

Network Working Group  
Internet-Draft  
Intended status: Standard Track

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Expires: August 2015

February 11, 2015

**GRE-in-UDP Encapsulation**  
**draft-ietf-tsvwg-gre-in-udp-encap-04**

Abstract

This document describes a method of encapsulating network protocol packets within GRE and UDP headers. In this encapsulation, the source UDP port can be used as an entropy field for purposes of load balancing, while the protocol of the encapsulated packet in the GRE payload is identified by the GRE Protocol Type. Usage restrictions apply to GRE-in-UDP usage for traffic that is not congestion controlled and to UDP zero checksum usage with IPv6.

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## 1. Introduction

Load balancing, or more specifically statistical multiplexing of traffic using Equal Cost Multi-Path (ECMP) and/or Link Aggregation Groups (LAGs) in IP networks is a widely used technique for creating higher capacity networks out of lower capacity links. Most existing routers in IP networks are already capable of distributing IP traffic flows over ECMP paths and/or LAGs on the basis of a hash function performed on flow invariant fields in IP packet headers and their payload protocol headers. Specifically, when the IP payload is a User Datagram Protocol (UDP) [[RFC768](#)] or Transmission Control Protocol (TCP) [[RFC793](#)] packet, router hash functions frequently operate on the five-tuple of source IP address, destination IP address, source port, destination port, and protocol/next-header

Several encapsulation techniques are commonly used in IP networks, such as Generic Routing Encapsulation (GRE) [[RFC2784](#)], MPLS [[RFC4023](#)] and L2TPv3 [[RFC3931](#)]. GRE is an increasingly popular encapsulation choice. Unfortunately, use of common GRE endpoints may reduce the entropy available for use in load balancing, especially in environments where the GRE Key field [[RFC2890](#)] is not readily available for use as entropy in forwarding decisions.

This document defines a generic GRE-in-UDP encapsulation for tunneling network protocol packets across an IP network. The GRE header provides payload protocol type as an EtherType in the protocol type field [[RFC2784](#)][GREIPV6], and the UDP header provides additional entropy by way of its source port.

This encapsulation method requires no changes to the transit IP network. Hash functions in most existing IP routers may utilize and benefit from the use of a GRE-in-UDP tunnel without needing any change or upgrade to their ECMP implementation. The encapsulation mechanism is applicable to a variety of IP networks including Data Center and wide area networks.

### 1.1. Applicability Statement

GRE encapsulation is widely used for many applications. For example, to redirect IP traffic to traverse a different path instead of the default path in an operator network, to tunnel private network traffic over a public network by use of public IP network addresses, or to tunnel IPv6 traffic over an IPv4 network, etc.

When encapsulating GRE in UDP, encapsulated traffic will be treated as a UDP application, not as a GRE application, in an IP network.



Thus GRE-in-UDP applications must meet UDP tunnel requirements as specified in [[RFC5405](#)]. This may constrain GRE-in-UDP tunnel usage in certain applications and/or environments. See [Section 6](#).

GRE-in-UDP encapsulation may be used to encapsulate already tunneled traffic, i.e. tunnel-in-tunnel. The tunneled traffic may use GRE-in-UDP or other tunnel encapsulation. In this case, GRE-in-UDP tunnel end points treat other tunnel endpoints as of the end hosts for the traffic and do not differentiate such end hosts from other end hosts.

## **[2](#). Terminology**

The terms defined in [[RFC768](#)][RFC2784] are used in this document.

### 2.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [[RFC2119](#)].

## **[3](#). Encapsulation in UDP**

GRE-in-UDP encapsulation format is shown as follows:

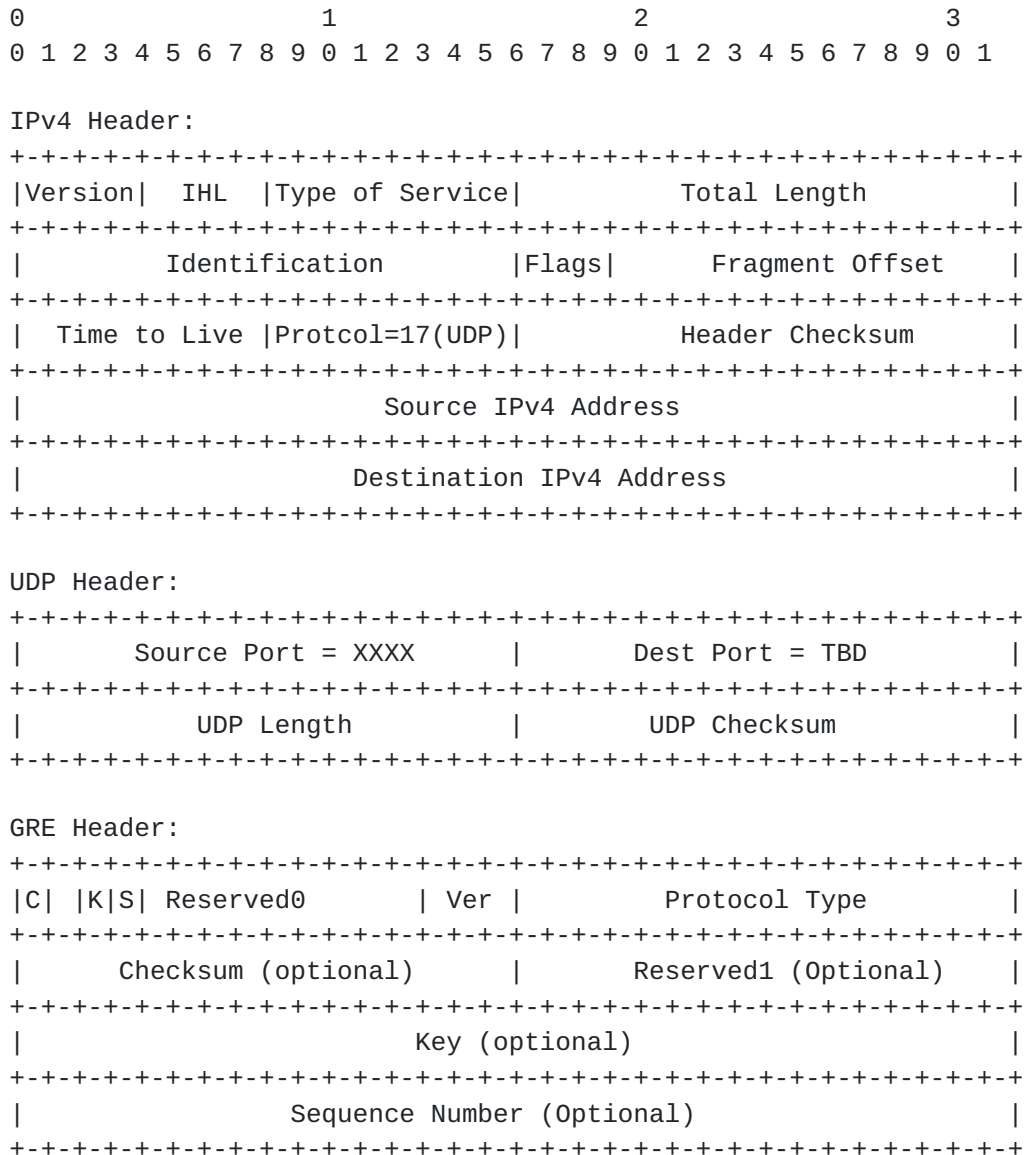


Figure 1 UDP+GRE Headers in IPv4







Figure 2 UDP+GRE Headers in IPv6



The contents of the IP, UDP, and GRE headers that are relevant in this encapsulation are described below.

### 3.1. IP header

An encapsulator **MUST** encode its own IP address as the source IP address and the decapsulator's IP address as the destination IP address. The TTL field in the IP header must be set to a value appropriate for delivery of the encapsulated packet to the peer of the encapsulation.

### 3.2. UDP header

#### 3.2.1. Source Port

The UDP source port contains a 16-bit entropy value that is generated by the encapsulator to identify a flow for the encapsulated packet. The port value **SHOULD** be within the ephemeral port range. IANA suggests this range to be 49152 to 65535, where the high order two bits of the port are set to one. This provides fourteen bits of entropy for the inner flow identifier. In the case that an encapsulator is unable to derive flow entropy from the payload header, it should set a randomly selected constant value for UDP source port to avoid payload packet flow reordering.

The source port value for a flow set by an encapsulator **MAY** change over the lifetime of the encapsulated flow. For instance, an encapsulator may change the assignment for Denial of Service (DOS) mitigation or as a means to effect routing through the ECMP network. An encapsulator **SHOULD NOT** change the source port selected for a flow more than once every thirty seconds.

How an encapsulator generates entropy from the payload is outside the scope of this document.

#### 3.2.2. Destination port

The destination port of the UDP header is set the GRE/UDP port (TBD) (see [Section 8](#)).

#### 3.2.3. Checksum

The UDP checksum is set and processed per [\[RFC768\]](#) and [\[RFC1122\]](#) for IPv4, and [\[RFC2460\]](#) for IPv6. Requirements for checksum handling and use of zero UDP checksums are detailed in [section 4](#).



### 3.2.4. Length

The usage of this field is in accordance with the current UDP specification in [\[RFC768\]](#). This length will include the UDP header (eight bytes), GRE header, and the GRE payload (encapsulated packet).

### 3.3. GRE header

An encapsulator sets the protocol type (EtherType) of the packet being encapsulated in the GRE Protocol Type field.

An encapsulator may set the GRE Key Present, Sequence Number Present, and Checksum Present bits and associated fields in the GRE header as defined by [\[RFC2784\]](#) and [\[RFC2890\]](#).

The GRE checksum MAY be enabled to protect the GRE header and payload. An encapsulator SHOULD NOT enable both the GRE checksum and UDP checksum simultaneously as this would be mostly redundant. Since the UDP checksum covers more of the packet including the GRE header and payload, the UDP checksum SHOULD have preference to using GRE checksum.

## 4. UDP Checksum Handling

### 4.1. UDP Checksum with IPv4

For UDP in IPv4, the UDP checksum MUST be processed as specified in [\[RFC768\]](#) and [\[RFC1122\]](#) for both transmit and receive. An encapsulator MAY set the UDP checksum to zero for performance or implementation considerations. The IPv4 header includes a checksum which protects against mis-delivery of the packet due to corruption of IP addresses. The UDP checksum potentially provides protection against corruption of the UDP header, GRE header, and GRE payload. Enabling or disabling the use of checksums is a deployment consideration that should take into account the risk and effects of packet corruption, and whether the packets in the network are already adequately protected by other, possibly stronger mechanisms such as the Ethernet CRC.

When a decapsulator receives a packet, the UDP checksum field MUST be processed. If the UDP checksum is non-zero, the decapsulator MUST verify the checksum before accepting the packet. By default a decapsulator SHOULD accept UDP packets with a zero checksum. A node MAY be configured to disallow zero checksums per [\[RFC1122\]](#); this may be done selectively, for instance disallowing zero checksums from certain hosts that are known to be sending over paths subject to packet corruption. If verification of a non-zero checksum fails, a



decapsulator lacks the capability to verify a non-zero checksum, or a packet with a zero-checksum was received and the decapsulator is configured to disallow, the packet MUST be dropped and an event MAY be logged.

#### 4.2. UDP Checksum with IPv6

For UDP in IPv6, the UDP checksum MUST be processed as specified in [\[RFC768\]](#) and [\[RFC2460\]](#) for both transmit and receive.

When UDP is used over IPv6, the UDP checksum is relied upon to protect both the IPv6 and UDP headers from corruption, and so MUST be used with the following exceptions:

- a. Use of GRE-in-UDP in networks under single administrative control (such as within a single operator's network) where it is known (perhaps through knowledge of equipment types and lower layer checks) that packet corruption is exceptionally unlikely and where the operator is willing to take the risk of undetected packet corruption.
- b. Use of GRE-in-UDP in networks under single administrative control (such as within a single operator's network) where it is judged through observational measurements (perhaps of historic or current traffic flows that use a non-zero checksum) that the level of packet corruption is tolerably low and where the operator is willing to take the risk of undetected packet corruption.
- c. Use of GRE-in-UDP for traffic delivery for applications that are tolerant of misdelivered or corrupted packets (perhaps through higher layer checksum, validation, and retransmission or transmission redundancy) where the operator is willing to rely on the applications using the tunnel to survive any corrupt packets.

For these exceptions, the UDP zero-checksum mode can be used. However the use of the UDP zero-checksum mode must meet the requirements specified in [\[RFC6935\]](#) and [\[RFC6936\]](#) as well as the additional requirements stated below.

These exceptions may also be extended to the use of GRE-in-UDP within a set of closely cooperating network administrations (such as network operators who have agreed to work together in order to jointly provide specific services).





As such, for IPv6, the UDP checksum for GRE-in-UDP MUST be used as specified in [\[RFC768\]](#) and [\[RFC2460\]](#) for tunnels that span multiple networks whose network administrations do not cooperate closely, even if each non-cooperating network administration independently satisfies one or more of the exceptions for UDP zero-checksum mode usage with GRE-in-UDP over IPv6.

The following additional requirements apply to implementation and use of UDP zero-checksum mode for GRE-in-UDP over IPv6:

- a. Use of the UDP checksum with IPv6 MUST be the default configuration of all GRE-in-UDP implementations.
- b. The GRE-in-UDP implementation MUST comply with all requirements specified in [Section 4 of \[RFC6936\]](#) and with requirement 1 specified in [Section 5 of \[RFC6936\]](#).
- c. A decapsulator SHOULD only allow the use of UDP zero-checksum mode for IPv6 on a single received UDP Destination Port. The motivation for this requirement is possible corruption of the UDP destination port, which may cause packet delivery to the wrong UDP port. If that other UDP port requires the UDP checksum, the mis-delivered packet will be discarded.
- d. By default a decapsulator MUST disallow receipt of GRE-in-UDP packets with zero UDP checksums with IPv6. Zero checksums May selectively be enabled for certain source address. A decapsulator MUST check that the source and destination IPv6 addresses are valid for the GRE-in-UDP tunnel on which the packet was received if that tunnel uses UDP zero-checksum mode and discard any packet for which this check fails.
- e. An encapsulator SHOULD use different IPv6 addresses for each GRE-in-UDP tunnel that uses UDP zero-checksum mode regardless of the decapsulator in order to strengthen the decapsulator's check of the IPv6 source address (i.e., the same IPv6 source address SHOULD NOT be used with more than one IPv6 destination address, independent of whether that destination address is a unicast or multicast address). When this is not possible, it is RECOMMENDED to use each source IPv6 address for as few UDP zero-checksum mode GRE-in-UDP tunnels as is feasible.
- f. Any middlebox support for GRE-in-UDP with UDP zero-checksum mode for IPv6 MUST comply with requirements 1 and 8-10 in [Section 5 of \[RFC6936\]](#). [\[RFC6936\]](#).



- g. Measures SHOULD be taken to prevent IPv6 traffic with zero UDP checksums from "escaping" to the general Internet; see [Section 6](#) for examples of such measures.
- h. IPv6 traffic with zero UDP checksums MUST be actively monitored for errors by the network operator.
- i. The use a zero UDP checksum should present the equivalent risk of undetected packet corruption when sending similar packet using GRE-in-IPv6 without UDP and without GRE checksums.
- j. If a packet with a non-zero checksum is received, the checksum MUST be verified before accepting the packet. This is regardless of whether a tunnel encapsulator and decapsulator have been configured with UDP zero-checksum mode.

The above requirements do not change either the requirements specified in [\[RFC2460\]](#) as modified by [\[RFC6935\]](#) or the requirements specified in [\[RFC6936\]](#).

The requirement to check the source IPv6 address in addition to the destination IPv6 address, plus the strong recommendation against reuse of source IPv6 addresses among GRE-in-UDP tunnels collectively provide some mitigation for the absence of UDP checksum coverage of the IPv6 header. Additional assurance is provided by the restrictions in the above exceptions that limit usage of IPv6 UDP zero-checksum mode to well-managed networks for which GRE encapsulated packet corruption has not been a problem in practice.

Hence GRE-in-UDP is suitable for transmission over lower layers in the well-managed networks that are allowed by the exceptions stated above and the rate of corruption of the inner IP packet on such networks is not expected to increase by comparison to GRE traffic that is not encapsulated in UDP. For these reasons, GRE-in-UDP does not provide an additional integrity check except when GRE checksum is used when UDP zero-checksum mode is used with IPv6, and this design is in accordance with requirements 2, 3 and 5 specified in [Section 5 of \[RFC6936\]](#).

GRE does not accumulate incorrect state as a consequence of GRE header corruption. A corrupt GRE results in either packet discard or forwarding of the packet without accumulation of GRE state. GRE checksum MAY be used for protecting GRE header and payload. Active monitoring of GRE-in-UDP traffic for errors is REQUIRED as occurrence of errors will result in some accumulation of error information outside the protocol for operational and management



purposes. This design is in accordance with requirement 4 specified in [Section 5 of \[RFC6936\]](#).

The remaining requirements specified in [Section 5 of \[RFC6936\]](#) are inapplicable to GRE-in-UDP. Requirements 6 and 7 do not apply because GRE does not have a GRE-generic control feedback mechanism. Requirements 8-10 are middlebox requirements that do not apply to GRE-in-UDP tunnel endpoints, but see [Section 3.2](#) for further middlebox discussion.

In summary, UDP zero-checksum mode for IPv6 is allowed to be used with GRE-in-UDP when one of the three exceptions specified above applies, provided that additional requirements stated above are complied with. Otherwise the UDP checksum MUST be used for IPv6 as specified in [\[RFC768\]](#) and [\[RFC2460\]](#).

#### 4.2.1. Middlebox Considerations for IPv6 UDP Zero Checksums

IPv6 datagrams with a zero UDP checksum will not be passed by any middlebox that validates the checksum based on [\[RFC2460\]](#) or that updates the UDP checksum field, such as NATs or firewalls. Changing this behavior would require such middleboxes to be updated to correctly handle datagrams with zero UDP checksums. The GRE-in-UDP encapsulation does not provide a mechanism to safely fall back to using a checksum when a path change occurs redirecting a tunnel over a path that includes a middlebox that discards IPv6 datagrams with a zero UDP checksum. In this case the GRE-in-UDP tunnel will be black-holed by that middlebox. Recommended changes to allow firewalls, NATs and other middleboxes to support use of an IPv6 zero UDP checksum are described in [Section 5 of \[RFC6936\]](#).

## 5. Encapsulation Process Procedures

This GRE-in-UDP encapsulation allows packets to be forwarded through "GRE-UDP tunnels". When performing GRE-in-UDP encapsulation by the encapsulator, the entropy value would be generated by the encapsulator and then be filled in the Source Port field of the UDP header. The Destination Port field is set to a value (TBD) allocated by IANA to indicate that the UDP tunnel payload is a GRE packet. The Protocol Type header field in GRE header is set to the EtherType value corresponding to the protocol of the encapsulated packet.

Intermediate routers, upon receiving these UDP encapsulated packets, could balance these packets based on the hash of the five-tuple of UDP packets.



Upon receiving these UDP encapsulated packets, the decapsulator would decapsulate them by removing the UDP headers and then process them accordingly.

Note: Each UDP tunnel is unidirectional, as GRE-in-UDP traffic is sent to the IANA-allocated UDP Destination Port, and in particular, is never sent back to any port used as a UDP Source Port (which serves solely as a source of entropy). This is at odds with a common middlebox (e.g., firewall) assumption that bidirectional traffic uses a common pair of UDP ports. As a result, arranging to pass bidirectional GRE-in-UDP traffic through middleboxes may require separate configuration for each direction of traffic.

GRE-in-UDP allows encapsulation of unicast, broadcast, or multicast traffic. Entropy may be generated from the header of encapsulated unicast or broadcast/multicast packets at an encapsulator. The mapping mechanism between the encapsulated multicast traffic and the multicast capability in the IP network is transparent and independent to the encapsulation and is otherwise outside the scope of this document.

### 5.1. Packet Fragmentation

Regarding Fragmentation, an encapsulator SHOULD perform fragmentation [[GREMTU](#)] on a packet before encapsulation and factor in both GRE and UDP header bytes in the effective Maximum Transmission Unit (MTU) size. Not performing the fragmentation will cause the packets exceeding network MTU size to be dropped or fragmented in the network. An encapsulator MUST use the same source UDP port for all packet fragments to ensure that the transit routers will forward the packet fragments on the same path. An operator should factor in the additional bytes of overhead when considering an MTU size for the payload to reduce the likelihood of fragmentation.

### 5.2. Differentiated services

To ensure that tunneled traffic gets the same treatment over the IP network, prior to the encapsulation process, an encapsulator should process the payload to get the proper parameters to fill into the IP header such as DiffServ [[RFC2983](#)]. Encapsulation end points that support ECN must use the method described in [[RFC6040](#)] for ECN marking propagation. This process is outside of the scope of this document.





## 6. Congestion Considerations

[Section 3.1.3 of \[RFC5405\]](#) discussed the congestion implications of UDP tunnels. As discussed in [\[RFC5405\]](#), because other flows can share the path with one or more UDP tunnels, congestion control [\[RFC2914\]](#) needs to be considered.

A major motivation for GRE-in-UDP encapsulation is to tunnel a network protocol over IP network and improve the use of multipath (such as ECMP) in cases where traffic is to traverse routers which are able to hash on UDP Port and IP address. As such, in many cases this may reduce the occurrence of congestion and improve usage of available network capacity. However, it is also necessary to ensure that the network, including applications that use the network, responds appropriately in more difficult cases, such as when link or equipment failures have reduced the available capacity.

The impact of congestion must be considered both in terms of the effect on the rest of the network over which packets are sent in UDP tunnels, and in terms of the effect on the flows that are sent by UDP tunnels. The potential impact of congestion from a UDP tunnel depends upon what sort of traffic is carried over the tunnel, as well as the path of the tunnel.

GRE encapsulation is widely used to carry a wide range of network protocols and traffic. In many cases GRE encapsulation is used to carry IP traffic. IP traffic is generally assumed to be congestion controlled, and thus a tunnel carrying general IP traffic (as might be expected to be carried across the Internet) generally does not need additional congestion control mechanisms. As specified in [RFC 5405](#):

"IP-based traffic is generally assumed to be congestion-controlled, i.e., it is assumed that the transport protocols generating IP-based traffic at the sender already employ mechanisms that are sufficient to address congestion on the path. Consequently, a tunnel carrying IP-based traffic should already interact appropriately with other traffic sharing the path, and specific congestion control mechanisms for the tunnel are not necessary."

For this reason, where GRE-in-UDP tunneling is used to carry IP traffic that is known to be congestion controlled, the UDP tunnels MAY be used within a single network or across multiple networks, with cooperating network operators. Internet IP traffic is generally assumed to be congestion-controlled.



However, GRE-in-UDP tunneling can be also used to carry traffic that is not necessarily congestion controlled. In such cases network operators may avoid congestion by careful provisioning of their networks, by rate limiting of user data traffic, and/or by using Traffic Engineering tools to monitor the network segments and dynamically steers traffic away from potentially congested links.

For this reason, where the GRE payload traffic is not congestion controlled, GRE-in-UDP tunnels **MUST** only be used within a single operator's network that utilizes careful provisioning (e.g., rate limiting at the entries of the network while over-provisioning network capacity) to ensure against congestion, or within a limited number of networks whose operators closely cooperate in order to jointly provide this same careful provisioning.

As such, GRE-in-UDP **MUST NOT** be used over the general Internet, or over non-cooperating network operators, to carry traffic that is not congestion-controlled.

Measures **SHOULD** be taken to prevent non-congestion-controlled GRE-in-UDP traffic from "escaping" to the general Internet, e.g.:

- o Physical or logical isolation of the links carrying GRE-in-UDP from the general Internet.
- o Deployment of packet filters that block the UDP ports assigned for GRE-in-UDP.
- o Imposition of restrictions on GRE-in-UDP traffic by software tools used to set up GRE-in-UDP tunnels between specific end systems (as might be used within a single data center).
- o Use of a "Managed Circuit Breaker" for the tunneled traffic as described in [\[CB\]](#).

## **7. Backward Compatibility**

It is assumed that tunnel ingress routers must be upgraded in order to support the encapsulations described in this document.

No change is required at transit routers to support forwarding of the encapsulation described in this document.

If a router that is intended for use as a decapsulator does not support or enable GRE-in-UDP encapsulation described in this

document, it will not be listening on destination port (TBD). In these cases, the router will conform to normal UDP processing and respond to an encapsulator with an ICMP message indicating "port unreachable" according to [[RFC792](#)]. Upon receiving this ICMP message, the node MUST NOT continue to use GRE-in-UDP encapsulation toward this peer without management intervention.

## 8. IANA Considerations

IANA is requested to make the following allocation:

Service Name: GRE-in-UDP  
Transport Protocol(s): UDP  
Assignee: IESG <iesg@ietf.org>  
Contact: IETF Chair <chair@ietf.org>  
Description: GRE-in-UDP Encapsulation  
Reference: [This.I-D]  
Port Number: TBD  
Service Code: N/A  
Known Unauthorized Uses: N/A  
Assignment Notes: N/A

## 9. Security Considerations

### 9.1. Vulnerability

Neither UDP nor GRE encapsulation effects security for the payload protocol. When using GRE-in-UDP, Network Security in a network is mostly equivalent to that of a network using GRE.

Use of ICMP for signaling of the GRE-in-UDP encapsulation capability adds a security concern. Upon receiving an ICMP message and before taking an action on it, the ingress MUST validate the IP address originating against tunnel egress address and MUST evaluate the packet header returned in the ICMP payload to ensure the source port is the one used for this tunnel. The mechanism for performing this validation is out of the scope of this document.

In an instance where the UDP source port is not set based on the flow invariant fields from the payload header, a random port SHOULD be selected in order to minimize the vulnerability to off-path attacks. [[RFC6056](#)]. The random port may also be periodically changed

to mitigate certain denial of service attacks. How the source port randomization occurs is outside scope of this document.

Using one standardized value in UDP destination port for an encapsulation indication may increase the vulnerability of off-path attack. To overcome this, an alternate port may be agreed upon to use between an encapsulator and decapsulator [[RFC6056](#)]. How the encapsulator end points communicate the value is outside scope of this document.

This document does not require that decapsulator validates the IP source address of the tunneled packets (with the exception that the IPv6 source address MUST be validated when UDP zero-checksum mode is used with IPv6), but it should be understood that failure to do so presupposes that there is effective destination-based (or a combination of source-based and destination-based) filtering at the boundaries.

## **10. Acknowledgements**

Authors like to thank Vivek Kumar, Ron Bonica, Joe Touch, Ruediger Geib, Lar Edds, Lloyd, and many others for their review and valuable input on this draft.

Thank the design team led by David Black (members: Ross Callon, Gorry Fairhurst, Xiaohu Xu, Lucy Yong) to efficiently work out the descriptions for the congestion considerations and IPv6 UDP zero checksum.

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