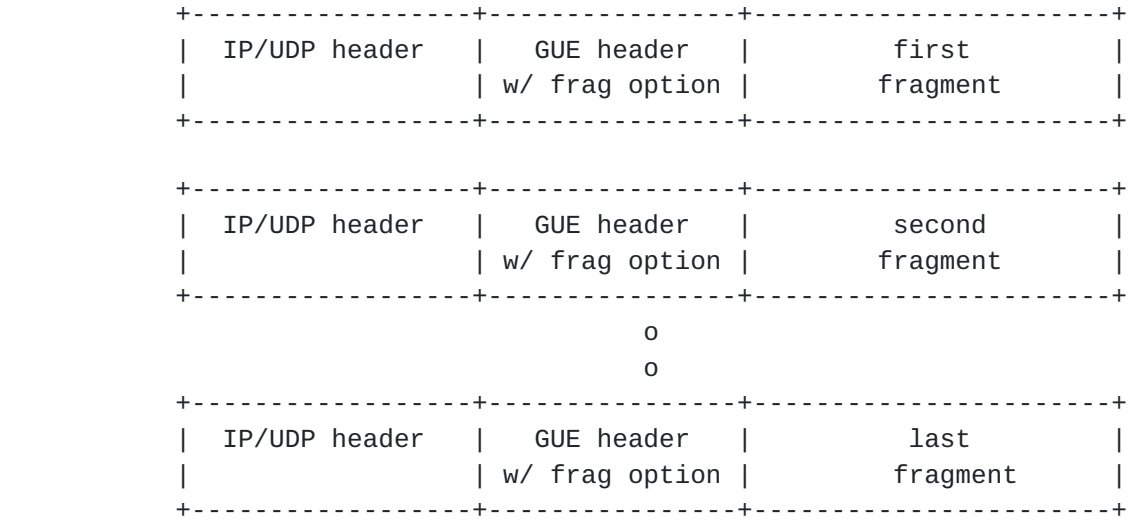


Fragmentation and encapsulation are performed on the original packet in sequence. First the packet is divided up in to fragments, and then each fragment is encapsulated. Each fragment, except possibly the last ("rightmost") one, is an integer multiple of 8 octets long. Fragments MUST be non-overlapping. The number of fragments should be minimized, and all but the last fragment should be approximately equal in length.

The fragments are transmitted in separate "fragment packets" as:



Each fragment is encapsulated as the payload of a GUE packet. This is illustrated as:



Each fragment packet is composed of:

(1) Outer IP and UDP headers as defined for GUE encapsulation.

o The IP addresses and UDP ports MUST be the same for all

fragments of a fragmented packet.

(2) A GUE header that contains:

- The C-bit which is set to the same value for all the fragments of a fragmented packet based on whether a control message or data message was fragmented.

- A proto/ctype. In the first fragment this is set to the value corresponding to the next header of the original packet and will be either an IP protocol or a control type. For subsequent fragments, this field is set to 0 for a fragmented control message or 59 (no next header) for a fragmented data message.

- The F bit is set and fragment extension field is present.

- Other GUE options. Note that options apply to the individual GUE packet. For instance, the security option would be validated before reassembly. The group identifier option MUST be set to the same value for all fragments.

(3) The GUE fragmentation option. The contents of the extension field include:

- Orig-proto specifies the protocol of the original packet.

- A Fragment Offset containing the offset of the fragment, in 8-octet units, relative to the start of the of the original packet. The Fragment Offset of the first ("leftmost") fragment is 0.

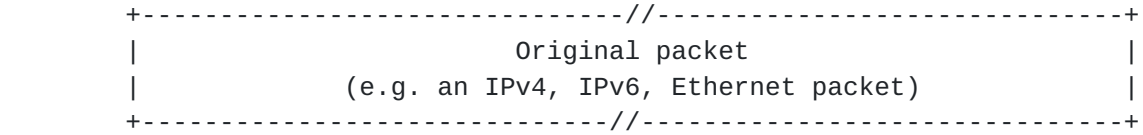
- An M flag value of 0 if the fragment is the last ("rightmost") one, else an M flag value of 1.

- The Identification value generated for the original packet.

(4) The fragment itself.

5.5. Reassembly procedure

At the destination, fragment packets are decapsulated and reassembled into their original, unfragmented form, as illustrated:



The following rules govern reassembly:

The IP/UDP/GUE headers of each packet are retained until all fragments have arrived. The reassembled packet is then composed of the decapsulated payloads in the GUE packets, and the IP/UDP/GUE headers are discarded.

When a GUE packet is received with the fragment extension, the proto/ctype field in the GUE header MUST be validated. In the case that the packet is a first fragment (fragment offset is zero), the proto/ctype in the GUE header MUST equal the orig-proto value in the fragmentation option. For subsequent fragments (fragment offset is non-zero) the proto/ctype in the GUE header must be 0 for a control message or 59 (no-next-hdr) for a data message. If the proto/ctype value is invalid for a received packet it MUST be dropped.

An original packet is reassembled only from GUE fragment packets that have the same outer source address, destination address, UDP source port, UDP destination port, GUE header C-bit, group identifier if present, orig-proto value in the fragmentation option, and Fragment Identification. The protocol type or control message type (depending on the C-bit) for the reassembled packet is the value of the GUE header proto/ctype field in the first fragment.

The following error conditions can arise when reassembling fragmented packets with GUE encapsulation:

If insufficient fragments are received to complete reassembly of a packet within 60 seconds (or a configurable period) of the reception of the first-arriving fragment of that packet, reassembly of that packet MUST be abandoned and all the fragments that have been received for that packet MUST be discarded.

If the payload length of a fragment is not a multiple of 8 octets and the M flag of that fragment is 1, then that fragment MUST be discarded.

If the length and offset of a fragment are such that the payload length of the packet reassembled from that fragment would exceed 65,535 octets, then that fragment MUST be discarded.

If a fragment overlaps another fragment already saved for reassembly then the new fragment that overlaps the existing fragment MUST be discarded.

If the first fragment is too small then it is possible that it does not contain the necessary headers for a stateful firewall. Sending small fragments like this has been used as an attack on IP fragmentation. To mitigate this problem, an implementation SHOULD ensure that the first fragment contains the headers of the encapsulated packet at least through the transport header.

A GUE node MUST be able to accept a fragmented packet that, after reassembly and decapsulation, is as large as 1500 octets. This means that the node must configure a reassembly buffer that is at least as large as 1500 octets plus the maximum-sized encapsulation headers that may be inserted during encapsulation. Implementations may find it more convenient and efficient to configure a reassembly buffer size of 2KB which is large enough to accommodate even the largest set of encapsulation headers and provides a natural memory page size boundary.

5.6. Security Considerations

Exploits that have been identified with IP fragmentation are conceptually applicable to GUE fragmentation.

Attacks on GUE fragmentation can be mitigated by:

- Hardened implementation that applies applicable techniques from implementation of IP fragmentation.
- Application of GUE security (section 4) or IPsec [RFC4301]. Security mechanisms can prevent spoofing of fragments from unauthorized sources.
- Implement fragment filter techniques for GUE encapsulation as described in [RFC1858] and [RFC3128].
- Do not accepted data in overlapping segments.
- Enforce a minimum size for the first fragment.

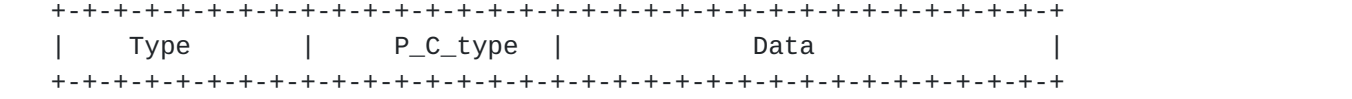
6. Payload transform option

The payload transform option indicates that the GUE payload has been transformed. Transforming a payload is done by running a function over the data and possibly modifying it (encrypting it for instance). The payload transform option indicates the method used to transform the data so that a decapsulator is able to validate and reverse the transformation to recover the original data. Payload transformations could include encryption, authentication, CRC coverage, and compression. This specification defines a transformation for DTLS.

6.1. Extension field format

The presence of the GUE payload transform option is indicated by the T bit in the GUE header.

The format of Payload Transform Field is:



The fields of the option are:

Type: Payload Transform Type or Code point. Each payload transform mechanism must have one code point registered in IANA. This document specifies:

0x01: for DTLS [RFC6347]

0x80~0xFF: for private payload transform types

A private payload transform type can be used for experimental purposes or proprietary mechanisms.

P_C_type: Indicates the protocol or control type of the untransformed payload. When payload transform option is present, proto/ctype in the GUE header is set to 59 ("No next header") for a data message and zero for a control message. The IP protocol or control message type of the untransformed payload MUST be encoded in this field.

The benefit of this rule is to prevent a middle box from inspecting the encrypted payload according to GUE next protocol. The assumption here is that a middle box may understand GUE base header but does not understand GUE option flag definitions.

Data: A field that can be set according to the requirements of each payload transform type. If the specification for a payload transform type does not specify how this field is to be set, then the field MUST be set to zero.

6.2. Usage

The payload transform option provides a mechanism to transform or interpret the payload of a GUE packet. The Type field provides the method used to transform the payload, and the P_C_type field provides the protocol or control message type of the of payload before being

transformed. The payload transformation option is generic so that it can have both security related uses (such as DTLS) as well as non security related uses (such as compression, CRC, etc.).

An encapsulator performs payload transformation before transmission, and a decapsulator performs the reverse transformation before accepting a packet. For example, if an encapsulator transforms a payload by encrypting it, the peer decaspsulator MUST decrypt the payload before accepting the packet. If a decapsulator fails to perform the reverse transformation or cannot validate the transformation it MUST discard the packet and MAY generate an alert to the management system.

6.3. Interaction with other optional extensions

If GUE fragmentation (section 5) is used in concert with the GUE transform option, the transform option processing is performed after fragmentation at the encapsulator and before reassembly at the decapsulator. If the payload transform changes the size of the data being fragmented this must be taken into account during fragmentation.

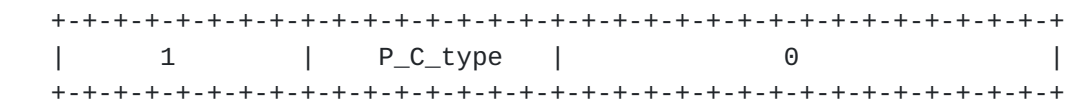
If both the security option and the payload transform are used in a GUE packet, an encapsulator MUST perform the payload transformation first, set the payload transform option in the GUE header, and then create the security option. A decapsulator does processing in reverse-- the security option is processed (GUE header is validated) and then the reverse payload transform is performed.

In order to get flow entropy from the payload, an encapsulator should derive the flow entropy before performing a payload transform.

6.4. DTLS transform

The payload of a GUE packet can be secured using Datagram Transport Layer Security [RFC6347]. An encapsulator would apply DTLS to the GUE payload so that the payload packets are encrypted and the GUE header remains in plaintext. The payload transform option is set to indicate that the payload is interpreted as a DTLS record.

The payload transform option for DLTS is:



DTLS [RFC6347] provides packet fragmentation capability. To avoid packet fragmentation performed multiple times, a GUE encapsulator

SHOULD only perform the packet fragmentation at packet encapsulation process, i.e., not in the payload encryption process.

DTLS usage [RFC6347] is limited to a single DTLS session for any specific tunnel encapsulator/decapsulator pair (identified by source and destination IP addresses). Both IP addresses MUST be unicast addresses - multicast traffic is not supported when DTLS is used. A GUE tunnel decapsulator implementation that supports DTLS can establish DTLS session(s) with one or multiple tunnel encapsulators, and likewise a GUE tunnel encapsulator implementation can establish DTLS session(s) with one or multiple decapsulators.

7. Remote checksum offload option

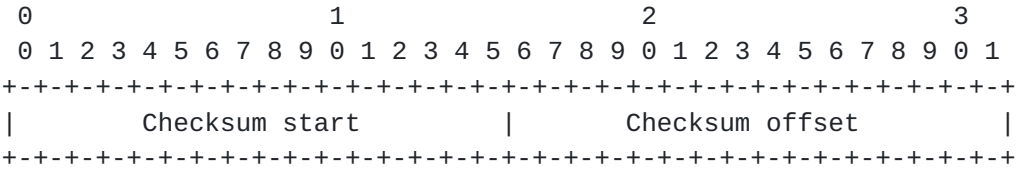
Remote checksum offload is mechanism that provides checksum offload of encapsulated packets using rudimentary offload capabilities found in most Network Interface Card (NIC) devices. Many NIC implementations can only offload the outer UDP checksum in UDP encapsulation. Remote checksum offload is described in [UDPENCAP].

In remote checksum offload the outer header checksum, that in the outer UDP header, is enabled in packets and, with some additional meta information, a receiver is able to deduce the checksum to be set for an inner encapsulated packet. Effectively this offloads the computation of the inner checksum. Enabling the outer checksum in encapsulation has the additional advantage that it covers more of the packet, including the encapsulation headers, than an inner checksum.

7.1. Extension field format

The presence of the GUE remote checksum offload option is indicated by the R bit in the GUE header.

The format of remote checksum offload field is:



The fields of the option are:

- Checksum start: starting offset for checksum computation relative to the start of the encapsulated payload. This is typically the offset of a transport header (e.g. UDP or TCP).

- Checksum offset: Offset relative to the start of the

encapsulated packet where the derived checksum value is to be written. This typically is the offset of the checksum field in the transport header (e.g. UDP or TCP).

7.2. Usage

7.2.1. Transmitter operation

The typical actions to set remote checksum offload on transmit are:

1) Transport layer creates a packet and indicates in internal packet meta data that checksum is to be offloaded to the NIC (normal transport layer processing for checksum offload). The checksum field is populated with the bitwise not of the checksum of the pseudo header or zero as appropriate.

2) Encapsulation layer adds its headers to the packet including the remote checksum offload option. The start offset and checksum offset are set accordingly.

3) Encapsulation layer arranges for checksum offload of the outer header checksum (e.g. UDP).

4) Packet is sent to the NIC. The NIC will perform transmit checksum offload and set the checksum field in the outer header. The inner header and rest of the packet are transmitted without modification.

7.2.2. Receiver operation

The typical actions a host receiver does to support remote checksum offload are:

1) Receive packet and validate outer checksum following normal processing (e.g. validate non-zero UDP checksum).

2) Validate the remote checksum option. If checksum start is greater than the length of the packet, then the packet MUST be dropped. If checksum offset is greater then the length of the packet minus two, then the packet MUST be dropped.

3) Deduce full checksum for the IP packet. If a NIC is capable of receive checksum offload it will return either the full checksum of the received packet or an indication that the UDP checksum is correct. Either of these methods can be used to deduce the checksum over the IP packet [UDPENCAP].

4) From the packet checksum, subtract the checksum computed from

the start of the packet (outer IP header) to the offset in the packet indicted by checksum start in the meta data. The result is the deduced checksum to set in the checksum field of the encapsulated transport packet.

In pseudo code:

```
csum: initialized to checksum computed from start (outer IP
      header) to the end of the packet
start_of_packet: address of start of packet
encap_payload_offset: relative to start_of_packet
csum_start: value from the checksum start field
checksum(start, len): function to compute checksum from start
      address for len bytes

csum -= checksum(start_of_packet, encap_payload_offset +
                 csum_start)
```

5) Write the resultant checksum value into the packet at the offset provided by checksum offset in the meta data.

In pseudo code:

```
csum_offset: value from the checksum offset field

*(start_of_packet + encap_payload_offset +
  csum_offset) = csum
```

6) Checksum is verified at the transport layer using normal processing. This should not require any checksum computation over the packet since the complete checksum has already been provided.

7.3. Security Considerations

Remote checksum offload allows a means to change the GUE payload before being received at a decapsulator. In order to prevent misuse of this mechanism, a decapsulator MUST apply security checks on the GUE payload only after checksum remote offload has been processed.

8. Checksum option

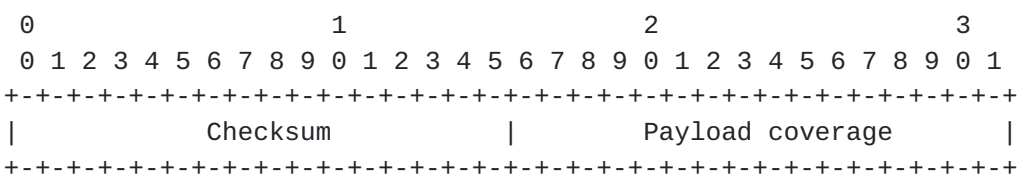
The GUE checksum option provides a checksum that covers the GUE header, a GUE pseudo header, and optionally part or all of the GUE payload. The GUE pseudo header includes the corresponding IP addresses as well as the UDP ports of the encapsulating headers. This checksum should provide adequate protection against address corruption in IPv6 when the UDP checksum is zero. Additionally, the

GUE checksum provides protection of the GUE header when the UDP checksum is set to zero with either IPv4 or IPv6. In particular, the GUE checksum can provide protection for some sensitive data, such as the virtual network identifier ([I.D.hy-nvo3-gue-4-nvo]), which when corrupted could lead to mis-delivery of a packet to the wrong virtual network.

8.1. Extension field format

The presence of the GUE checksum option is indicated by the K bit in the GUE header.

The format of the checksum extension is:



The fields of the option are:

- Checksum: Computed checksum value. This checksum covers the GUE header (including fields and private data covered by Hlen), the GUE pseudo header, and optionally all or part of the payload (encapsulated packet).

- Payload coverage: Number of bytes of payload to cover in the checksum. Zero indicates that the checksum only covers the GUE header and GUE pseudo header. If the value is greater than the encapsulated payload length, the packet MUST be dropped.

8.2. Requirements

The GUE header checksum SHOULD be set on transmit when using a zero UDP checksum with IPv6.

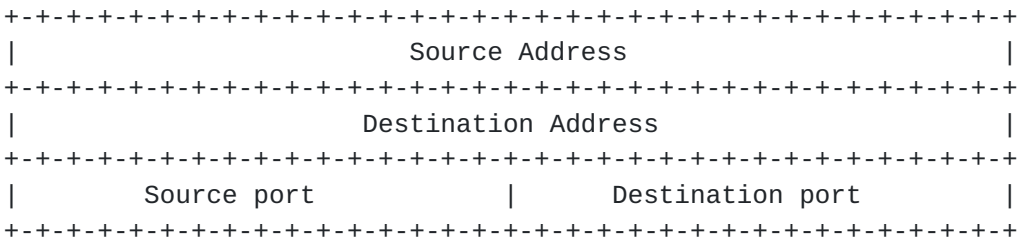
The GUE header checksum SHOULD be used when the UDP checksum is zero for IPv4 if the GUE header includes data that when corrupted can lead to misdelivery or other serious consequences, and there is no other mechanism that provides protection (no security field that checks integrity for instance).

The GUE header checksum SHOULD NOT be set when the UDP checksum is non-zero. In this case the UDP checksum provides adequate protection and this avoids convolutions when a packet traverses NAT that does address translation (in that case the UDP checksum is required).

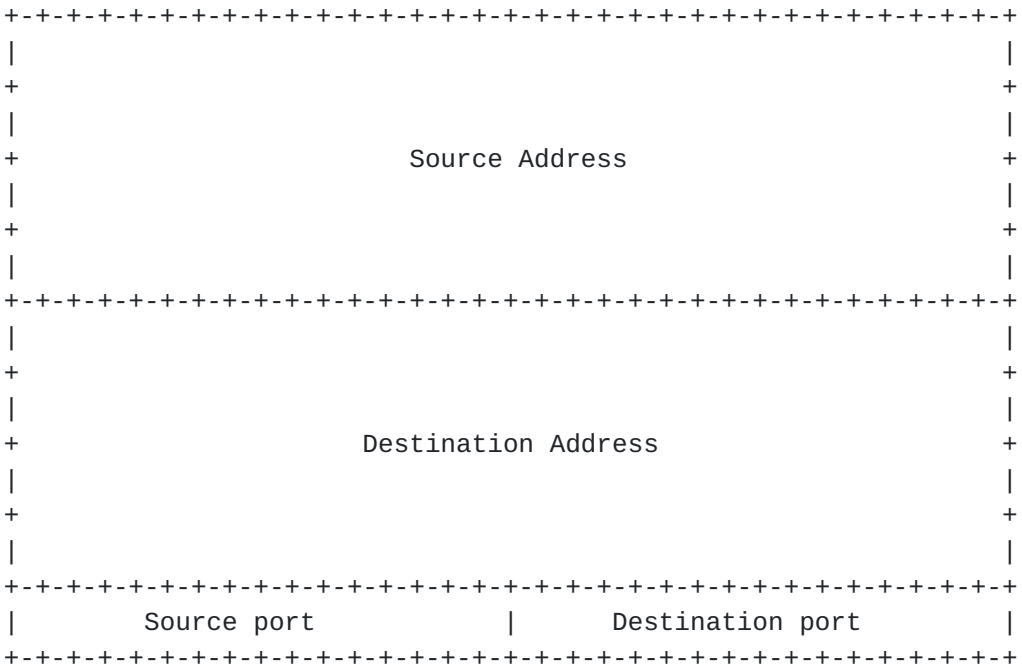
8.3. GUE checksum pseudo header

The GUE pseudo header checksum is included in the GUE checksum to provide protection for the IP and UDP header elements which when corrupted could lead to misdelivery of the GUE packet. The GUE pseudo header checksum is similar to the standard IP pseudo header defined in [RFC0768] and [RFC0793] for IPv4, and in [RFC8200] for IPv6.

The GUE pseudo header for IPv4 is:



The GUE pseudo header for IPv6 is:



The GUE pseudo header does not include payload length or protocol as in the standard IP pseudo headers. The length field is deemed unnecessary because a corrupted length field should not cause mis-delivery, the GUE checksum is applied after GUE fragmentation, and without the length field the GUE pseudo header checksum is the same for all packets of flow.

8.4. Usage

The GUE checksum is computed and verified following the standard process for computing the Internet checksum [RFC1071]. Checksum computation may be optimized per the mathematical properties including parallel computation and incremental updates.

8.4.1. Transmitter operation

The procedure for setting the GUE checksum on transmit is:

1) Create the GUE header including the checksum and payload coverage fields. The checksum field is initially set to zero.

2) Calculate the 1's complement checksum of the GUE header from the start of the GUE header through the its length as indicated in GUE Hlen.

3) Calculate the checksum of the GUE pseudo header for IPv4 or IPv6.

4) Calculate checksum of payload portion if payload coverage is enabled (payload coverage field is non-zero). If the length of the payload coverage is odd, logically append a single zero byte for the purposes of checksum calculation.

5) Add and fold the computed checksums for the GUE header, GUE pseudo header and payload coverage. Set the bitwise not of the result in the GUE checksum field.

8.4.2.Receiver operation

If the GUE checksum option is present, the receiver MUST validate the checksum before processing any other fields or accepting the packet.

The procedure for verifying the checksum is:

1) If the payload coverage length is greater than the length of the encapsulated payload then drop the packet.

2) Calculate the checksum of the GUE header from the start of the header to the end as indicated by Hlen.

3) Calculate the checksum of the appropriate GUE pseudo header.

4) Calculate the checksum of payload if payload coverage is enabled (payload coverage is non-zero). If the length of the payload coverage is odd logically append a single zero byte for

the purposes of checksum calculation.

5) Sum the computed checksums for the GUE header, GUE pseudo header, and payload coverage. If the result is all 1 bits (-0 in 1's complement arithmetic), the checksum is valid and the packet is accepted; otherwise the checksum is considered invalid and the packet MUST be dropped.

8.6. Corrupted flags

Note that the GUE checksum does not protect against the checksum flag (K flag) being corrupted. If an encapsulator sets the checksum flag and option but the K bit flips to be zero, then a decapsulator will incorrectly process the GUE packet as not having a checksum field.

To mitigate this issue an encapsulator and depcapsulator might agree that checksum is always required. This agreement could be established by configuration or GUE capability negotiation.

8.5. Security Considerations

The checksum option is only a mechanism for corruption detection, it is not a security mechanism. To provide integrity checks or authentication of the GUE header, the GUE security option SHOULD be used.

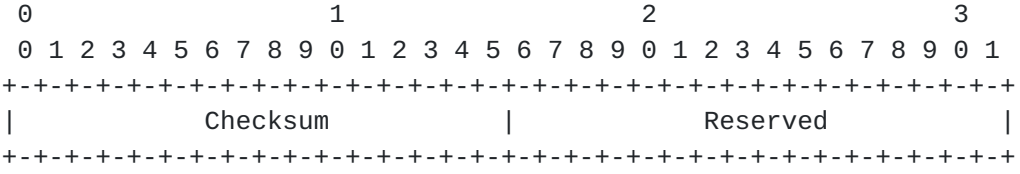
9. NAT checksum address option

The NAT address checksum (NAC) option contains the checksum computed over the IP addresses of the packet. The computed value can be used by a receiver to adjust a transport layer checksum that was affect by NAT changing the IP addresses. This option is only useful when GUE encapsulates a transport layer packet with a checksum with a pseudo header that includes the IP addresses (such as TCP or UDP).

9.1. Extension field format

The presence of the NAT checksum address option is indicated by the N bit in the GUE header.

The format of the NAT checksum address extension is:



The fields of the option are:

- Checksum: Computed checksum value. This checksum covers the outer IP addresses.

- Reserved: Must be zero on transmit.

9.3. Usage

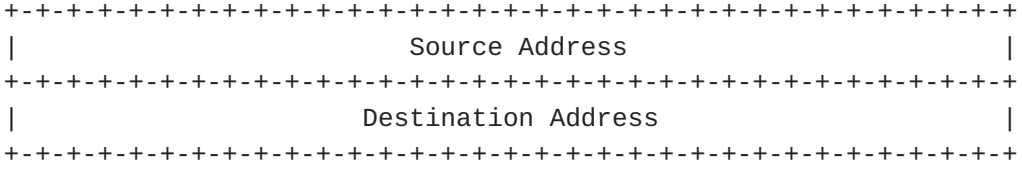
The NAT address address extension SHOULD be set on transmit when encapsulating a transport layer protocol whose checksum might be affected by NAT being performed on the outer IP header. If this option is used then the UDP checksum MUST be used (sent with non-zero value).

The NAT address checksum is computed using the Internet checksum [RFC1071].

9.3.1. Transmitter operation

An encapsulator computes the checksum value over the IP addresses in the IP header.

For IPv4 the checksum is computed over:



For IPv6 the checksum is computed over:

```
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

9.3.2. Receiver operation

1) Validate the UDP checksum is correct

2) Compute the checksum over the IP address in the received packet

3) Subtract the value in step #1 from the NAC value. If the difference is non-zero then NAT has changed the addresses

4) When processing a transport layer containing a checksum affected by NAT on the IP addresses, add the difference into the checksum calculation when verify the packet.

In pseudo codes this is:

```
actual = checksum(IP addresses)
diff = actual - NAC_value
verify = checksum(transport packet) + checksum(pseudo header)
         + diff

if (verify == 0)
  packet is good
```

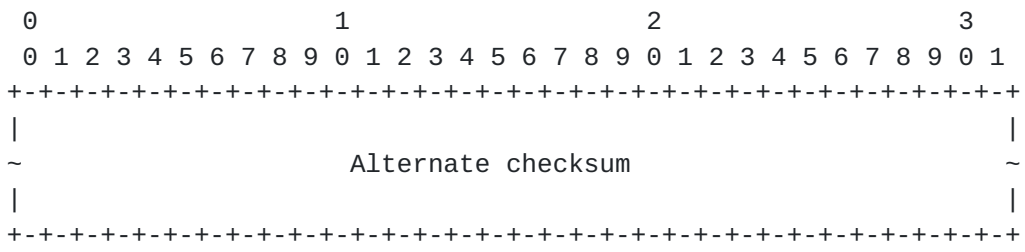
10. Alternative checksum option

The alternative checksum option contains a checksum over the GUE header and optionally all or part of the GUE payload. The alternative checksum can provide stronger protection against data corruption than provided by the one's complement checksum used in the UDP checksum or the GUE checksum (section 8).

The alternative checksum flags are two bits which allow three methods to be defined. This specification proposes two: a 16-bit CRC method and a 32-bit CRC method.

10.1. Extension field format

The format of the alternate checksum option is:



The fields of the option are:

- Alternate checksum (variable length). Contains the checksum information.

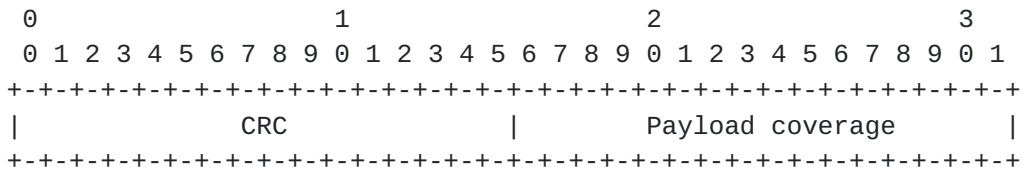
The presence of the alternate checksum option is indicated by the ACS bits in the GUE header.

The values in the ACS flags are:

- 00b - No alternate checksum field
- 01b - 16-bit CRC
- 10b - 32-bit CRC
- 11b - Reserved

10.1.1. 16-bit CRC alternate checksum

The format of the 16-bit CRC alternative checksum field is:



The fields of the option are:

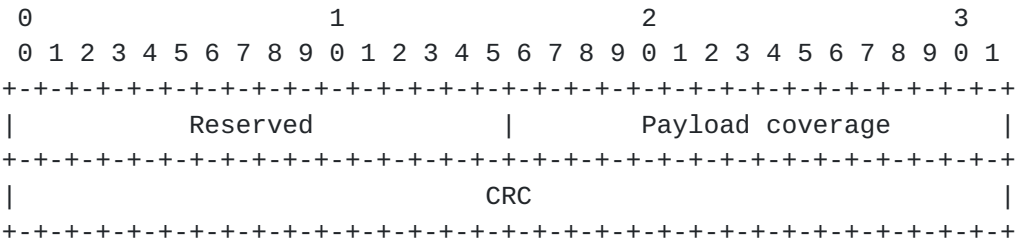
- CRC: Computed CRC value. This CRC covers the GUE header (including fields and private data covered by Hlen) and optionally all or part of the payload (encapsulated packet).
- Payload coverage: Number of bytes of payload to cover in the CRC calculation. Zero indicates that the checksum only covers the GUE header. If the value is greater than the encapsulated payload length, the packet MUST be dropped.

The 16-bit alternative checksum does not include a pseudo header

containing IP addresses or ports. The CRC is calculated using CRC-CCITT algorithm (x^16 + x^12 + x^5 + 1 or polynomial 0x1021).

10.1.2. 32-bit CRC alternate checksum

The format of the 32-bit CRC alternative checksum field is:



The fields of the option are:

- CRC: Computed CRC value. This CRC covers the GUE header (including fields and private data covered by Hlen) and optionally all or part of the payload (encapsulated packet).

- Payload coverage: Number of bytes of payload to cover in the CRC calculation. Zero indicates that the checksum only covers the GUE header. If the value is greater than the encapsulated payload length, the packet MUST be dropped.

The 16-bit alternative checksum does not include a pseudo header containing IP addresses or ports. The CRC is calculated using CRC-32 algorithm (x^32 + x^26 + x^23 + x^22 + x^16 + x^12 +x ^10 + x^2 + x^7 + x^5 + x^4 +x^2 + x + 1 or polynomial 0x04C11DB7).

10.2. Usage

The usage of the alternate checksum is the same for both the 16-bit CRC and the 32-bit CRC methods except that the output CRC values have different size.

10.2.1. Transmitter operation

The procedure for setting the GUE alternative checksum on transmit is:

1) Create the GUE header including the alternative checksum field. The CRC field is initialized to zero.

2) Calculate the alternative checksum (either a 16-bit or 32-bit CRC) from the start of the GUE header through the its length as indicated in GUE Hlen.

3) Continue the calculation to cover the payload portion if payload coverage is enabled (payload coverage field is non-zero). If the length of the payload coverage is not aligned per the algorithm (four bytes for CRC-32 and two bytes for CRC-16), logically append zero bytes up to the necessary alignment for the purposes of CRC calculation.

4) Set the resultant value in the CRC field.

10.2.2. Receiver operation

If the GUE alternative checksum option is present, the receiver MUST validate the checksum before processing any other fields or accepting the packet.

The procedure for verifying the alternate checksum is:

1) If the payload coverage length is greater than the length of the encapsulated payload then drop the packet.

2) Note value in the CRC field and set the CRC field to zero.

3) Calculate the alternative checksum (either a 16-bit or 32-bit CRC) from the start of the GUE header through the its length as indicated in GUE Hlen.

4) Continue the calculation to cover the payload portion if payload coverage is enabled (payload coverage field is non-zero). If the length of the payload coverage is not aligned per the algorithm (four bytes for CRC-32 and two bytes for CRC-16), logically append zero bytes up to the necessary alignment for the purposes of CRC calculation.

5) Compare the computed value with the original value of the CRC field. If they are equal then that packet is accepted, if they are not equal then verification filed and the packet MUST be dropped.

6) Restore the CRC field to its original value.

10.3. Corrupted flags

Similar to GUE checksum properties, the GUE alternate checksum does not protect against the alternative checksum flags (ACS flags) being corrupted. If an encapsulator sets the alternative checksum flags and option but the ACS bits flips to be zero, then a decapsulator will incorrectly process that packet as not having an alternate checksum field.

To mitigate this issue an encapsulator and depcapsulator might agree that an alternate checksum is always required. This agreement could be established by configuration or GUE capability negotiation.

10.4. Security Considerations

The alternate checksum option is only a mechanism for corruption detection, it is not a security mechanism. To provide integrity checks or authentication of the GUE header, the GUE security option SHOULD be used.

11. Processing order of options

Options MUST be processed in a specific order for both sending and receive. Note that some options, such as the checksum option, depend on other fields in the GUE header to be set.

11.1. Processing order when sending

When setting the security option (HMAC option in particular), the checksum option, and the alternate checksum option-- all the GUE fields being used must be present and properly set in the header. The checksum value in the checksum option or alternate checksum option MUST be initialized to zero to ensure consistent HMAC and checksum calculation.

The order of processing options to send a GUE packet are:

1) Set group identifier option.

2) Fragment if necessary and set fragmentation option. If the group identifier is present it is copied into each fragment. If payload transformation will increase the size of the payload that MUST be accounted for when deciding how to fragment

3) Perform payload transform (potentially on a fragment) and set payload transform option.

4) Set Remote checksum offload.

5) Set NAT address checksum option.

6) Set security option per cookie or HMAC calculation.

7) Calculate GUE checksum and set checksum option.

8) Calculate GUE alternate checksum and set the alternate checksum option.

11.2. Processing order when receiving

On reception the order of actions is reversed.

1) Verifiy GUE alternate checksum.

2) Verify GUE checksum. If the alternate checksum option is present, set the checksum fields to zero for computing the GUE checksum. After computation, restore the GUE checksum value.

3) Verify security option. If the GUE checksum option or alternate checksum option is also present and HMAC computation is being done over the GUE header, then set the checksum fields to zero for computing the HMAC. After computation, restore the checksum values.

4) Save the NAT address checksum value. It will be applied when processing the encapsulated packet.

5) Adjust packet for remote checksum offload.

6) Perform payload transformation (i.e. decrypt payload).

7) Perform reassembly.

8) Process packet (take group identifier into account if present).

The relative processing order of GUE extensions and private fields is unspecified in this specification.

12. Security Considerations

Encapsulation of network protocol in GUE should not increase security risk, nor provide additional security in itself. GUE requires that the source port for UDP packets SHOULD be randomly seeded to mitigate some possible denial service attacks.

If the integrity and privacy of data packets being transported through GUE is a concern, GUE security option and payload encryption using the the transform option SHOULD be used to remove the concern. If the integrity is the only concern, the tunnel may consider use of GUE security only for optimization. Likewise, if privacy is the only concern, the tunnel may use GUE encryption function only.

If GUE payload already provides secure mechanism, e.g., the payload is IPsec packets, it is still valuable to consider use of GUE security.

GUE may rely on other secure tunnel mechanisms such as DTLS [RFC6347] over the whole UDP payload for securing the whole GUE packet or IPsec [RFC4301] to achieve the secure transport over an IP network or Internet.

IPsec [RFC4301] was designed as a network security mechanism, and therefore it resides at the network layer. As such, if the tunnel is secured with IPsec, the UDP header would not be visible to intermediate routers in either IPsec tunnel or transport mode. This is a drawback since it prohibits intermediate routers to perform load balancing based on the flow entropy in UDP header. In addition, this method prohibits any middle box function on the path.

By comparison, DTLS [RFC6347] was designed with application security and can better preserve network and transport layer protocol information than IPsec [RFC4301]. Using DTLS over UDP to secure the GUE tunnel, both GUE header and payload will be encrypted. In order to differentiate plaintext GUE header from encrypted GUE header, the destination port of the UDP header between two must be different, which essentially requires another standard UDP port for GUE with DTLS. The drawback on this method is to prevent a middle box operation to GUE tunnel on the path.

Use of two independent tunnel mechanisms such as GUE and DTLS over UDP to carry a network protocol over an IP network adds some overlap and complexity. For example, fragmentation will be done twice.

As the result, a GUE tunnel SHOULD use the security mechanisms specified in this document to provide secure transport over an IP network or Internet when it is needed. GUE encapsulation can be used as a secure transport mechanism over an IP network and Internet.

13. IANA Consideration

IANA is requested to assign flags for the extensions defined in this specification. Specifically, an assignment is requested for the Group Identfier, Security, Fragmentation, Payload Transform, Remote Checksum Offload, and Checksum extensions in the "GUE flag-fields" registry.

Flags bits	Field size	Description	Reference
Bit 0	4 bytes	Group identifier	This document
Bit 1..3	001->8 bytes 010->16 bytes	Security	This document

	011->32 bytes 100->40 bytes			
Bit 4	8 bytes	Fragmen- tation	This document	
Bit 5	4 bytes	Payload transform	This document	
Bit 6	4 bytes	Remote checksum offload	This document	
Bit 7	4 bytes	Checksum	This document	
Bit 8	4 bytes	NAT checksum address	This document	
Bit 9..10	01->4 bytes 10->8 bytes	Alternate checksum	This document	
Bit 11..15		Unassigned		

IANA is requested to set up a registry for the GUE payload transform types. Payload transform types are 8 bit values. New values for control types 1-127 are assigned via Standards Action [RFC5226].

Transform type	Description	Reference
0	Reserved	This document
1	DTLS	This document
2..127	Unassigned	
128..255	User defined	This document

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